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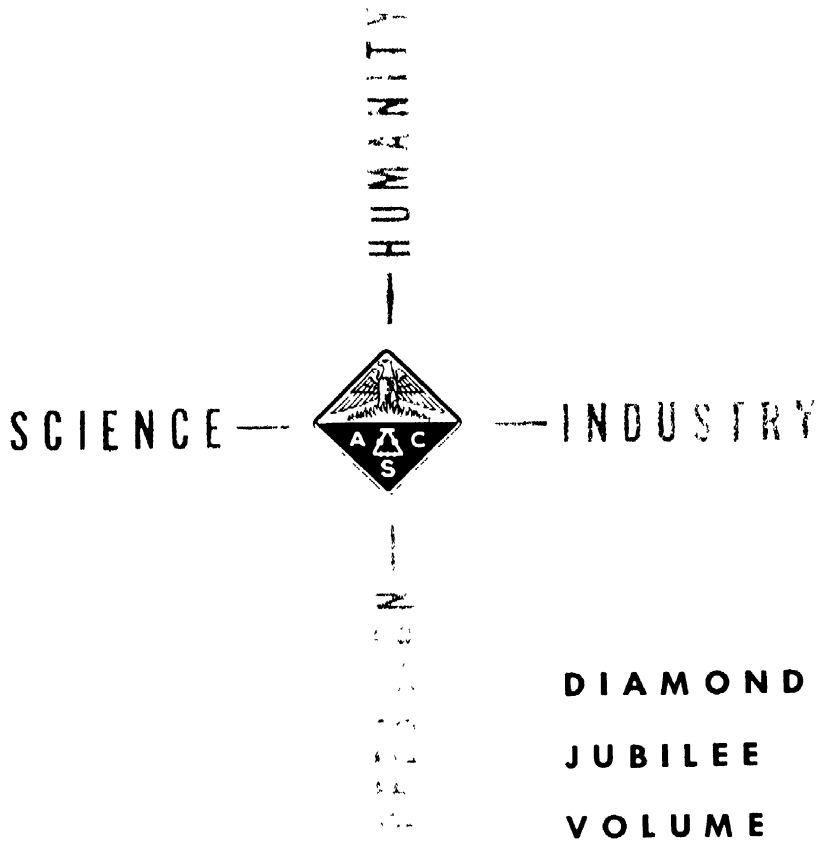
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chemistry...
key to
better living

chemistry... key to better living



DIAMOND
JUBILEE
VOLUME

A record of chemical progress during the first 75 years of the American Chemical Society. Reprinted from *Chemical and Engineering News* and *Industrial and Engineering Chemistry*

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Preface

On the evening of April 6, 1876, in the lecture room of the New York College of Pharmacy, a pioneering band of 35 chemists resolved that the time had arrived when action should take the place of discussion. A simple show of hands and the American Chemical Society came into being. The idea of forming a society exclusively for chemists originated two years earlier, when over 100 chemists gathered at Northumberland, Pa., to attend the centennial celebration of Priestley's discovery of oxygen.

Certainly the founders of the Society who met on that historic soft spring evening in 1876 in the dignified atmosphere of Washington Square did not visualize the size of their organization in the year 1951, but we can well believe they had great hopes for its future success. Similarly we who will assemble next month in New York for the Diamond Jubilee Meeting, cannot describe accurately what our Society will be 75 years hence. Like the founders, however, we are supremely confident the organization will continue to serve the broad interests of chemistry and chemical engineering, the chemical profession, the country's industries, and the welfare of mankind. These objects are set forth clearly and concisely in the Federal Charter granted by Congress in 1938. By continuing and further expanding the programs designed to meet these objectives, the Society will grow in size, stature, influence, and in the respect of the public.

Let us never forget for a moment that courage and strong convictions were in evidence on that April evening 75 years ago. The future for a Society devoted to a single discipline was uncertain, yet the intervening 75 years have demonstrated amply the wisdom of the action taken on that occasion. Ours is a rich heritage. It is our obligation to see that our Society continues to meet new and great responsibilities.

The principal reason for the success of the Society is not difficult to discern. It has been the loyal and devoted service performed by the membership that has brought it to its present size and position of influence. There have been crises, of course, but these have been met with a strong determination to resolve differences and to create a bigger and better Society. The five principal publications of the Society, the 20 scientific and technical divisions, and the 138 local sections attest to the vigor of the organization and its broad scope.

It is particularly fitting in this year when we celebrate the 75th anniversary of the Society that we act as host to foreign chemists and chemical engineers who will assemble in New York for the International Congress of Pure and Applied Chemistry, and the meeting of the International Union of Pure and Applied Chemistry. These two events, together with the Diamond Jubilee Meeting of the Society, will constitute the largest World Chemical Conclave ever held. We welcome our fellow chemists and chemical engineers from abroad and trust they will find their stay with us pleasant and profitable.

The editors of this publication dedicate this issue which commemorates the 75th anniversary of the Society to international good will and understanding among chemists and chemical engineers throughout the world. They particularly wish to emphasize the international aspects of the coming conclave.

Chemistry, combined with other physical sciences and engineering, is accountable for many startling and wonderful advances. The science, however, is no better than the abilities of those who practice it. The men and women of the chemical profession may well be proud of their achievements and the services they have performed.

Let us stress also on the eve of the World Chemical Conclave the fact that scientific and technical discoveries and inventions have been made in all parts of the world demonstrating conclusively that science is truly international and recognizes no geographical boundaries.

We salute the chemists and chemical engineers from all parts of the world who have served mankind so unselfishly. To these men and women the world owes an eternal debt of gratitude. As we gather to celebrate the accomplishments of the past 75 years, we are not unmindful of the troubled state of the world and the fears for the future. We believe science, including chemistry, can bring to the world the physical necessities for a good and full life, but man must learn how to use this new knowledge properly.

Walter J. Murphy

The President's Message

The accompanying reviews and special articles on the progress of chemistry and the contributions of our Society to this progress during the past 75 years show clearly how our science has become an integral and important factor in the American way of life. Our Society has given constructive leadership and efficient service in the encouragement of research and the dissemination of chemical knowledge and in the raising of standards of training and professional attainments and ethics in our profession.

The surveys that were published at our silver anniversary in 1901 and in the Golden Jubilee number of the *Journal of the American Chemical Society* in 1926 serve, in a sense, as two points on the curve of progress that appears to have developed almost exponentially through the past quarter century. A most noteworthy expansion in the quality and amount of scientific material published, in number of members, and in varied services has occurred during this period.

The public has been made increasingly aware through effective science reporting of the more spectacular chemical advances such as new drugs, new classes of materials in the fields of textiles, plastics, alloys, and countless organic and inorganic products. A grasp of the broad significance of theoretical advances is now quite widespread, thanks to skilled popular presentations. A more general appreciation of the power of scientific research has resulted and the nation's chemical research potential has increased sharply because our industrial leaders have been keenly aware of the potentialities of modern research.

The successful development of chemical and biochemical agents for control and cure of disease has given reasonable basis for the hope that through further research, often of necessity slow and laborious as well as expensive, many other human ills may be ameliorated or cured by chemical agents as yet undiscovered. It is difficult to estimate the full physical and psychological benefits that have already resulted from this type of research, not to mention those that lie in the future.

The engineer has found that many of his dreams as to ideal or superior qualities for chemical processing equipment have come true through intensive research. The existence of superior materials of construction, ingenious control instruments, new tools and energy sources has profoundly altered the technology of chemical production. Types of reactions that were regarded as improbable or even impossible a decade ago have since been made to go with high yields due to the discovery of catalysts, through developments in equipment for high pressures and temperatures or through proper variation of other factors.

In retrospect it is certain that an indirect by-product of World War I was the establishment of an independent and self-sustaining chemical industry in the United States. This industry has been in a position to lend aid to the world at large in the supply of products and technical information and in the rebuilding of the economy of the nations that were hardest hit during World War II.

Prior to 1914 numerous young chemists of this country received advanced training in European universities. In the years between wars the majority of our young scientists completed their advanced training in this country. In the present decade our educational institutions have been of increasing aid to students of other lands who are in search of advanced training in chemistry. It is the hope of educators that in the not distant future political and economic conditions will be such that there is a free interchange of students and information to an extent that has not been realized. It is a significant and welcome fact that some three hundred of the leading younger scientists of various countries will attend our chemical conclave and thereafter visit numerous industrial and academic installations, thanks to the Ford Foundation and the ECA, through a plan administered by the American Chemical Society.

What of the future? Predictions are always hazardous; for example, it was predicted in 1901 that there would be 10,000 members at the Society's century mark in 1976. The 10,000 mark was passed in 1917 and our number now stands at about 66,000. There is every reason to believe that our present slogan, "Chemistry . . . Key to Better Living" will be justified in myriads of ways in the next quarter century. Chemistry and chemical products must play a significant role in the establishment of economic conditions that will be conducive to the firm establishment of peaceful cooperation among nations.

It seems safe to predict that in spite of its size and its complicated tasks our Society will continue to be increasingly effective. Operations under the Constitution and Bylaws of the Society are a faithful reflection of the virtues and difficulties of the democratic way of life on the larger national scene. It lies within the power of every member to give greater service to his science and his fellowmen through active participation in the affairs of the Society.

N. Howell Furman

The Objects of the American Chemical Society shall be

to encourage in the broadest and most liberal manner the advancement of chemistry in all its branches;

the promotion of research in chemical science and industry;

the improvement of the qualifications and usefulness of chemists through high standards of professional ethics, education, and attainments;

the increase and diffusion of chemical knowledge; and

by its meetings, professional contacts, reports, papers, discussions, and publications, to promote scientific interests and inquiry;

Thereby

fostering public welfare and education,

aiding the development of our country's industries, and

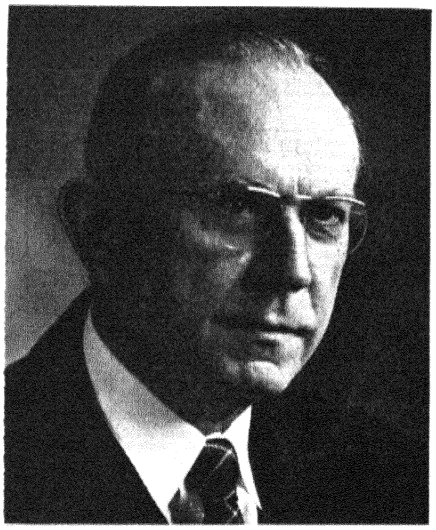
adding to the material prosperity and happiness of our people

. . . NATIONAL CHARTER, GRANTED BY THE
75th CONGRESS OF THE UNITED STATES, 1937

NATIONAL HEADQUARTERS AMERICAN CHEMICAL SOCIETY, WASHINGTON, D



the officers



N. HOWELL FURMAN
President



EDGAR C. BRITTON
President-Elect



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Executive Secretary



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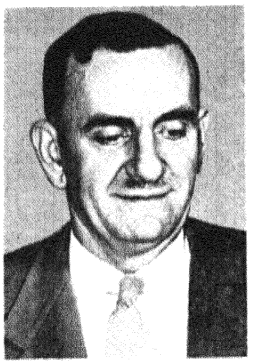
S. C. LIND
Journal of Physical and Colloid Chemistry



WALTER J. MURPHY
Analytical Chemistry, Chemical and Engineering News, Industrial and Engineering Chemistry



W. A. NOYES, JR.
Journal of the American Chemical Society



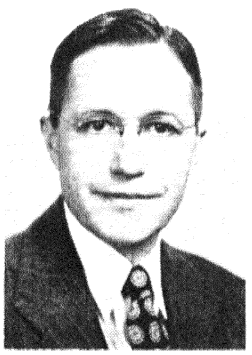
RALPH L. SHRINER
Chemical Reviews



A. C. COPE



FARRINGTON DANIELS



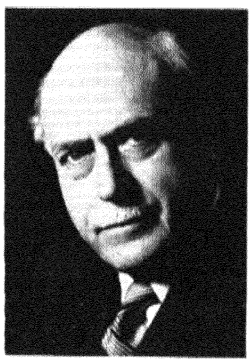
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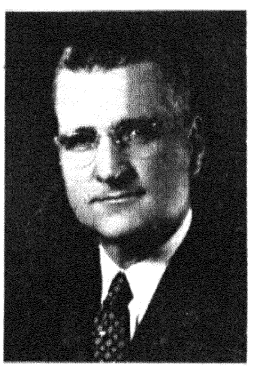
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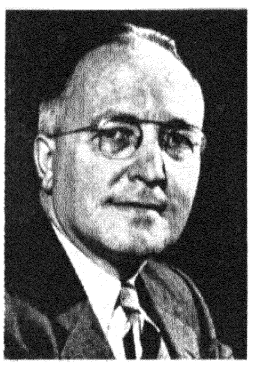
R. E. KIRK



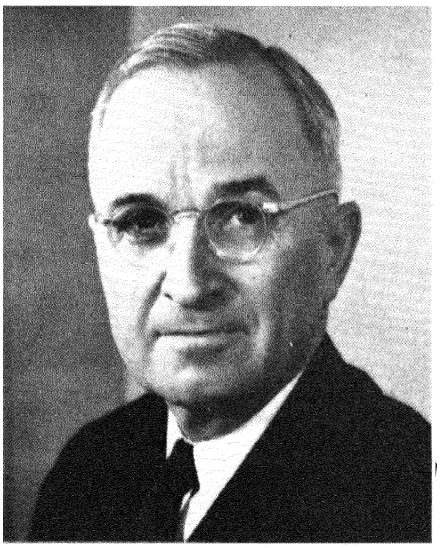
W. A. SCHMIDT



E. H. VOLWILER



J. C. WARNER



THE WHITE HOUSE
WASHINGTON

August 13, 1951

Dear Dr. Furman:

I wish to extend my warm congratulations to the American Chemical Society on the occasion of its Diamond Jubilee. The meeting in New York City in September will be one of the greatest gatherings of scientists in recent times, and a fitting climax to the Society's Seventy-fifth Anniversary year. I hope especially that the distinguished scientists who are coming from other countries for the meetings will enjoy and profit by their visit to the United States.

While the attention of chemists, chemical engineers, and scientists of many related fields attending the meetings in New York will quite properly be directed primarily to the astounding progress of chemistry since the A.C.S. was organized, and to the promise of even greater future progress, I should like to suggest that they also give sober thought to the basic social and political problem facing our democratic society today. That is the problem of preserving personal freedom.

It is a striking tribute to our democracy that so great a number of scientists can assemble here free from suspicion of one another, and free from fear of outside interference. This kind of personal freedom is our most precious national asset. It needs to be carefully guarded and zealously watched, for freedom is in more serious danger today than at any time in our national history.

We all know what a totalitarian system means to the individual. Many of the members of the A.C.S. have seen at first hand the perversion and destruction of free inquiry in other countries in recent years. There can be no question about the urgent necessity of building strong defenses against communist totalitarianism. But, at the same time, we must be equally alert to certain dangers here at home. Liberty can be endangered by the "Right" as well as by the "Left." The increasing frequency with which emotional at-

tacks are made against men and women whose ideas now are -- or once were -- different from those of the majority is most dangerous. Reckless, irresponsible criticism if it goes on unchecked, could soon confine us to a mental strait-jacket. Clear and calm thinking is just as necessary on political and economic matters as it is in the chemical laboratory. Many of the ideas, social and scientific alike, which now seem axiomatic were once regarded as radical. Progress will come to an end if Americans are ever afraid to experiment boldly with new ideas.

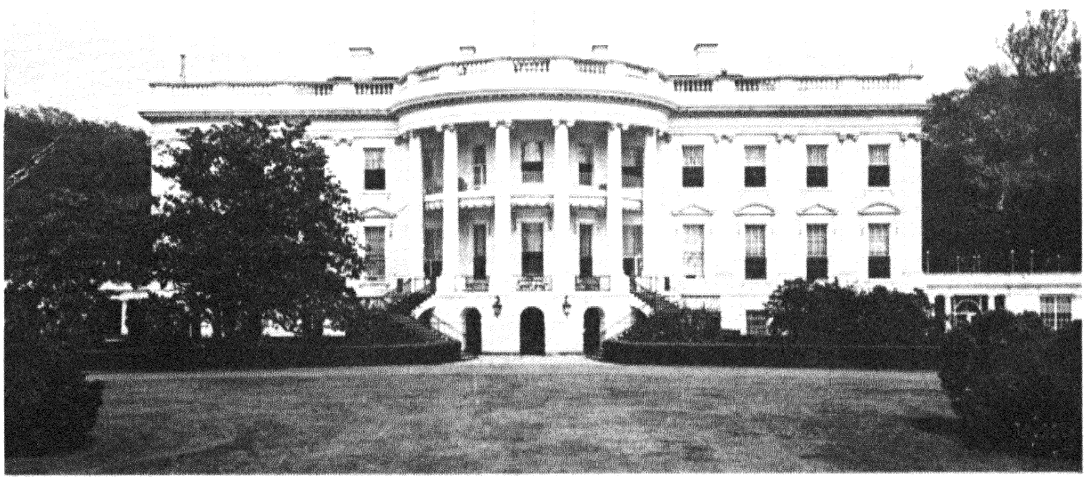
I am sure that the members of the American Chemical Society recognize these facts, and I trust that each will accept a personal responsibility in the continuing effort to protect individual liberties in this country.

With best wishes for a successful meeting, which I sincerely hope will mark the beginning of a new era of brilliant accomplishments in American chemistry,

Very sincerely yours,

Harry Truman

Dr. N. Howell Furman,
President,
The American Chemical Society,
Frick Chemical Laboratory,
Princeton,
New Jersey.





Charles Lathrop Parsons
Marston Taylor Bogert

Honorary Co-Chairmen, ACS Diamond Jubilee Meeting

TWO of the greatest personalities in American chemistry - men whose lives have been intimately bound up in the affairs of the AMERICAN CHEMICAL SOCIETY for over half a century—will be honorary co-chairmen of next month's Diamond Jubilee Meeting. They are Charles L. Parsons, former Secretary of the ACS, and Marston T. Bogert, twice President of the ACS. Few men have added so much to the stature of the AMERICAN CHEMICAL SOCIETY.

At official Diamond Jubilee ceremonies on Sept. 3, Dr. Parsons will unveil a bronze plaque marking the site where 75 years ago the Society held its first meeting. Two days later, Dr. Bogert, on behalf of the ACS, will acknowledge the greetings of scores of delegates from technical societies the world over. Surely no more appropriate persons could have been chosen to serve as key figures at these historic events—for, in the minds of countless chemists both in this country and abroad, the names of Parsons and Bogert and the eminence of the AMERICAN CHEMICAL SOCIETY have been virtually synonymous.

Throughout their busy, far-ranging careers, Parsons and Bogert have worked as a team. Theirs has been a consuming interest in the welfare of the AMERICAN CHEMICAL SOCIETY. In the cause of the chemical profession, they have marched on together.

Charles Lathrop Parsons

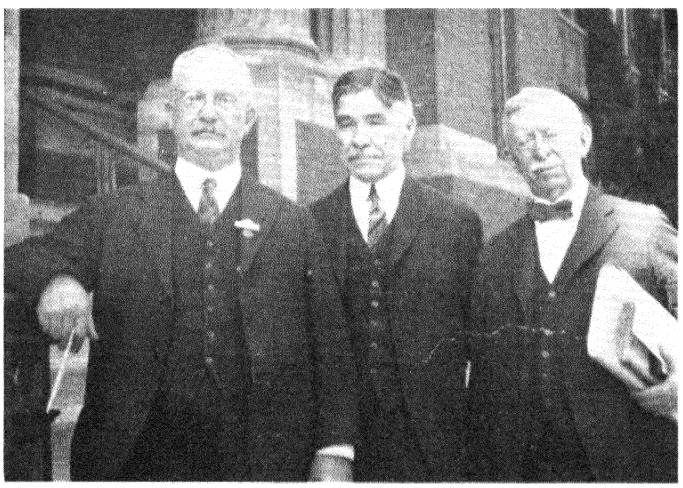
Parsons, a New Englander by birth, received his B.S. degree from Cornell in 1888. Two years later, he became an instructor in chemistry at the University of New Hampshire. In 1892, at the youthful age of 25, he was appointed head of the university's department of chemistry. A lively advocate of scientific education, Parsons once touched off a bristling campus controversy by quietly suggesting that the hours of prayer in required chapels be shortened to allow his pupils to spend more time in their laboratories.

At the Chicago meeting in 1893, attended by 182 chemists, Dr. Parsons joined the AMERICAN CHEMICAL SOCIETY. In the ensuing years, he undertook his detailed studies of atomic weights, the compounds of beryllium, the fixation of nitrogen, and the extraction of radium from its ores. In 1905, in honor of his pioneering work on beryllium, Dr. Parsons was presented with the Nichols Medal, an award which was bestowed upon Dr. Bogert in the following year for his study of the quinazolines.

In 1907, during Dr. Bogert's first term as President of the ACS, Dr. Parsons became Secretary of the AMERICAN CHEMICAL SOCIETY. At first, this was strictly a part-time job for Dr. Parsons, who continued on as chemistry professor at the university. However, by 1911, the increasing pressure of his ACS duties forced him to relinquish his teaching responsibilities.

Dr. Parsons inherited a crisis the moment he hung up his hat as ACS Secretary. Many highly vocal chemists in those days were busy advocating that the Society be broken up into an assortment of separate, more specialized technical organizations. Dr. Parsons fought the threat of ACS disintegration with all the vigor at his command. To a considerable extent, his plea for unity was heeded. "His theory" an associate once said, "was that while it might be well for chemists to split atoms, it was not well for chemists to become atomized." To Parsons' everlasting credit, the Society remained united, strengthened by the very diversity of its far-flung interests.

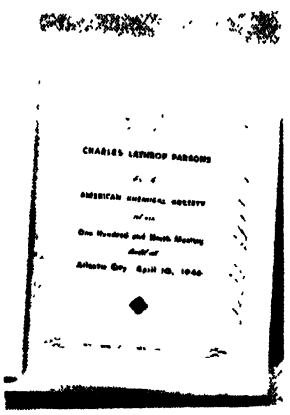
In September 1912, Dr. Parsons moved his office to Washington and, in the succeeding years, worked continually to promote the best interests of chemists and chemical engineers. During



At the 50th Anniversary Meeting of the ACS in Philadelphia in 1926, Secretary Parsons poses with past presidents Edward C. Franklin and Edgar Fahs Smith

World War I, Parsons became a foremost figure in the government's nitrogen program, for several years serving also as chief chemist of the U. S. Bureau of Mines.

To many during World War I, it seemed inevitable that the



Dr. Parsons was presented with a testimonial volume from his associates at the time of his retirement

American chemical industry, despite its impressive wartime achievements, would shrink into insignificance once the shooting was over. Yes, they said, after the war the German chemical industry would once again reign supreme. Parsons would not have it so In the councils of Government and industry, he argued for a sizable postwar build-up of American chemical production. With insistent logic, he challenged the notion that somehow—because of some special touch of craftsmanship—imported products were necessarily superior to American chemicals and apparatus. The robust American chemical industry of today—an industry which has long since thrown off the limitations of its earlier days—owes much to Parsons' vision and to his unbounded confidence in the future of American science.

In 1945, Dr Parsons concluded his career as the Society's Secretary and Business Manager. During his 39 years of service, the ACS flourished, expanding from 3400 to 43,000 members. That twelvefold advance was one of Dr. Parsons' greatest attainments. Continuing to build on its solid foundation, the Society has grown to a total of more than 66,000 members today.

Marston Taylor Bogert

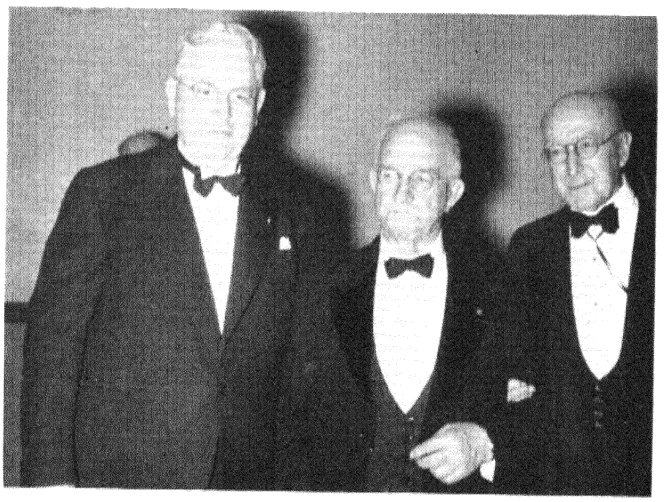
Like the immense contributions of Dr. Parsons to the advancement of the AMERICAN CHEMICAL SOCIETY, those of Marston Bogert defy detailed analysis. In 1908, during Dr. Bogert's second term as President of the AMERICAN CHEMICAL SOCIETY, the ACS established its first division—the Division of Industrial Chemists and Chemical Engineers (later rechristened the Division of Industrial and Engineering Chemistry). Bogert worked closely with Parsons in setting up four additional divisions that same year—an effort that largely checked the threatened formation of innumerable splinter groups within the chemical profession. Without doubt, the presidency of Dr Bogert marked a critical turning point in ACS affairs—a time when the organizational structure of the AMERICAN CHEMICAL SOCIETY was strengthened as never before.

Educated at Columbia University, Dr. Bogert received his Ph.B. in 1894. In 1904, Dr. Bogert became professor of organic chemistry at Columbia. In the prolific years that followed, Dr. Bogert authored over 400 scientific papers, principally in the field of organic chemistry. His researches on dyestuffs, pharmaceuticals, and perfumes (especially the relationship between odor and molecular structure) have made their lasting imprint.

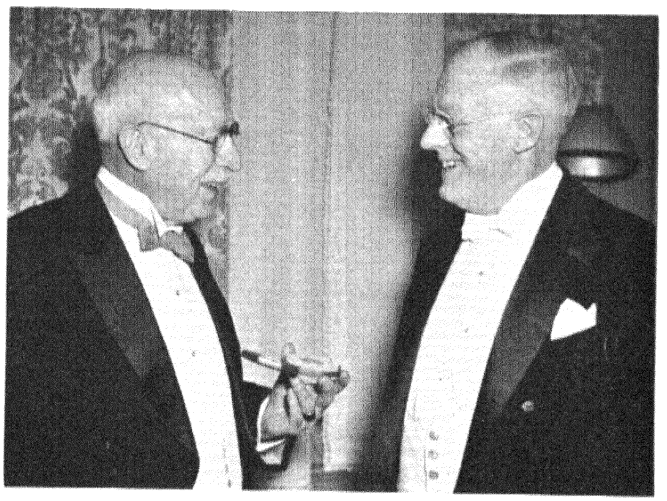
During World War I, Dr. Bogert was invited to Washington to organize and serve as first chairman of the Chemistry Committee of the National Research Council. In 1918, he was appointed a colonel in the Chemical Warfare Service. Some years later, Bogert packed his bags and journeyed to Czechoslovakia, to become first visiting Carnegie professor of international relations at Charles University.

Today, in the hearts of hundreds of his associates and former students, Dr. Bogert is esteemed as a gifted teacher and an incomparable personality. Harry L. Fisher, a former pupil and now administrative secretary of the forthcoming International Congress, wrote many years ago, "Prof. and Mrs. Bogert are wonderful guests, as my wife and I know. Well do we remember their coming to dinner in our humble New York apartment when I was a struggling young instructor. The walls seemed to recede and we felt not only honored but truly blessed."

A man of captivating wit and charm, Bogert is a toastmaster with few equals. When the occasion arises for a distinguished chemist to receive a medal at a scientific gathering in New York City, the chances are that Marston Bogert, at his effervescent best, will present the award. For such events, Dr. Bogert almost invariably sports his famed mauve tie—the one worn by all who attended the dinner in New York honoring Sir William H. Perkin, Sr., in 1907. For Bogert, that Perkin tie has become something of a trade-mark.



At testimonial banquet in 1946 ACS President Dewey, retiring Secretary Parsons, and Past President Bogert



Marston T. Bogert, wearing his famous mauve tie, presents Perkin Medal to E. K. Bolton

In the recent past, one of Dr. Bogert's most absorbing interests has been the task of rebuilding the International Union of Chemistry out of the ashes of World War II. "This was an uphill job," he once said, ". . . but slowly definite progress was made." Dr. Bogert, as president of the Conference of the International Union of Chemistry in London in 1947, had a gratifying opportunity to see what enormous progress actually had been made. Thanks to his courageous, sometimes singlehanded efforts, the International Union is today a vital force uniting chemists in all parts of the world.

On the occasion of the Parsons Testimonial Banquet in 1946, an elderly gentleman, known to all, delivered the introductory remarks "If you are seeking a monument to Charles Lathrop Parsons," he said, "look about you and you will find it in the minds and hearts of those who cherish what is in every respect the greatest association of chemists the world has known, the AMERICAN CHEMICAL SOCIETY—a splendid and enduring monument of which its chief architect is justly proud."

The speaker at that meeting was Marston Taylor Bogert, fellow-architect



JOHN H. NAIR
Chairman

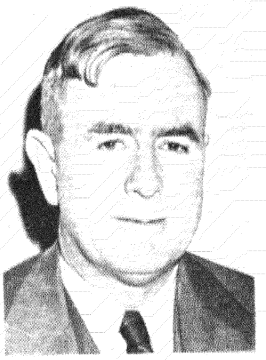
ACS DIAMOND JUBILEE COMMITTEE



MRS. L. W. BASS
Ladies Program



H. L. FISHER
Liaison



R. E. KIRK
Honorary Membership

CONDENSED PROGRAM OF

AMERICAN CHEMICAL SOCIETY
NEW YORK

Monday, Sept. 3

Dedication of ACS Commemorative Plaque

General Meeting, PRESIDENT N HOWELL FURMAN, presiding
- Presentation of Priestley Medal to E. J. CRANE
- Address by HONORABLE ALFRED E. DRISCOLL, Governor of New Jersey

Tuesday, Sept. 4

Welcome by Mayor of the City of New York

Post Office Ceremony presenting ACS Commemorative stamp

Divisional meetings

Wednesday, Sept. 5

Diamond Jubilee Ceremonial
- Presentation of greetings to ACS by societies and associations of the world
  - SIR ERIC RIDEAL, The Chemical Society (London)
  - Response by ACS Past President MARSTON T. BOGERT
  - DETLEV W BRONK, president of the National Academy of Sciences
  - Response by ACS PRESIDENT FURMAN
  - Address by JAMES B. CONANT, Honorary President of the XIIth International Congress of Pure and Applied Chemistry

Diamond Jubilee Banquet
- Toastmaster, CHARLES A. THOMAS, Chairman of the ACS Board of Directors
- Address by the Vice President of the United States, ALBEN W. BARKLEY
- "The View Ahead in Chemistry" by C. E. K. Mees
- Selections by Risé Stevens, Metropoliton Opera Co.

Divisional Meetings

Thursday, Sept. 6

Divisional Meetings

Friday, Sept. 7

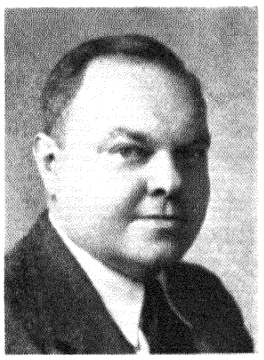
Divisional Meetings

INTERNATIONAL UNION
NEW YORK

Saturday, Sept. 8

Meetings of Commissions

Reception for Delegates, Metropolitan Museum of Art



H. C. LINDWALL
Memorial Plaque



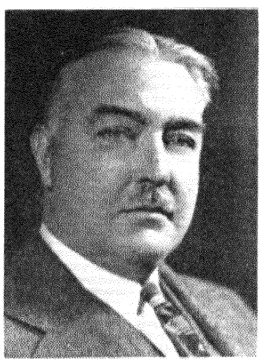
HERMAN MARK
Hospitality



WALTER J. MURPHY
Publicity



NORMAN SHEPARD
Public Relations



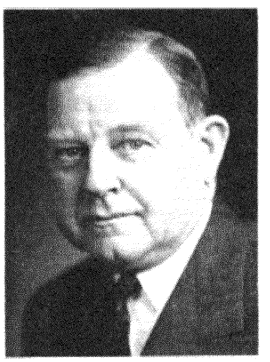
FOSTER D. SNELL
Banquet



W. J. SPARKS
Program



A. W. THOMAS
Ceremonial



EDWARD R. WEIDLEIN
Finance

WORLD CHEMICAL CONCLAVE

Sunday, Sept. 9

Meetings of Commissions

MONDAY, Sept. 10

Reception for delegates and members, New York Academy of Sciences

WASHINGTON, D. C.

Friday, Sept. 14

Visit to National Bureau of Standards

Banquet observing 50th anniversary of the founding of the National Bureau of Standards
Toastmaster, DETLEV W. BRONK
HUGO R. KRUYT, President of the Union
EDWARD U. CONDON, Director of the National Bureau of Standards
Address by CHARLES A. SAWYER, U. S. Secretary of Commerce

Saturday, Sept. 15

Meeting of the Council, National Academy of Sciences
Garden Party, grounds of the National Academy of Sciences

INTERNATIONAL CONGRESS NEW YORK

Sunday, Sept. 9

Reception for members, American Museum of Natural History

Monday, Sept. 10

Sectional Meetings
General Lecture, E. W. R. STEACIE

Tuesday, Sept. 11

Sectional Meetings
General Lecture, K. U. LINDERSTROM-LANG

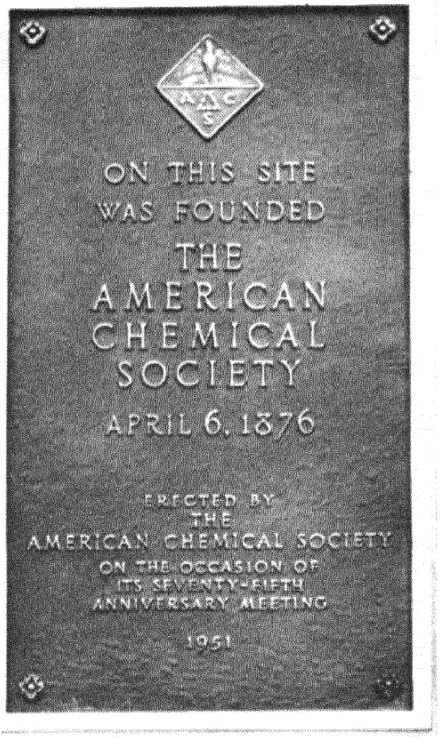
Wednesday, Sept. 12

Sectional Meetings
General Lecture, ALEXANDER R. TODD
International Congress Banquet
Address by Honorary President, JAMES B. CONANT

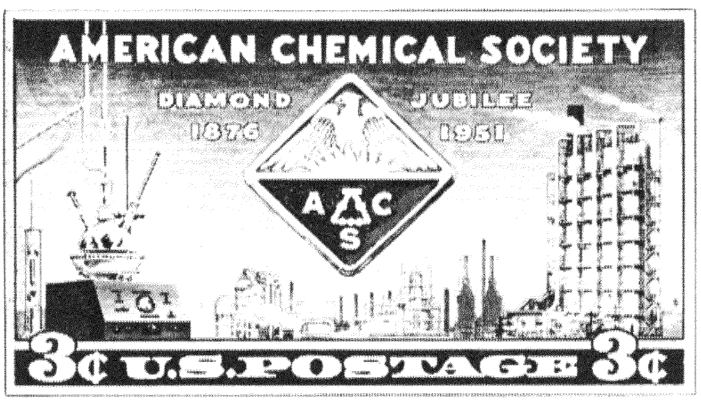
Thursday, Sept. 13

Sectional Meetings
General Lecture, VENANCIO DEULOFEU

the plaque



This bronze plaque commemorating the founding of the American Chemical Society has been placed on the building now occupying the original site of the old building of the New York College of Pharmacy on Washington Square where the first meeting for the organization of the American Chemical Society was held on the evening of April 6, 1876. Formal unveiling of the plaque took place during the 75th anniversary meeting of the American Chemical Society by Charles L. Parsons. In an address at the unveiling ceremonies, Arthur B. Lamb contrasted the status of chemistry in the United States in 1876 and 1951.



the commemorative stamp

On Sept. 4, 1951, the U. S Post Office Department issued a stamp commemorating the 75th anniversary of the American Chemical Society. The central design of the stamp is the emblem of the American Chemical Society. On the left is a modern alembic symbolizing chemical synthesis, an ionization indicator symbolizing the use of electronics and instrumentation in modern chemical investigations and manufacturing, and a conventional hydrometer. To the right is the horizon of the Chemical Century, typified by the towers of the catalytic cracker, a butadiene reactor, and a fractionating unit. The wording, "American Chemical Society" and "Diamond Jubilee 1876–1951," is in white face gothic, and the inscription, "3c U. S. Postage 3c" is in white face Roman. The color of the stamp is maroon.

The stamp is 0.84 by 1.44 inches in dimensions, arranged horizontally with a double line frame. It was printed by rotary press, electric-eye perforated, and issued in sheets of 50. An initial printing order of 110 million was authorized.

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The Book of Nature! Shall not we chemists and all our brother students, whether they be naturalists, astronomers, mathematicians, geologists, shall we not all humbly and earnestly read it? Nature, the mother of us all, has inscribed her unfading, her eternal record on the canopy of the skies. She has put it all around us on the platform of the earth...

...John W. Draper, Inaugural address as first President of the ACS

The First 75 Years

ANTHONY STANDEN

THE AMERICAN CHEMICAL SOCIETY is 75 years old.

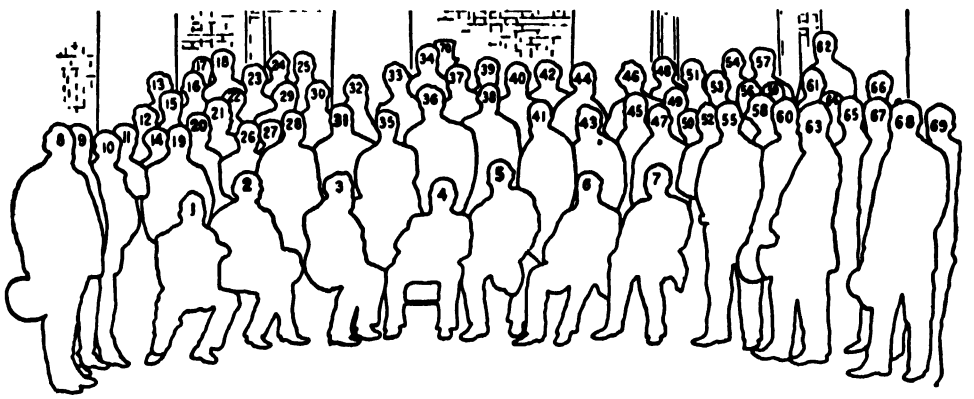
The American chemical industry, although much older than this, is, in anything like its modern form, a recent growth considerably younger than the AMERICAN CHEMICAL SOCIETY. If a chemist or chemical engineer, familiar with what goes on in industry nowadays, were to be transported back to the first decade of this century, he would find just a few vague points of similarity to modern chemical industry, a skeleton as it were, and no more. He would find a sulfuric acid industry, which is familiar enough, but rather unexciting. He would find a few alkali plants, electrolysis as well as ammonia soda, some plants carrying out tar distillation in what he would consider a primitive sort of way, a relatively large amount of old-fashioned bleaching powder, and a small handful of other commonplaces of the basic chemical industry. He would see products manufactured in untidy looking buildings, characterized by a haphazard appearance and usually by a smell. And since he might have come straight from a gigantic 1951-type cat cracker, or a beautiful, spotless, antiseptic antibiotics plant, both of them a delight for professional photographers, he would have ample stimulation to reflect on the truly gigantic changes brought about by chemistry in the past half century.

Fifty years ago, alcohol was alcohol, a product obtained by fermentation of vegetable matter, and in no other way. Now, fully half of our industrial alcohol is obtained from petroleum. Rubber was rubber. It was the product of the latex of *Hevea brasiliensis*. No one dreamed that, 50 years later, chemistry would be developed to the point where it would be possible to build up a 900,000-ton synthetic rubber industry almost overnight. Soap was manufactured, but synthetic detergents were practically undreamed of. Carbon black was a pigment and ink ingredient only. Words such as nylon, Orlon, Vinyon, Dacron (and any other such "ons") had never been heard of. Polymers had been heard of, but usually were referred to only as "gunk." The visitor from 1951 might be tempted to wonder what chemists did pay attention to. They did have plenty of problems, and the fact that they paid attention to them so well is what made it possible for the chemical industry to shoot up and branch out in all directions. Fifty years ago, the chemical industry was a bare skeleton of what it is now. Yet 50 years ago, the AMERICAN CHEMICAL SOCIETY was already 25 years old.

It is extremely fortunate for American chemistry and industry that the AMERICAN CHEMICAL SOCIETY was founded when it was, back in 1876, rather than later. The great challenge to American chemistry came, as every student of history knows, when World War I vividly brought home to us our appalling dependence on the German chemical industry. The challenge was met by American chemists and chemical engineers who were organized in a society that had already showed some stability, that had gotten over its growing pains.



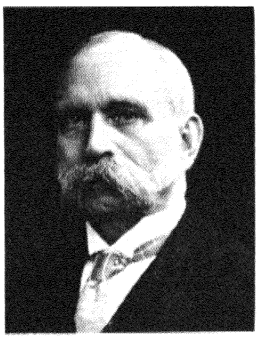
The inspiration for the founding of the ACS came from this group of chemists gathered at the Priestley Centennial, Northumberland, Pa., Aug. 1, 1874



1. B. S. Hedrick
2. E. N. Horsford
3. T. S. Hunt
4. J. L. Smith
5. B. Silliman
6. H. Coppee
7. Rev. T. R. Pynchon
8. Thos. Lyon
9. Conyers Button
12. W. M. Iles
14. E. J. Hallock
15. W. H. S. Thorburn
16. John A. Church
18. S. St. John
19. H. C. Bolton
20. C. F. Chandler
21. E. Waller
22. Arthur Macy
23. H. G. Torrey
24. E. L. Youmans
25. W. K. Kedzie
26. C. A. Joy
27. M. S. Thompson
28. S. P. Sharples
31. J. Priestley
32. S. H. Douglass
33. J. M. Maisch
34. R. C. Kedzie
35. M. B. Priestley
36. David Taggart
37. F. Hoffmann
38. E. T. Cox
39. C. G. Wheeler
43. P. W. Bedford
44. W. W. Daniels
45. H. B. Nason
46. A. P. S. Stewart
47. T. G. Wormley
48. F. W. Clarke
49. A. A. Breneman
50. C. S. Allen
53. H. Endemann
55. P. Frazer, Jr.
56. A. H. Gallatin
57. C. H. Chandler
58. Traill Green
60. W. H. Chandlee
62. J. P. Remington
64. E. W. Hilgard
65. A. R. Leeds
67. T. M Drowne
68. P. H. Vander-Weyde

The ACS may be said to have begun with a backward glance at Priestley, for the first serious suggestions for its formation were made at a meeting of chemists which was held in 1874 at Northumberland, Pa., Priestley's home in America, to celebrate the hundredth anniversary of his discovery of oxygen. The AMERICAN CHEMICAL SOCIETY was founded in 1876, in New York, with a membership of 133. Recently, the growth curve of the Society has shown a pleasing tendency to rise almost vertically to the limits of the graph paper, but it must be remembered that it began very slowly, like one of those reactions that are catalyzed by the products of the reaction, and show an induction period. The membership was in the 200 to 300 range for 15 years: the figure was 302 in 1891. Then it began to rise slowly, passing the thousand mark in 1896. It was a cause, at the time, of great satisfaction and great hopes for the future when the number of members in 1910 was 5081. The AMERICAN CHEMICAL SOCIETY had found its feet. It had already made several mistakes, and had profited by them. In its early years it had made the mistake of being too much of a local society, concentrated in New York. In 1892, it had found the solution to this problem, with a revised Constitution and Bylaws, not limiting the officers to residents of New York City, and with an organization permitting local sections to be formed wherever there were enough chemists to make this desirable. In the early years of this century it had faced,

and solved in principle, a much more difficult problem, a problem which could be formulated in various ways, but which perhaps can be broken down into two simple-sounding but extremely fundamental questions. Upon some sort of answer to these depends the answer to the more immediate question, What form or organization is appropriate for the chemical profession? This question the AMERICAN CHEMICAL SOCIETY has been answering ever since.



Charles F. Chandler of Columbia University was president of the Priestley Centennial Celebration and leading spirit in events that led up to the founding of the ACS

The ACS is now the largest scientific society in the world. It has 66,000 members, an annual budget in excess of $3,250,000, and is proud to have the distinction of a Federal Charter. Of its members, over one quarter, or more than 16,000 are chemical engineers, the rest have had professional training as chemists. Both groups are extremely varied in the type of work they do. The Society, too, carries on a varied group of activities, all of them connected with the profession. In considering the various activities of the ACS, it will be found that *all* of them contribute in different ways to answering the questions, Who is a chemist? — Who is a chemical engineer?

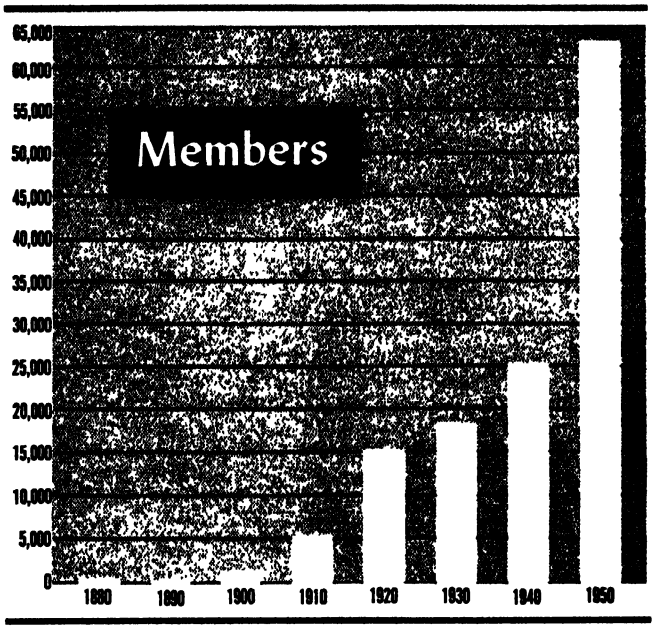
In "The Beggars' Opera" the highwaymen sing:

> Let chemists toil like asses
> Our fire their fire surpasses
> And turns all our lead to gold.

Such was the reputation of chemists in the 18th century. It may have been somewhat better in the 19th century, and perhaps a shade better still in the early years of this century. A chemist was a queer fish. It was not entirely certain whether he was *quite* respectable. He certainly did not enjoy the respectability of the lawyer, the physician, the minister, or the banker. But now all is entirely changed. Chemistry is a most respectable and respected profession. The chemist and the chemical engineer are held in high regard for their intellectual as well as practical achievements. Almost everyone has heard of them and thinks well of them.

And yet, what is a chemist? If one were to enter one of the rather bedraggled looking chemical plants of a half century ago, one could ask to see "the chemist," and would then be brought in to meet an underpaid, little-respected creature, with a pipet in his hand, doing routine analyses. By contrast today, it has been estimated by M. C. Whitaker that "A typical research organization in a growing and well diversified chemical company would add up to approximately 550 chemists, 60 physicists, 80 engineers, 75 biologists, 20 metallurgists, five physicians, 450 technicians, and 400 nontechnical employees —a total of 1640."

And speaking of personnel, one of the most fascinating developments in the chemical industry, the past quarter of a century, is the movement of the technically trained into the administrative and executive positions. Twenty-five years ago very, very few vice presidents or presidents of our chemical companies were chemists or chemical engineers. Lawyers, yes, bankers, yes, but the majority were graduates only of the school of hard knocks and experience. The man with a degree in chemistry or chemical engineering was usually thought to be two things: one, a long-hair, and two, thoroughly impractical. This impression has given way to a thorough realization that the chemically trained mind is an absolute essential in administrative and executive circles. Accordingly, a study of the top brass of the chemical industry today will disclose that a high percentage hold degrees in chemistry or chemical engineering and have reached their present pinnacles of success via the research, or production, or sales, or market development departments. There is a good reason why this trend has taken place over the past quarter of a



century. Industrial chemicals today are mighty complex, and it takes the technically trained mind to understand them thoroughly and to explore their potentialities.

It is also a noteworthy fact that the versatility of the structure of the AMERICAN CHEMICAL SOCIETY is such that at local section meetings of the Society at Midland, Mich., one would frequently see the late Willard H. Dow, president of the company, seated alongside the newest member of the research staff. This pattern has been one of the great strengths of the AMERICAN CHEMICAL SOCIETY in carrying out the objects of its charter.

What Do Chemists Do?

The physicists have a way of saying that they cannot tell us what an electron *is* (nor an atom, for that matter). All they can tell us is what an electron *does*, and that in exceedingly abstract mathematical terms.

What a chemist does can be explained in quite practical and usually superlative terms.

Hitting only a few high spots, taken from recent history, here are a few. The magazine *Fortune*, after a careful study, said, weighing its words solemnly, "Chemicals must now be considered the premier industry of the U. S." The magazine's editors were astonished at the seething, boiling, bubbling pot which was before their gaze, an industry in which it is common for a single large company to introduce a dozen or more new products every year. They said "The chemical industry cannot be matched by any other in dynamics, growth, earnings, and potential for the future."

Said another authority, "The chemical industry has not reached maturity it's just a growing boy." This speaker, Leland I. Doan, certainly ought to know, for he is president of the Dow Chemical Co., whose remarkable rate of progress gave them 1170% higher sales in fiscal 1950 than in 1939. And yet Dow, although a gigantic grower, is by no means unique in the chemical industry, where 16 other companies registered increases of over 300% in the same period, and one of them, Charles Pfizer, chalked up an 885% increase.

The chemist is the person who makes these things possible. Granted that these companies have had strong, aggressive managements, excellent sales forces, streamlined organizations, every thinkable other advantage, but these things alone don't make

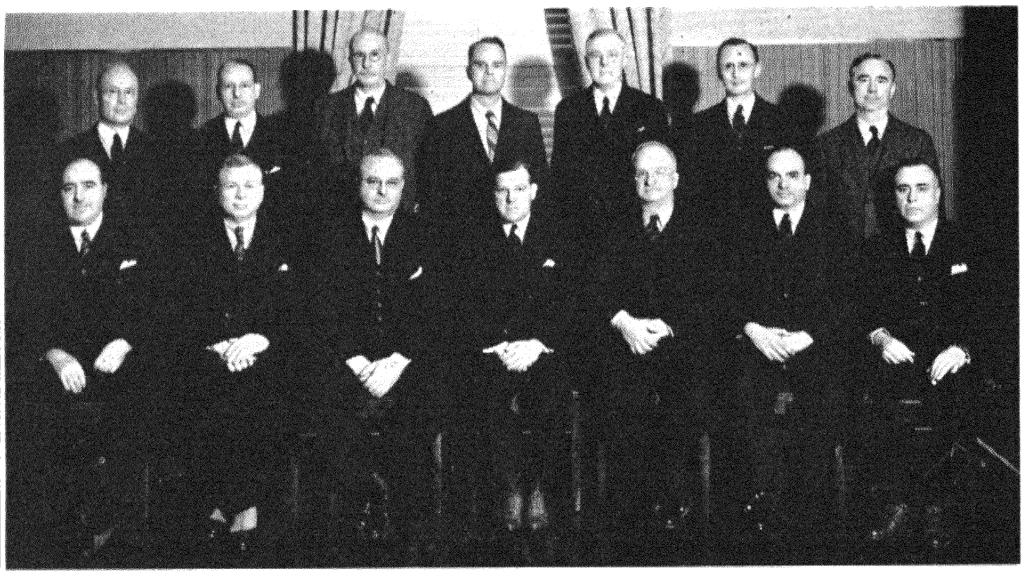
such huge increases in sales. There has to be something to sell, and in the chemical industry it usually has to be something new to sell. Among major companies, some 40% of the 1950 sales was in products that were commercially unheard of in 1935.

A chemist is a person who takes bromine out of the sea, where it is present to the extent of only 65 parts per million. And what does he want the bromine for? Why, to take the lead out of the cylinders of the internal-combustion engines in our cars and our airplanes. And why is there lead in the cylinders? Because the curious compound, tetraethyllead, has the property of reducing "knock," and is added to gasoline to give better fuel economy and permit more efficient engine design. This was discovered by Thomas Midgley and T. A. Boyd. Midgley was President of the ACS for 1944 and (as has been jokingly pointed out) by far the greatest industrial chemist who received his principal university training not in chemistry, but in mechanical engineering (and certainly one of the great industrial chemists of all time, even without this qualification).

Not content with the bromine, the chemist also takes magnesium out of the sea. There are slightly over 6 million tons of magnesium in a cubic mile of sea water, a little more than one part per thousand. Dow Chemical Co., major U. S. producer, estimates that if we took magnesium out of the sea at a rate of 100 million tons a year (1950 U. S. production about 20,000 tons) for the next million years, the concentration would have dropped from the present 0.13% to 0.12%. Consequently, magnesium is one metal of which the "ore" reserves are practically limitless.

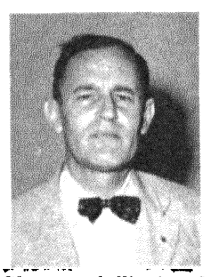
As recently as five years ago there were serious fears of a petroleum shortage. Large discoveries of petroleum deposits since then have shown that the danger is not acute, but even if it were, there are things that can be done about it, using chemistry. We have very large reserves of natural gas, and a huge plant is at present being constructed to make gasoline and oil products, 7000 barrels a day, out of natural gas. And not only gasoline, but a by-product line of at least 20 other chemicals. The basic synthesis used here, the so-called Fischer-Tropsch process, was German, but when it came over to this country and was worked over by American chemists and chemical engineers, it expanded like a balloon—became so enormously increased in scale and scope as to be hardly the same process. This new plant is at Brownsville, Tex., for Texas has not been content to stay quietly home on the range. It is a huge chemical industry state now, flourishing and bustling with chemicals and "petrochemicals," a term which would have sounded most mysterious to our old-timer from the early 1900's.

In the old days, there was a distinction, or at least people tried to make a distinction, between the chemical industries and the industries using chemistry. The fertilizer industry used chemistry, and the petroleum industry used chemistry, and they both even employed a certain number of chemists—but nobody called them chemical industries, because they did not produce "chemicals," where a "chemical" is a reasonably pure substance sold under a chemical name. If you make acetone, that is a chemical, but if you make a mixture of hydrocarbons, of most complex composition but of a definite boiling range, and suitable for use in an internal combustion engine, that is gasoline and is not a chemical—although it is a far more complicated and challenging chemical study than the acetone. If you take petroleum and



ACS Board of Directors in 1937, when National Charter was granted by the Congress of the United States. Seated: R. E. Wilson, R. T. Baldwin, Thomas Midgley, Jr., E. R. Weidlein, C. L. Parsons, F. C. Whitmore, Elisha Hanson, ACS Counsel. Standing: E. M. Billings, G. J. Esselen, Edward Bartow, H. H. Willard, E. K. Bolton, A. J. Hill, T. R. Leigh

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Anthony Standen brings a fresh British viewpoint to this resume of the doings of the American Chemical Society in its first 75 years, and of the American chemical industry. The same happy blend of American enthusiasm and the cooler objectivity of a cooler clime went into his brainchild (written as pastime) "Science Is a Sacred Cow" (E. P. Dutton and Co., 1950). His present position is assistant editor of "Encyclopedia of Chemical Technology," which is being compiled at the Polytechnic Institute of Brooklyn. In 1928 he took a first class honors degree in chemistry from Oxford, and then was sent by Imperial Chemical Industries, Ltd., on an industrial fellowship to study at MIT, where he took a master's degree in chemical engineering in 1930. Back in England he worked in the research department of ICI at Billingham, largely on cyanides. Several visits were made to Spain and Brazil in connection with the HCN fumigation of citrus trees, and in 1939 he decided to resist no longer his "pull" toward the U. S., and became an American citizen.

After studying entomology at the University of New Hampshire for a couple of years he wrote "Insect Invaders" (Houghton Mifflin, 1943), then taught at St. John's College in Annapolis until 1945. He has published articles in *Life*, *Good Housekeeping*, *Collier's*, *Atlantic Monthly*, and *Harper's*.

prepare from it a stream of reasonably pure ethylene, is that a "chemical" or isn't it? If from the ethylene you make ethylene chlorohydrin, ethylene oxide, and then ethylene glycol, well, they are chemicals beyond any doubt. They can be called "petrochemicals" because they are the sort of thing that chemists create when they are turned loose on petroleum. And they are only a beginning. A chemist can make scores of products from ethylene glycol. There is no particular reason why he should ever stop as long as the products serve useful purposes.

In the old days chlorine was chlorine. Or at least bleaching powder was chlorine, because it was the best available method of transporting chlorine. Liquid chlorine, in cylinders or tank cars, is a familiar story now, and chlorine has gone, besides, into hundreds of other products. Chlorine used to be the by-product, rather than the co-product, of electrolytic alkali manufacture, and was sometimes rather difficult to dispose of. In that period it could jokingly be said that the instructions to chemists in an alkali research department were "Whatever you've got, put chlorine into it and see what happens." As a result, a host of chlorinated hydrocarbons and other compounds containing chlorine are in large-scale production--chlorinated paraffin, chlorinated naphthalene, chlorinated rubber, chlorinated everything else, and chlorine is in short supply. DDT contains chlorine, and of the post-DDT insecticides (DDT started a new era in this field) some contain chlorine hooked up with most complex bridged ring systems that only an organic chemist could think up.

Fluorine was, to use a dreadfully hackneyed phrase, a "laboratory curiosity." Since Moissan first prepared it in 1886, it was seldom prepared by anybody. As for fluorine compounds, a few were known and used, for instance calcium fluoride in metallurgy as a flux, and cryolite in Hall's process for manufacturing aluminum. These compounds are poisonous, and chemists were cautious of fluorine compounds outside of a laboratory hood. It was Midgley, again, who first cracked this, by showing by abstract analogy from the Periodic Table and confirming his conclusions by experiment, that the fluorinated hydrocarbons need not be poisonous at all. The Freons followed from this, almost perfect refrigerants with additional uses such as for aerosol insecticide bombs. Since then, fluorine chemistry has grown by leaps and bounds. Fluorine itself is an article of commerce, and so is hydrogen fluoride, and so are a number of fluorocarbons and partly fluorinated organic compounds. And from this most active of all elements are made plastic materials with the most remarkably inert properties. It is noteworthy that the theoretical chemistry of fluorine and the applied chemistry have grown together. There has never in this country been a sharp separation between the two.

At the AMERICAN CHEMICAL SOCIETY meeting in Rochester in 1925, E. K. Bolton heard Father J. A. Nieuwland, of Notre Dame University, give a talk in a symposium on organic chemistry on some acetylene reactions, in which larger molecules were formed from the smaller ones. This was pure chemistry, undertaken purely for the scientific interest. It made an impression in the mind of Dr. Bolton, director of the chemical section of Du Pont's dyestuffs department, and of W. A. Carothers, who in 1927 left Harvard to head the section on organic chemistry in the new program of fundamental research then being started at Du Pont. Polymerization, the formation of large molecules from smaller ones, was Carothers' study, and he studied it in an extremely fundamental way. Nieuwland's particular approach, in the field of hydrocarbons, led in the general direction of rubber. The ideas germinating in the brilliant mind of Carothers, backed by the resources of Du Pont, and helped by the ability and teamwork of the chemists working with and under Carothers, led to the synthetic rubber neoprene. This synthetic was announced and shown at the annual dinner of the Rubber Division of the AMERICAN CHEMICAL SOCIETY at Akron in 1931.

Carothers was also interested in the polymerization, or rather polycondensation, of diamines and dicarboxylic acids. This reaction leads to "polyamides" a word which is in danger of becoming synonymous with "stockings." Carothers' untimely death in 1936 prevented him from seeing the fruits of his fundamental research. The famous nylon was formally announced to the world in 1938. Note the timing; not that chemical research can be timed, but as it happened nylon *was* brought to the commercial stage at *that* time, so that when, a few years later, World War II cut us off completely from Japanese silk, the practical chemists and the chemical engineers had taken the process so far that nylon was available in large quantities, just when it was needed for parachutes, towing lines, and lots of other things.



Styles have changed! Members of the Division of Chemistry of U. S. Department of Agriculture, Washington, D. C., in 1885 included Augustus E. Knorr, John Dugan, C. A. Crampton, H. W. Wiley (President of the ACS in 1893, 1894), T. C. Trescot, and Miles Fuller

Standing at the forefront, of course, are the theoreticians --men working in science for its sake alone—who have contributed in a fundamental way to our knowledge of the properties of matter. Who is not familiar with the names of the American winners of the world's highest accolade, the Nobel prize —Irving Langmuir, 1932, for his discoveries in the realm of surface chemistry; Harold Urey, 1934, for his discovery of heavy hydrogen; Peter Debye, 1936, for his contributions to the knowledge of molecular structure; the joint winners of 1946 –James Sumner and John Northrop, first to crystallize an enzyme, and Wendell Stanley, whose work led to the discovery that viruses are purely chemical, nonliving proteins that reproduce themselves inside living cells, William Giauque, 1949, for his studies of the behavior of matter near absolute zero which led, among other things, to his discovery of the oxygen isotopes. Nor could we rightly omit from our list the husband-and-wife team, Carl and Gerty Cori, biochemists who got the Nobel award in medicine in 1947 for their work on the metabolism of glycogen, or the 1950 award in medicine received in part by chemist E. C. Kendall whose work on the suprarenal cortex hormones, their structure, and biological effects led to the discovery of cortisone. Others will say, "What about the new antibiotics like streptomycin, or the new transuranium elements?" Surely, they deserve a place on any list. Indeed they do and so do many others.

These, of course, are only a few of the achievements of chemists, taken entirely at random, to illustrate defining who chemists *are* by what they *do*. And they don't confine themselves to digging out knowledge for the sake of knowledge. They do, of course, gain plenty of fundamental knowledge which can be regarded as partly for the sake of the insight it gives us into the nature of the universe in which we live. There may be some chemists who do nothing but this. But we know enough about science now to realize that *any* theoretical discovery is potentially

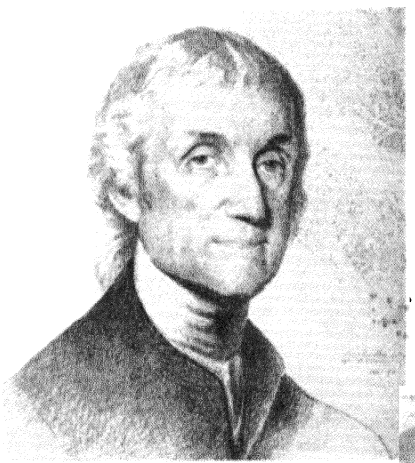
capable of being developed, and of eventually leading to some new product, or a better way to an old product. And those who develop the fundamental discoveries are also interested in chemistry, and they don't drop this interest anywhere along the line, from the original germ of an idea in the minds of the research chemists and the chemical engineers in the plant to the president of the company.

The development of a new product has been described as an eight-step process: (1) research, (2) economic study, (3) scale-up (pilot plant), (4) design, (5) construction, (6) production, (7) sales of new product, (8) improvement. A definite stage in the development of a product is the *improvement* of it after it has first been put on the market. At *all* of these stages chemists are required. Even at the "construction" stage, which is the least chemical, chemical knowledge is required, and in any case, construction depends heavily upon stages 3, pilot plant, and 4, design, which must be carried out by chemical engineers. Stage 7, sales, must be made by salesmen who are also chemists, and all kinds of chemists can cooperate in the improvement stage. Different *people* carry out the different stages, but they all depend on chemistry, and they all must know chemistry (as much as possible). This country has been very fortunate in the close cooperation that is traditional between the chemists and chemical engineers working at all the different levels. They all are served by the same scientific and professional society, the AMERICAN CHEMICAL SOCIETY.

Priestley House . . .

. . . shrine of American chemistry

When the centennial of the discovery of oxygen was observed there in 1874, the Priestley House was a focal point in the formation of the American Chemical Society and has been hallowed in ACS history



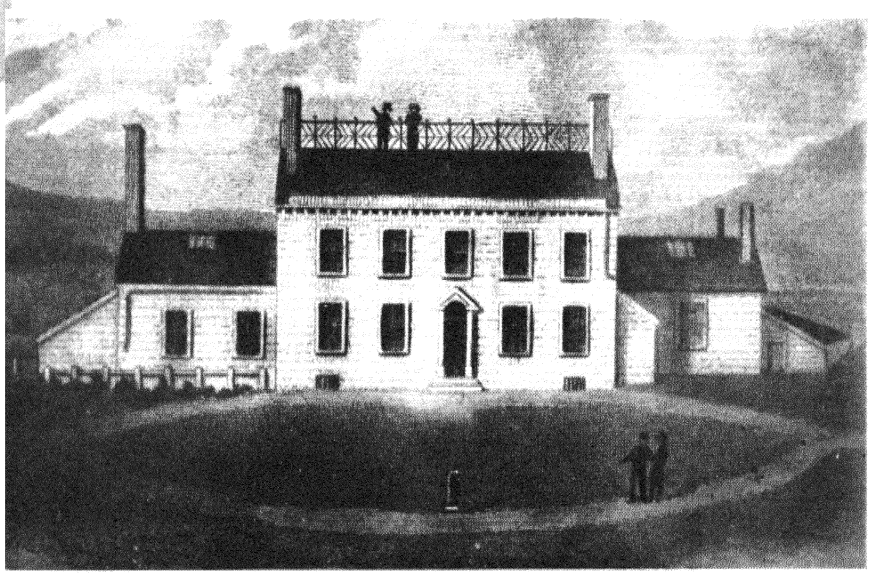
Joseph Priestley

FOLLOWING the turmoil of the Birmingham riots, in which his laboratory was confiscated, Joseph Priestley traveled to Northumberland, Pa., to visit his sons, who had settled there a year or so before. It was August of 1794, and Northumberland at that time was a frontier town of a hundred houses. But the location, at the confluence of the north and west branches of the Susquehanna river, so attracted him that Priestley decided to settle there himself. It would be a peaceful and pleasant place to continue his writings and experiments.

Priestley selected a site overlooking the north branch of the river and himself helped in clearing the land. His original intention was to build a house of brick, but "an uncommonly wet and unhealthy summer" the next year made it impossible to make bricks. Hence he changed his plans to a frame house.

Only freshly sawed lumber was to be had, but it was kiln dried by heating for 10 days in a shallow pit—10,000 feet at a time. "A house constructed with such boards," wrote Priestley, "I prefer to one of brick or stone."

The plan of the house is that of a typical English manor house of the period. One-story, gabled wings on each end housed the kitchen and the laboratory.



The home of Joseph Priestley in Northumberland, Pa.; from an old drawing

Towards the end of 1797 the house was finished, and Priestley turned again to his experiments. He had brought a great deal of equipment with him—not only chemical but also electrical, optical, mathematical, and philosophical—so that his laboratory was now the finest in the country. It was here that Priestley discovered carbon monoxide. In this house he also wrote his last defense of phlogiston, for Priestley's strongest desire in his later years was to "overturn the French new theory of chemistry."

But theology was perhaps a more consuming interest. He founded a Unitarian congregation in Northumberland but did not resume the ministry. His theological writings of this period are voluminous; it was here that he completed his "General History of the Christian Church."

Priestley also conducted a wide

Looking Backward

If an old-timer from the early 1900's were to visit 1951 by time-machine, there is one other important change that he would notice. If he had found it necessary to go into a bank, to ask for a sizable loan to construct a chemical plant, his reception would be very different. In point of fact, in the early 1900's he would probably not have done this; it was customary then for the chemical industry to finance plant expansion out of its own savings, and bankers looked with a jaundiced eye upon the chemical industry as a speculative venture. "Too many firms go bankrupt" they would say, or "Not enough stability. The industry changes too quickly. Plants become obsolete. We like things like railroads, there always were railroads, and always will be. You chemists constantly think up new ways of doing things; you have no stability; you are not a good investment." But in 1951, a banker will listen most seriously to any proposal in the chemical industry. The general financial respectability of this industry would astonish our old-timer. And if he were to ask "Why, doesn't the chemical industry change its ways of doing things as rapidly as it did in my day?" the answer would be "Indeed it does! In fact, much more rapidly," and the banker would know this, and in spite of it he would be well disposed toward the investment. In fact, he would make quite sure, before granting the loan, that the would-be investor maintained a large active research department, well stocked with chemists.

Like those highwaymen, but by different methods, modern phy si-

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correspondence from Northumberland, not only with his old friends in England but with his new friends in America. He counted among them Benjamin Rush, Thomas Jefferson, Samuel L. Mitchell, and others prominent in public life. He was received by George Washington, and he had become acquainted with Benjamin Franklin in England; indeed, it was Franklin who is said to have made Priestley a man of science. So intertwined by friendly influences and personal contacts were the lives of Franklin, Jefferson, and Priestley, said C. A. Browne, historian of chemistry, that this memorial in Northumberland should be a Mecca not only for chemists but for every loyal American.

Priestley died at home on Feb. 6, 1804. Gradually, the house fell into decay, accelerated by its use, just following World War I, as a boarding house for foreign laborers. In addition, a report was circulated about that time that the house was to be torn down to make way for a new railroad through the town.

These events stimulated George Gilbert Pond to action. Dr. Pond, professor of chemistry and dean of the school of natural sciences at Pennsylvania State College, had long been interested in the house and felt that it should be saved. His original plan was to dismantle the house and reconstruct it on the Penn State campus.

He found support in the trustees and the chemistry alumni of Penn State, but before the fund was complete Dr. Pond received notice that the house and grounds would be sold at auction. Through the aid of William H. Teas, an alumnus, Dr. Pond was able to buy the property and later, with the approval of the chemical alumni, the deed passed to the Pennsylvania State College.

But Dr. Pond died in 1920 before carrying out his plan. It was found, however, that the house was too old to stand dismantling. And by that time the railroad had been abandoned. So it was decided to restore the house and grounds as they stood.

Dr. Pond's plan also included converting the laboratory to a fireproof room where apparatus used by Priestley would be assembled. This proved to be impractical. A brick building was erected on the grounds near the laboratory, however, and dedicated in 1926 to Dr. Pond as a Priestley museum. Here has been collected a majority of the known pieces of Priestley's apparatus that are in existence today.

Before Joseph Priestley 2nd returned to England he left his father's apparatus in the care of Thomas Cooper, an English chemist who had followed Priestley to Northumberland. Cooper used the laboratory and apparatus until 1811 when he went to Dickinson College at Carlisle, Pa., as professor of chemistry. At that time he negotiated the purchase of some of the pieces for the college, which still has them. Joseph's grandson returned to Northumberland when he was 19, and he and his son, Joseph 4th, cared for the collection, which is thought to have been diminished over the years by breakage and distribution to heirs. At the death of Joseph 4th in 1883, however, much of the remaining equipment passed to the Smithsonian Institution.

Most of the equipment on display in the Priestley museum came from the Smithsonian Institution which has deposited it there as an indefinite loan.

A private collection of Priestley's book has been assembled by Mrs George H. Neff and is on display in the library. Mrs. Neff and her husband, proprietor of the Neff Hotel in nearby Sunbury, are present occupants of the Priestley House. They maintain it for Penn State and keep it open for visitors, except when they are away.

The original grounds extended from Northway Avenue, close behind the house, to the river, some 200 yards away. The grand sweep of lawn in front was foreshortened a number of years ago by a canal that was dug parallel to the river. Later the canal was filled in and a railroad built in its bed so the front yard now ends at the overgrown right-of-way. But in this yard are two giant hemlocks said to have been planted by Priestley himself.

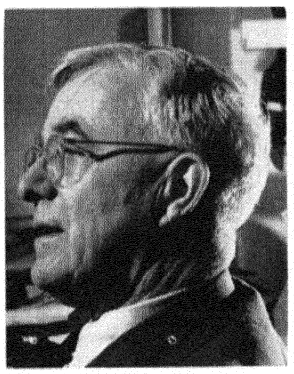
The street behind the house was renamed several months ago by village authorities to Priestley Avenue. Local sentiment is divided on the change, however, some preferring Northway, as it was known when Priestley chose the site.

Priestley's blood descendants are few and scattered. When the museum was dedicated in 1926 as a part of the golden anniversary celebration of the ACS, there were present at least 17 descendants, many of them from Williamsport, Pa. Among descendants in America today, there are two brothers in the direct line, and bearing the Priestley name, on the staff of the Mayo Clinic at Rochester, Minn. There are others in England.

Priestley's scientific heirs, however, are unnumbered; counted among them are not only those who practice chemistry but those who benefit from it. For although Priestley fought to his dying day against the "new" theory of combustion, it was his discovery of oxygen that made it possible; and it was on the foundation of this theory that the modern science of chemistry arose.

The Priestley House at Northumberland is a memorial to a great scientist, who, although he had done his greatest work before he came to America, here found refuge and rest. The house is also a shrine of American chemistry and of the AMERICAN CHEMICAL SOCIETY. For it was there, at the centennial celebration of the discovery of oxygen, that the idea of an organization of American chemists was first broached. Since then it has been a source of inspiration and pride to those who have visited it in contemplation of its connections with the past.

cists and chemists *can* turn lead into gold. If we had any need for large quantities of gold at a fabulously high price, it would be possible to make this transformation on as large a scale as we chose. It would be an entirely similar problem to the manufacture of plutonium. Fundamentally, of course, atomic energy depends upon nuclear reactions, but it is not always realized to what a large extent ordinary chemistry and engineering contributed to the success of that project, in fact, were essential to it. Just one of its incidental requirements was a large quantity of graphite of fabulous purity. Chemists were on hand to produce that, almost as a routine research problem. The researchers could say that U^{235} was "fissionable material," and that there was 0.7% of it in ordinary uranium, but the separation of the small quantity of U^{235} was a problem for the chemical engineers. A purely physical method, based on a separation by the mass spectrometer and actual collection of the stream of different products, gave too small a yield. Far more productive was the gaseous diffusion method. Chemists found the volatile compound UF_6 of that extremely heavy element, and chemical engineers found materials of construction for equipment that would handle it, and devised the diffusion separation by the application of purely chemical engineering methods. Even more striking still was the separation of plutonium from the products of the neutron reaction pile. This was quite purely, though not exactly simply, a chemical problem - routine stuff for chemists, since it was not a question here of separating isotopes, of all but identical chemical properties, but different elements, with different properties. But what were the properties of plutonium? It was an entirely new element, and no more than a pin point of it had ever been isolated. Normally, it would have been considered a matter of years of study before even a moderately large pilot plant would have been carefully designed, for the purpose of giving even better information and test data preparatory to the design of a full-scale plant. But this could not be done during the war. The chemical properties of plutonium had to be determined on the minute sample available, and simultaneously a full-scale plant had to be designed. And here it could be seen how extremely fortunate we are in this country in having our chemists and our chemical engineers thoroughly accustomed to working closely with one another. Quite in the normal course of industrial development, there is no abrupt discontinuity between test-tube men with their glass apparatus, and pilot plant men with their pipe wrenches. Only in this case, the jump was from micro-test



Irving C. Langmuir

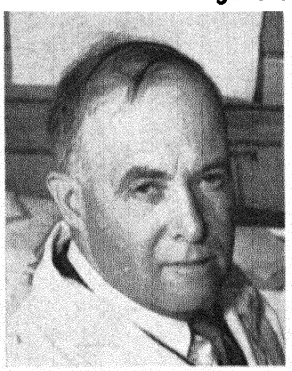
American chemists on the frontiers of science have won Nobel prizes for their contributions to fundamental knowledge . . .



Peter Debye



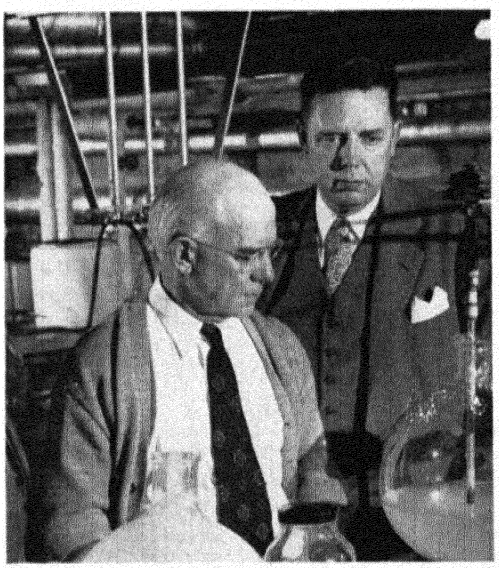
Harold C. Urey



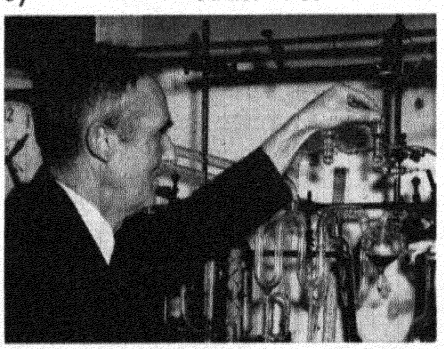
James B. Sumner

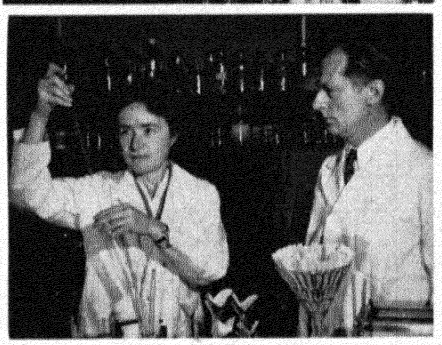


John H. Northrop

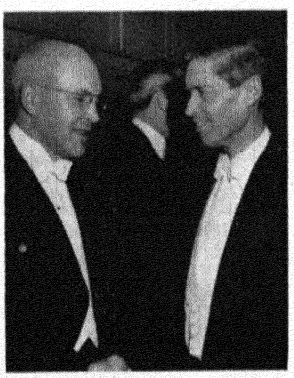


Edward C. Kendall with coworker Philip S. Hench, who shared award in medicine





Left. William F. Giauque
Below, left. Gerty and Carl Cori



Wendell M. Stanley and The Svedberg, famous Swedish chemist, and Nobel prize winner as well

tube chemistry clear through the pilot plant stage and up to large full-scale plant. There was not time to build a pilot plant at all. By extremely skillful microchemical work, the properties of plutonium were determined on a microgram sample, and the chemical engineers took the figures and believed them -for there was no opportunity to check them on any larger sample. They were not deterred from the problem of scaling up by a factor of approximately 10^{10}, 10-billion-fold, a figure utterly unheard of in chemical engineering before. A full-scale plant was quickly built to this design at Hanford, Wash., AND IT WORKED.

Men who can do this kind of thing are chemists and chemical engineers. By such men and women has the AMERICAN CHEMICAL SOCIETY been built. Today, they are the AMERICAN CHEMICAL SOCIETY.

Divisions and Sections of the ACS

Going back to the beginnings of the AMERICAN CHEMICAL SOCIETY, Article II of its first Constitution, adopted in 1876, says "The objects of this Society shall be the encouragement and advancement of chemistry in all its branches." A beautifully clear and succinct statement, and there is no doubt whatever that the Society has succeeded.

But the phrase "chemistry in all its branches," although short and simple, is a weighty mouthful. It contain within it the germ of one important reason for the Society's present greatness. But by the same token, it also contained in it the source of one great problem for the Society, in the course of its historical development.

For if the AMERICAN CHEMICAL SOCIETY was dedicated to the encouragement and advancement of chemistry in *all* its branches, one may well ask: How many branches of chemistry are there? In the very early days, the days of the 300-member Society, it hardly mattered. Just before World War I the problem became important. Already meetings were getting large enough and diversified enough so that organic chemists were getting tired of sitting through physical chemistry papers, full of mathematics that they did not understand while physical chemists had no interest in the organic chemists' pretty-looking structural formulas. Pure chemists lived, and wanted to go on living, in what the industrial men thought of as an ivory tower, from which the scientists could look with equal disdain on the applied (or "impure") chemists' paint-pot formulations, or even, what must have seemed inexplicable, or unforgivable, their interest in pieces of commercial equipment—such things, for example, as stills for fractionating petroleum. It was thought by some that a membership of several thousand, and such diverse interests, would necessitate a breaking-up of the Society. There would then have been no longer a Society devoted to chemistry "in all its branches." There would have been societies, each devoted to a branch.

The AMERICAN CHEMICAL SOCIETY found a solution to this problem, as it has, up to now, always found a solution to its problems. It has very seldom indeed had to admit a serious mistake, or had to backtrack. The solution that was found seems straightforward to the point of obviousness to us in 1951, accustomed as we are to the Society as it is now, constituted on the same general principles as were decided on in those days over 40 years ago. It has a clear logic that seems, *after the event*, inescapable. For it amounted simply to the realization that, if chemistry has branches, *so can the American Chemical Society!* The flexible organization was then created that allows divisions, according to subject matter, within the Society. This was the first answer to the question, who is a chemist? The answer was (as it still is) anybody is a chemist who works in chemistry. The enumeration of the possible kinds of chemists was at first incomplete, but it did establish that most important principle, that *one* society can represent anybody whose work is in chemistry. That principle permitted the food chemist, the fertilizer man, the educator, the technically trained chemical executive, together with any other chemist working in the field, and even the mathematics-loving physical chemist, to belong to one scientific society, meeting together so as not to drift completely out of one another's orbits, and above all, pooling their resources, so as to be represented by a strong society.



In addition to their atomic research, leading chemists like G. T. Seaborg and C. D. Coryell take an active part in ACS affairs

An important decision was made by implication at this time This was that a chemical engineer is a chemist, as well as an engineer. In a formal way a chemical engineer might be defined as a person who has received his major training in a department of chemical engineering, whereas a chemist (without qualifying) received his in a department of chemistry, but this does not always work. Plenty of people, graduated from schools of chemistry, find their way into the plant after they take up employment and, after some years' experience there, are indistinguishable from chemical engineers. Of those who graduated as chemical engineers, some spend their professional lives making the complex design calculations they were taught in school, some spend their time in the plant, with a Stillson wrench as a symbol of their type of work, while others are found later on in the laboratory, doing work indistinguishable from that of the graduate in plain chemistry. And how shall we classify those who, irrespective of their chemical or chemical engineering training, end up doing excellent work in the sales department, patent department, or library?

A chemical engineer has been defined in a great many other ways, some of them facetious. Most simply he can be described as the person who makes things go the chemist who makes a reaction go on a pilot or full plant scale. He is the one who takes things out of beakers and filter paper and deals with them in pipes, valves, and pumps He comes into a plant, sees something being done batchwise, and says, "Let's make this process continuous"—and does it! Or perhaps he could be most simply described as "a chemist who has become dollar conscious "

Whatever definition is adopted, two things about the chemical engineer stand out clearly; (1) he is absolutely indispensable, and (2) chemistry is indispensable to his work. A chemical engineer could never be called in to "commercialize" a reaction if there were no chemical reaction to commercialize. A chemical engineer ought to know as much engineering as he can, but over and above this, or rather before this, he *must* know his chemistry!—again, as much as he possibly can. From the point of view of practical applications, the chemist feeds the chemical engineer. Both depend upon the same chemistry They draw upon the same mass of chemical knowledge Both are deeply concerned with "the encouragement and advancement of chemistry in all its branches."

How many kinds of chemists are there? And where are they?



Staff of the ACS Executive Secretary's office in Washington. Left to right, seated: B. R. Stanerson, Arlena Thomas, Betty Chase, Ronald M. Warren, Lucy Massey, Frances Sansbury. Standing: Ivan Rice, Albert Winstead, Evelyn Henderson, Frances Howard, Anne Lanshe, Evelyn Trantham, Dolores Homer (Marion Richardson directly behind), Virginia Stevens, Alden H. Emery, Lois Sherry, Frances Benner, Phyllis Powers, Wilma Woodhall, Phyllis Devoe, June McConnell, Sally Metzger, Theresa Schneider, Virginia Norton, and Bertha Bishop



Staff of the ACS business office in Washington. Left to right, seated: George G. Taylor, Della Bruce, Dorothy Pritchard, Nellie Madden, Dorothy Lane, Everette Harris. Standing: W. B. Lodder, Judy Hummer, Mary Turner, Virginia McHorney, Barbara McMillin, Lois Jenkins, Edythe Daskam, Margaret Hodge, Suzanne Duckworth, Gisela Jeffers, Esther Burke, Virginia Parker, Bessie Vitt, Alma Horn, Ruth McConnell, Alice Crim, Eleanor Greco, Barbara Balencie, Priscilla Buterbaugh, Gloria Hack, Betty Sullivan, and M. Hoseh, assistant editor at CA's office at Library of Congress



Staffs of the ACS financial and service offices, Washington. Lillian Rose, R. V. Mellefont, Lois Danahy, Jeanne Smith, Joan Bennett, Helen Messenger, Genevieve Pavone, Madelyn Bell, William Muehlhause, Reta Carpenter, Beatrice Manis, Theresa Durniak, Mary Casey, Betty Shipman, Florence Quinn, Thelma Chaires, Gladys Clark, and K. C. Barnes

The AMERICAN CHEMICAL SOCIETY has developed over the years into a most elastic institution. It can be compared to a strawberry plant, that puts out runners, each of which sends roots into the ground and starts another plant, connected with the first. The AMERICAN CHEMICAL SOCIETY constantly gives rise to new "plants," in the form of new divisions, new sections, new activities, new problems, and new solutions. Like the strawberry plant, these new growths arise from the ground upward.

Basic to the AMERICAN CHEMICAL SOCIETY is its subdivision in two entirely separate ways. On the one hand it is divided into divisions according to subject matter, and on the other it is cut into sections according to locality. It is as if the map of the United States, with all the local sections on it, according to the density of chemist population, were then to be all melted up, cast into a new mold, and divided again in a different manner The AMERICAN CHEMICAL SOCIETY is not like a cast block of lead; it is like lead shot, only some mathematician skilled in the fourth dimension, could think of a way in which a solid block can be divided into portions in two entirely independent ways. For one of the prime purposes of the Society is that chemists and chemical engineers get together and meet one another. Owing to the great size of this country, some sort of local subdivision is clearly necessary. And in another respect members of the chemical profession should be able to understand one another when they do meet. For this purpose, subject matter divisions are necessary.

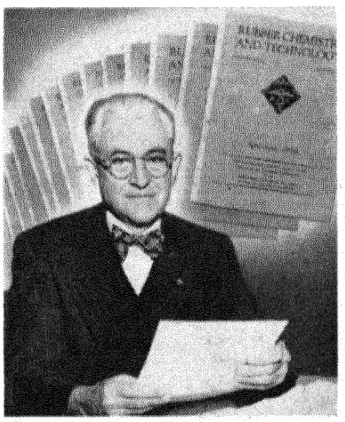
The divisions, according to subject matter, of the AMERICAN CHEMICAL SOCIETY, are as follows, in historical order of formation:

Division	Year Organized	Membership (1950)
Agricultural and Food Chemistry	1908	1,067
Fertilizer Chemistry	1908	788
Industrial and Engineering Chemistry	1908	1,346
Organic Chemistry	1908	1,681
Physical and Inorganic Chemistry	1908	1,488
Medicinal Chemistry	1909	1,289
Biological Chemistry	1913	1,188
Water, Sewage, and Sanitation Chemistry	1915	510
Rubber Chemistry	1919	1,773
Sugar Chemistry	1921	735
Cellulose Chemistry	1922	290
Petroleum Chemistry	1922	1,791
Chemical Education	1924	716
Gas and Fuel Chemistry	1925	349
Colloid Chemistry	1926	854
History of Chemistry	1927	152
Paint, Varnish and Plastics Chemistry	1927	944
Analytical Chemistry	1938	881
Chemical Literature	1948	675
Polymer Chemistry	1950	450
		18,967

A member of the Society is not required to belong to any of the divisions. The fact that so many are willing to pay extra dues to support divisional activities is a sign of their strong interest in the advancement of their science and profession.

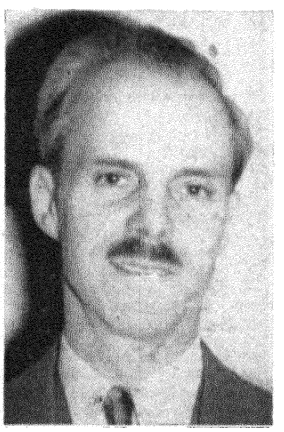
The remarkable diversity of the AMERICAN CHEMICAL SOCIETY stands out most clearly from this table. The divisions are most unequal, in membership and also in scope. Industrial and Engineering Chemistry, Organic Chemistry, Physical and Inorganic Chemistry, to mention three of the first-formed divisions, are of course huge subjects; Sugar Chemistry and Cellulose Chemistry are more limited in scope, although those who work in these fields would insist that the subjects are quite large enough to require a man's full attention. Rubber and petroleum attract many members each; at the other end of the size scale is the division of the History of Chemistry where fewer members have a specialized interest. But these are not impractical pedants, indulging a harmless but nonproductive hobby. The past of chemistry is well worth studying, for it can give us signposts for the future.

When the AMERICAN CHEMICAL SOCIETY holds its national meetings twice a year there is an opportunity for chemists and chemical engineers to get together, meet one another, and talk about chemistry. Each wants to talk chiefly, but not entirely, to those in more or less his own line of business, since he can understand their language; the divisions exist for this purpose. The physical chemists meet together in one (or more) lecture room where papers on physical chemistry are read from nine o'clock in the morning until lunch time, and again from 2:00 until 5:00. Meanwhile the organic chemists, whose language is very different, are doing the same thing in another lecture room (or rooms). At lunchtime the physical chemists, and the organic chemists, and the analytical chemists, and the chemical engineers, the researchers, and the executives, can meet one another, if they want to, and they will certainly meet one another at the evening functions dinners of various groups, presentations of awards, and addresses. The divisions contribute greatly to the success of the meetings by arranging symposia, such as Symposium on Fluorine Chemistry, Symposium on Synthetic Lubricating Oils, Symposium on Anomalies in Reaction Kinetics, Symposium on Engineering Aspects of Food Technology, and Symposium on Radioactive Waste Problems and Treatment Particularly fruitful are joint symposia between two or more divisions, such as Chemicals for Agriculture (Divisions of Fertilizer Chemistry, Industrial and Engineering Chemistry, and Agricultural and Food Chemistry) and Textiles (Divisions of Colloid Chemistry, Cellulose Chemistry, and Physical and Inorganic Chemistry)



C. C. Davis, editor of *Rubber Chemistry and Technology*

In their other activities the divisions vary greatly. Two of them have full-dress publications. The Division of Chemical Education owns and edits the *Journal of Chemical Education*, which prints articles of interest to teachers of chemistry, from high school to advanced college levels In addition, it often publishes articles on the history of chemistry (a recent popular series was on Chinese chemistry) and on quite general chemical subjects. The Division of Rubber Chemistry publishes a quarterly, *Rubber Chemistry and Technology*, an outstanding periodical in the technology of rubber, and also an annual Bibliography of Rubber Literature. The division has recently sponsored a rubber library in connection with the University of Akron, where its members can obtain almost anything that has been published in the field of rubber technology

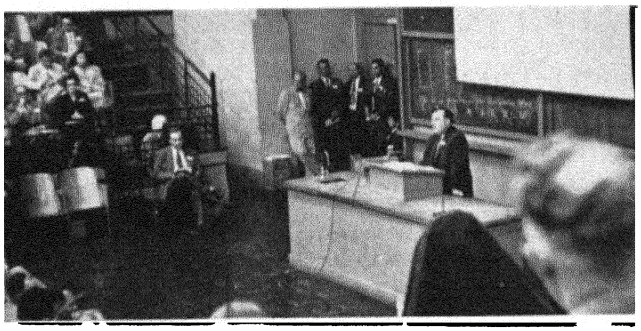


Norris W. Rakestraw, editor of the *Journal of Chemical Education*

Many divisions distribute to their members abstracts of all papers presented before the divisions. Many of them have active committees, for example, the committees on nomenclature of the Divisions of Organic and Analytical Chemistry and the committee on standards and methods of testing of the Division of Cellulose Chemistry.



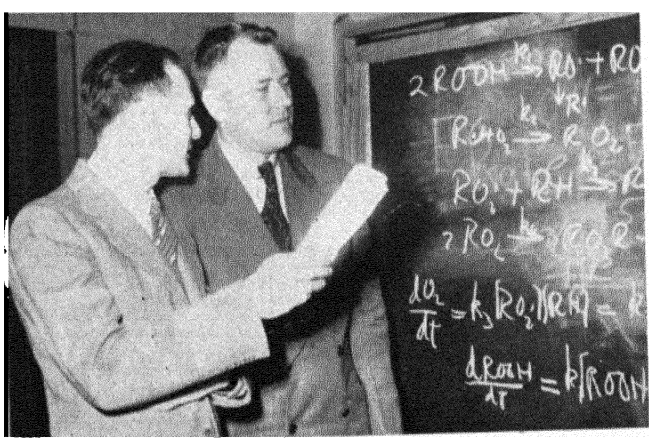
There is much informal discussion at ACS meetings



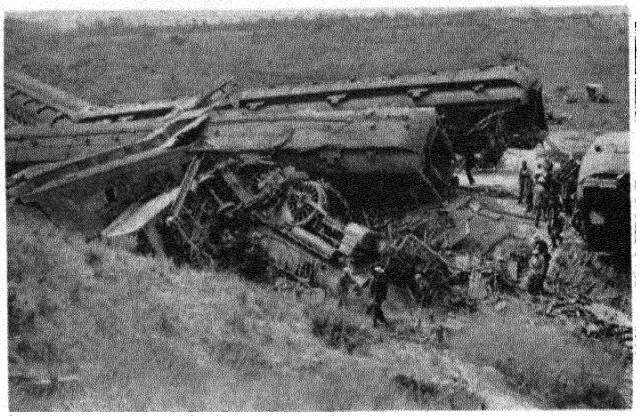
Papers are presented by leading chemists, this one by Carl S. Marvel, University of Illinois



The ladies take an active part not only in the technical programs but also in the social activities. Here, Mrs. Volwiler, wife of former ACS president, serves tea to Mrs. Paul Numerof and Mrs. W. F. Henderson



Opportunity to exchange information is a great stimulus



Famous wreck of ACS special train on way to San Francisco meeting in 1910. Fortunately none of the chemists were injured seriously, but the engineer, fireman, and conductor were killed

Several divisions hold annual symposia at times other than those held at the semiannual national meetings. The Division of Industrial and Engineering Chemistry, for example, has been holding symposia for years, usually during the week between Christmas and New Years. These symposia cover some highly specialized field of chemical engineering, the sessions usually occupying two days. Other divisions which follow a somewhat similar practice include Analytical, Medicinal, Organic, Physical and Inorganic, and Colloid. The Division of Industrial and Engineering Chemistry gives a scroll each year to the author or authors of the paper which in the opinion of the papers committee of the annual symposium shows the greatest originality and is presented most satisfactorily.

The local sections number 138 and their activities are exceedingly diverse and lively. About 40 of them have their own publications, with attractive titles, such as *The Indicator, The Catalyst, The Accelerator, The Branched Chain, The Condenser, The Double Bond, The Filter Press, The Nucleus, The Resonator, The Retort, The Vapor Pressure, The Condensate, The Pipet* No less than 11 awards are administered by local sections. For some of these, the recipient must be a chemist working in the area, but others are geographically unrestricted. The Nichols Medal, administered by the New York Section, the Willard Gibbs Medal of the Chicago Section, and the Theodore William Richards Medal of the Northeastern Section are awarded without geographical limitations. The North Jersey Section established the Leo Hendrik Backeland Award to encourage the creative talents of the younger American chemists, and the two latest comers are the Austin M Patterson Award (Dayton Section) for outstanding contributions in the editorial field of chemistry and chemical engineering, and the Northeastern Section's James F. Norris Award for outstanding achievement in the teaching of chemistry. Awards for particular localities or regions are the Hillebrand Award of the Washington Section, the Jacob F. Schoellkopf Medal of the Western New York Section for outstanding chemical work in the territory of the section, the Pittsburgh Award, the Midwest Award of the St. Louis Section (Missouri and its eight bordering states), the Herty Medal given by the Chemistry Club of the Georgia State College for Women and administered by the Georgia Section, the Virginia Section Award, the Iowa Award, and the Southwest Regional Award.

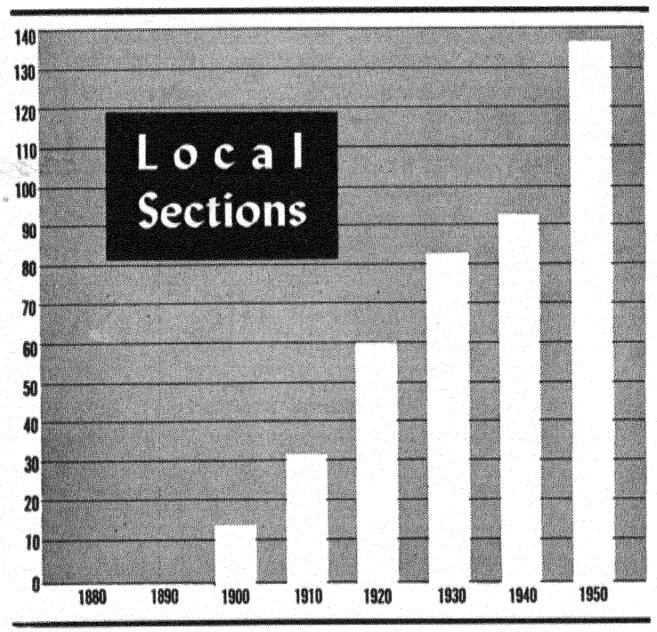
Local sections usually hold eight to 10 meetings a year, at many of which talks will be given on chemical subjects, either by local speakers or by visitors. They also hold social events—dinners, and even dances or Christmas parties.

Some of them supply local libraries with chemical publications, such as *Chemical Abstracts*. Many are active in encouragement of chemical students at high schools or colleges in their localities through competitions, awards, and sometimes loan funds. More

than 70 sections sponsor radio programs. Some organize speakers' bureaus, to provide interesting talks on chemical subjects to civic groups, women's clubs, PTA's, and other organizations. Many are active in local publicity and public relations. Some offer employment-finding facilities. Others organize courses of lectures by outstanding speakers.

Local sections in a particular area frequently get together and organize "regional meetings." An example of this is the Southwest Regional Meeting which is an annual event now in its seventh year. Its attendance has more than once passed the 700 mark. Sometimes a "meeting-in-miniature" will be arranged, a meeting with papers presented, symposia held, visits to local plants, and all other activities, like one of the full ACS meetings, only "in miniature."

These thriving local sections present a picture of great activity—coordinated activity. No local section may claim to speak for the ACS as a whole, and it may not, for example, get into any political activity that would embarrass the whole Society. But there is a minimum of this sort of restriction, and a maximum of healthy individual enterprise.

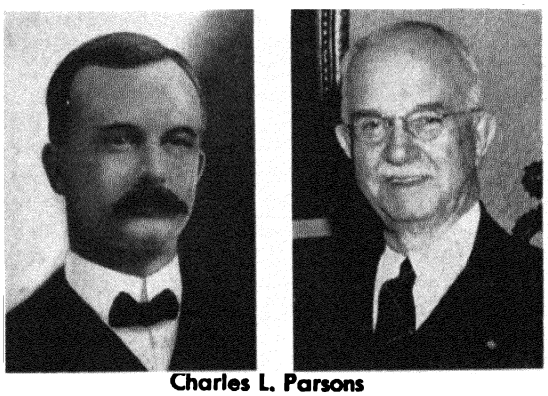


The Society's organization goes even further than breakdown by subject matter and by locality. Local sections form subsections, such as the Metropolitan Long Island Subsection of the New York Section. The California, Alabama, North Jersey, and other local sections operate through subsections. Divisions form subdivisions; for example, the Division of Industrial and Engineering Chemistry has subdivisions for Chemical Marketing and for Fluorine Chemistry. In some cases local sections form groups based on subject matter. For example, the Pittsburgh Section has groups on biochemistry, coal technology, and several others, and the North Jersey Section has groups on analytical chemistry, industrial and engineering chemistry, and several others. Just as examples of the activity of these smallest "partitionings" (the language seems to lack sufficient synonyms for these divisions and subdivisions and groups and subgroups), the organic group of the Pittsburgh Section puts out a newsletter, and the Metropolitan Long Island Subsection of the New York Section recently ran a meeting-in-miniature. And since these local activities are usually reported by the local press (the local sections themselves seeing to that) chemistry receives good publicity right at the community grassroots level.

The ACS is unquestionably a lively organization, but this liveliness has to be put into it by its members. Behind all the activity of the local sections, in fact behind all the achievements of the Society, lies an immense amount of spadework. Somebody has to go on the committees, somebody has to see that this is done and that that gets organized, somebody has to take the trouble to *do* the innumerable things that actually get done. That many chemists and chemical engineers have at all times been willing to give freely of their time for such work is one of the causes, perhaps the main cause, of the greatness of the AMERICAN CHEMICAL SOCIETY.

What Is Chemistry?

But if all these different groups, and divisions, and sections, make up the answer (or one sort of answer) to the questions: Who is a chemist? Who is a chemical engineer?, one may well inquire: What is it that keeps the AMERICAN CHEMICAL SOCIETY together?



Charles L. Parsons

25 years old . . . 84 years young . . .

Many chemists, if they were asked, "What has kept the AMERICAN CHEMICAL SOCIETY together all these years?" would reply without hesitation "Dr. Charles L. Parsons." On Sept. 1, 1907, Dr. Parsons officially started his work, in his spare time from being a professor at the University of New Hampshire, as Secretary of the AMERICAN CHEMICAL SOCIETY. He left it 39 years and four months later at the end of 1945, handing it over to Alden H. Emery, the present Executive Secretary. Dr. Parsons started as Secretary of the Society when it had 3389 members. When he left it had 43,075 members and was growing rapidly. What the Society would have done without Dr. Parsons is quite literally unthinkable, for the Society did not have to do without Dr. Parsons; it *had* him. And though it would be scientifically inaccurate to consider Dr. Parsons as the sole cause of the Society's growth, everyone will concur in granting him a generous share of credit for it.

If one puts the question—What kept the AMERICAN CHEMICAL SOCIETY together to Dr. Parsons, he replies in two words, *Chemical Abstracts*. Now it may be that in this reply he is speaking with becoming modesty, for although his achievements are great, he is not a boastful man. But on the other hand, who should know the AMERICAN CHEMICAL SOCIETY better than Dr. Parsons? Or again, he may be recalling the earlier days when every member of the Society received *Chemical Abstracts*. In later years other activities and publications probably have contributed just as much to the success of the Society.

But why have chemical abstracts?

Way back in the middle of the 19th century, Liebig is said to have warned one of his students of the immense amount of reading that he would be required to do. "You have to kill yourself with reading to get anywhere in chemistry nowadays," he said. Liebig was referring to reading every paper that was published in chemistry, a task that was still just possible, but beginning to be impossible. At the present day it is calculated that if a man were to undertake to read all the papers that are published in any basic science, just reading them right through at a regular reading pace, not pausing to understand or assimilate them, and if

he were to work all day and every day doing this, then at the end of every year he would be 10 years further behind in his reading! Hence the importance of abstracts.

Chemical Abstracts

In any chemical research (other than say looking up a melting point or a standard property that will be given in a reference book) *Chemical Abstracts* is the first place to search. If a large research project is to be started, one or several library chemists will work for weeks or months, and their report may be a sizable volume in itself. Not only the main research project but any subproject and subsubproject will follow what is now the universal custom among chemists—start by looking in *CA*, *whatever* it is you want to do.

The original number of *Chemical Abstracts*, Volume 1, Number 1, was a slim, handlable thing, in general appearance resembling our modern "little" magazines—one of the intellectual ones.

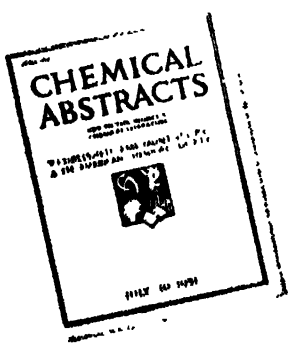
Now, in its forty-fifth year, *CA* occupies about 148 inches of shelf for an entire set and weighs about 760 pounds. It is increasing at the approximate rate of 12 inches, and 25 5 pounds, per annum. These figures exclude the four decennial indexes, which comprise 20 volumes, 56 inches, and 95 pounds, while for the fifth decennial, to appear some time after 1956, the librarian must prepare for, at a rough estimate, 38 inches and 72 pounds. If one were to judge by size alone, *Chemical Abstracts* is what the French would call "formidable."

Judging not only by size but also by quality, it has long been the opinion of this writer that *Chemical Abstracts* is one of the wonders of the world. It is a huge undertaking. The 1950 issue contained 57,559 abstracts printed on 5592 pages, containing reading matter extending a distance (laying all the lines end to end) of 2,617,156 inches, or 41.3 miles, not including the indexes. *Chemical Abstracts* does an all but perfect job in covering *all* the new work that is published on chemistry in the entire world. It boils all this information down to a bare minimum, to the point where further boiling would inevitably result in loss of yield, and publishes it all with exceedingly few mistakes. *And it comes out on time.* Oh yes, there have been occasions when the second number of the annual indexes was not in readers' hands until April or even later, but that is hardly late for over 2000 pages of fine-print index! *Chemical Abstracts* abstracts *current* literature. It has never been running appreciably behind time.

To achieve all this is a triumph of organization, and successful organization on this scale is a typically American ability. But *Chemical Abstracts* has another feature that is characteristic of American organization—it is convenient for the user. Americans frequently do not notice this, for in this country we take it for granted, but, coming from Europe, one certainly notices it. There are Europeans, notably German, who are good at organization, and delight in systems, sometimes system for the sake of the system. The idea that an organization should be not only systematic, but also convenient for the user, *this* idea is typically American. It is this that has been achieved with such astonishing success by *Chemical Abstracts*, and this that has made it into a world-wide institution. Of its circulation of about 23,000 copies (1950), roughly a quarter went abroad. In every country where there are chemists, *Chemical Abstracts* is a necessity.

Chemical Abstracts is unlike the AMERICAN CHEMICAL SOCIETY in that its headquarters have been in the same place, Columbus, Ohio, almost from the very beginning; also in that it started in Washington and then moved away, instead of gravitating to Washington. It started under the editorship of W. A. Noyes, Sr., who was at that time also editing the *Journal of the American Chemical Society*, and who had been a leader in persuading the AMERICAN CHEMICAL SOCIETY to undertake an abstract journal as well, with full coverage of the world's chemical literature. On account of his many other duties and obligations, W. A. Noyes, Sr., had to relinquish the editorship of *Chemical Abstracts* after two years, handing it over to Austin M. Patterson. Dr. Patterson soon afterward gave up the actual editorship, but has retained a close connection with the work to the present day. John J. Miller was editor for a short period; in 1911 he handed it over to E. J. Crane, who has been editor ever since, and has made it his life work. Certainly it is a splendid life's work.

A question that immediately arises, on planning an abstracts journal in chemistry, is, What is chemistry? The men and women who have made *Chemical Abstracts* answered this question in typical ACS fashion—*Everything* is chemistry that has chemistry in it. A wise decision was taken right from the start to abstract in one journal both "pure" and "applied" chemistry. This was something new at the time. *Chemisches Zentrallblatt*, the German abstract journal, that had been appearing since 1830 did not at that time abstract applied chemistry. It started doing so in 1919. The British had abstracts of theoretical papers





Editorial Staff of *Chemical Abstracts*. Left to right, front row: Karis Lyon, Isabel Mundell, Ruth Jones, Marilyn MacLaughlin, Alice Hopson, Ruth Beer, Alice Padan, Helen Crane, Donna Smith, Gladys Crane. Second row: Barbara Manahan, Julia Olsen, Frances Reichard, Betty Myers, Helen Suttner, Esther Salisbury, Nellie G. Mahaffey, Harriet L. Durand, Virginia Kingery. Third row: Betty Roulston, Shirley Soules, Margaret Ann Long, Anne Webster, Mary Winters, Myriame Wilson, Ethel Swank, Mary A. Magill, Helen Griesemer, Sara Gilfert. Fourth row: Ella Muthard, Caroline Sexton, Mary Frances Brown, Ruth Steelman, Marion Kenkel, Bonnie Bawn, Audrey Dudley, Mary Stellarini, Robert L. Messier, John H. Stone. Fifth row: Alfred W. Wilson, Richard D. Hanks, Elmer Hockett, Leonard T. Capell, Dale B. Baker, E. J. Crane, Gerard O. Platau, Cecil C. Langham, W. Russell Stemen, Charles L. Bernier. Absent at the time the picture was taken were: Gertrude Gibbons, Frances Prather, Melville F. Ravely, and Russell J. Rowlett, Jr.

in their *Journal of the Chemical Society*, and for industrial papers they had abstracts in the *Journal of the Society of Chemical Industry*. In 1926 they started *British Chemical Abstracts*, covering both pure and applied chemistry. Imitation is the sincerest form of flattery!

What *CA* Covers

But what are the boundaries of chemistry? It is a science that stretches as far as the eye can see in almost every direction. Is biochemistry chemistry? Is medicine chemistry? Is physics chemistry, or is chemistry physics? Is an electron chemistry? A proton, being a hydrogen ion, H^+, is usually chemistry. These subquestions have been perplexing the editor and staff of *Chemical Abstracts* ever since the beginning. If a paper is written on the effect of small quantities of boron on the hardenability of steel, is that chemistry? Another paper may be on the effect of a narcotic on the contraction of striped muscle; how about that? The borderline between chemistry and biology has always been particularly difficult. Are enzymes chemistry? *Yes*, because they are chemical catalysts, working in a biological system. Are diagnostic pathological tests chemistry? *Yes*, if they involve a chemical method, *no*, if they do not. How far are fertilizer experiments chemistry? Answer, pretty far, and experiments on pesticides are almost always chemistry.

How far is physics chemistry? Answer: Surprisingly far. *Chemical Abstracts* abstracts about three quarters of all the papers appearing in journals devoted to physics, and is widely consulted by physicists, as well as chemists. And then what is physical chemistry? If ionization in solution is chemistry, what about gaseous ionization? Ionization potentials? Is solution a chemical process? What about distillation? An improved apparatus for laboratory distillation would certainly be abstracted. Then what about industrial distillation columns? If a chemical engineer publishes, as chemical engineers so frequently do, a new method for calculating the number of plates in a distillation column, there is nothing to stop that from being classed as chemistry, for no perceptible line has been passed between that and the laboratory column. And so here is the chemical engineer, plumb in the middle of *Chemical Abstracts*. It is impossible to draw any fixed dividing line between "pure" and "applied" chemistry, and *Chemical Abstracts* has never attempted to do so.

Where is chemistry to be found? Any *new* material on chemistry, the world over, finds its way into *Chemical Abstracts*. All journals that contain new information are abstracted and there are now about 5300 journals, in 31 languages -from Arabian to Ukrainian- -that regularly or occasionally publish new material in chemistry. Books do not usually contain results of new research, and so they are not usually abstracted, but are noted by title. Government publications, now running into great volume, often contain new work, and are abstracted, and so also are patents, in enormous numbers, the record being 28,051 in 1933.

CA has followed the principle that an abstract must be made by a man who thoroughly understands the particular subject that the paper deals with. If a translation is to be made, he must also thoroughly understand the language. Thus, highly specialized papers in the less usual languages present a problem, and for such it is occasionally necessary to relax the specialist-in-the-field requirement slightly. In general, however, it is true to say that every abstract is prepared by an expert. Abstracting for *Chemical Abstracts* is tedious work, and at the standard rate of $8.00 per printed page no one gets rich on it. Abstracters serve partly out of public spirit, and partly because *having* to read all the papers on a particular specialty is the best way to make yourself keep up with your subject. And abstracters' lives are brightened by an Abstracters' Luncheon at the regular meetings of the ACS, and also by a little house organ gotten out by Editor Crane, called *The Little CA*. *The Little CA*, in contrast to the big one, is bright reading, enlivened by pictures, jokes, and pep talks from the editor in terse verse, which is his avocation. And even in this line, *Chemical Abstracts* claims a record. Crane imagined that nothing could be terser than his appeal "*CA* Today," but this record was promptly shattered by Dr. Patterson's reply "Aye. I."

Abstracting all the world's chemical literature is only half the story. The information would be of no use at all unless one could find what one was looking for. It has to be indexed. And this brings up one of the foremost principles of indexing, as *Chemical Abstracts* discovered very early: *subjects*, not names, have been indexed, as it says at the beginning of each year's subject index. But what is a subject? Is Paint Removers the same subject as Varnish Removers? And what about Lacquer Removers? And what *is* lacquer? There was a time when it was a product of the lac insect. Now it is . . . here any specialist is invited to give his definition, and to remember that indexing involves problems of this kind in *all* fields.

No less than five kinds of index are prepared annually by *CA:* author, subject, numerical patent, formula, and ring number.

Indexing by subject demands that every subject dealt with in the paper shall appear in the abstract. If a chemist has determined a certain property of methyl, ethyl, isopropyl, stearyl, and cetyl alcohols, it is not enough to say "properties of several lower and higher alcohols were determined." The alcohols must be mentioned by name, and the abstract will be indexed under each of them. Frequently a paper will describe an investigation made on hundreds of compounds, sometimes even a thousand or more. Subject and formula index entries will appear under *all* of them. And not only substances are entered, but methods, apparatus, anything else that is new. If the refractive indexes of 20 compounds are determined by the Abbe refractometer, then the 20 compounds will be indexed; if they were determined, (or "detd," as *CA* says) by a new refractometer, then this too will appear under refractometers. And yet it has been possible to prevent the number of subject entries from building up to anything totally impossible and unusable. The average number of subject entries for each abstract is just over five, and the indexes, though enormous, are still less than the text, by about 33%.

Decennial Index

Not content with preparing the five indexes annually, *Chemical Abstracts* undertakes the colossal task of collecting them decennially. And if anyone thinks that this is a straightforward task of just putting all the cards together and alphabetizing them, he had better consider that for the Fourth Decennial, covering 1937–46, there were approximately 2 million cards! Furthermore, chemistry changes in the course of 10 years. New names come into use. A compound may be wrongly identified at the start of the period, or identified only as "Factor X," or "Component Z," so that cross references must be carefully made between its older and its newer designation. At what point did powder metallurgy become a subject in its own right? And what happens to the cards that referred to this subject before it had received its name? The galley proof of the Fourth Decennial, laid end to end, would extend for five miles. This all had to be proofread, and then checked again, and it is in closely set six-point type (like this), yet the result is comprehensive, accurate, consistent, and above all, READILY USABLE. It is truly one of the wonders of the world.

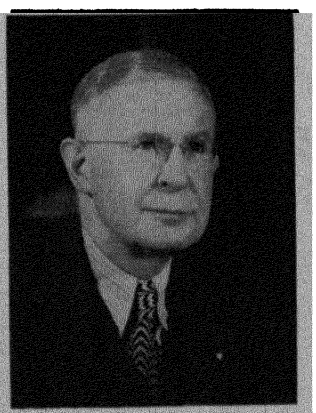
Besides "What is chemistry?" there is another simple-sounding but huge question that has been the concern of *Chemical Abstracts* from the beginning. What is a chemical? What is its name? There are many chemists who still think that naming a chemical compound is easy. They can name sodium chloride, and they speak of nitric acid and nitrous acid, nitrates and nitrites. They would probably be all but unanimous in referring to CH_3Cl as methyl chloride, but for C_6H_5Br some would say "brombenzene" and others "bromobenzene," or else use both terms in the same breath. *Chemical Abstracts* has to deal with these names. Brom may alphabetize in a different position from

bromo, and it is desirable to have them both together. Worse still are names that do not say clearly what they mean. Such names are extraordinarily widespread. Sodium tetraborate can mean either $Na_2B_4O_7$ or $Na_2B_8O_{13}$. The well-known initials DDT stand for *d*ichloro*d*iphenyl*t*richloroethane, but this name is highly ambiguous. It has been calculated that it could stand for over 50 distinct compounds. The "real" name for the compound intended—the *CA* name, that is—is 1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane, and it may be noted that it does not have a "D" in it anywhere.

The thinking of many chemists parallels that of Shakespeare. "What's in a name?" is for them a rhetorical question. But poets should not be followed in the realms of science. A rose by any other name would smell as sweet, but for scientific purposes a rose has to be *Rosa*, for this genus name plus a species name identifies the plant exactly. Far too many chemists use names that do not clearly identify the compounds they have used. There should be no names like iso-octane. This name, if it means anything at all, could mean either (1) 2-methyl-heptane or (2) *any* branched-chain hydrocarbon C_8H_{18}. Actually it is generally understood that the name denotes 2,2,4-trimethylpentane. In this case the denotation is clear, for this compound is so well known. But there are plenty of other cases where the intended designation of an ambiguous name is not obvious. "Chromium trioxide" may refer to either Cr_2O_3 or CrO_3. There are commercially used names that are clearly wrong, for example, "undecanol," which is *not* an undecanol (although it is an undecyl alcohol), but is 5-ethyl-2-nonanol. These misnomers are a big headache for the abstracters, for what is the use of reporting very careful work, if it is not possible afterward to identify with certainty the compound that was investigated? Often an abstracter engages in correspondence with the author of a paper, to find out what it was he did use, and when this is cleared up, the abstract in *CA* is better than the original paper.



R. L. Shriner, editor of *Chemical Reviews*



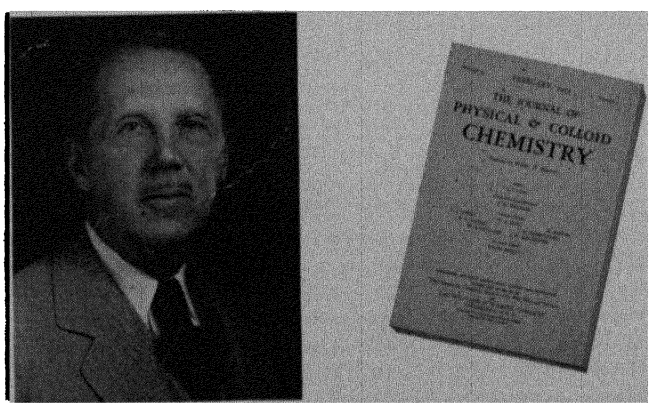
William A. Hamor, editor of ACS Monographs

Chemical Abstracts, and the ACS itself, have been intensely concerned with nomenclature. Dr. Crane is chairman of the ACS Committee on Nomenclature, and Dr. Patterson and others have done invaluable work on nomenclature for many years. The work on nomenclature has been a steady push. The results can be regarded as definitive. Just as it might be said that one of the "properties" of an organic compound is its volume and page number in Beilstein, so one of the definitive pieces of information about a compound is its "*CA* name." In Volume 39 of *Chemical Abstracts* (1945) part of the introduction is a 109-page note on "The Naming and Indexing of Chemical Compounds by *Chemical Abstracts*," prepared largely by Austin M. Patterson, Leonard T. Capell, Mary A. Magill, and Janet D. Scott. Many thousands of reprints of this treatise have been sold at cost price. It is a chemical classic.

And let it not be thought that work on nomenclature is a sort of secondary activity in science, little more than "pushing commas around," a degradation of interest from the things themselves, the true subject matter of science, to the mere words that describe them. Concern with chemical nomenclature has a highly respectable pedigree, going back to Lavoisier. The introduction of a rational nomenclature into chemistry stands among Lavoisier's great achievements. It is not so well known as his classic work on oxygen, but it was in effect part of it. As he himself expressed it "The impossibility of separating the nomenclature of a science from the science itself, is owing to this, that every branch of physical science must consist of three things; the series of facts which are the objects of the science, the ideas which represent these facts, and the words by which these ideas are expressed.... And, as ideas are preserved and communicated by means of words, it necessarily follows that we cannot improve the language of any science without at the same time improving the science itself." The situation is similar now. Who can see his way clearly among the ions FeO_2^-, FeO_3^{--}, and FeO_4^{--} when these have all been called, indiscriminately, "ferrates"? Who can form a clear conception of "acetals" when this word is used in three, or perhaps more, distinguishable senses, from the narrowest sense to the widest sense, like concentric circles? Crane and his fellow workers are not mere recorders, writers-down-on-paper of what others have achieved, sorters and putters-together doing work that, in the electronic age of the future, will be done exclusively by machines. In continuing this work of nomenclatural clarification, they are doing scientific work of a high order and *Chemical Abstracts* makes an extremely valuable contribution to the chemistry, hence to the prosperity, of our country and our age.

Other Publications of the ACS

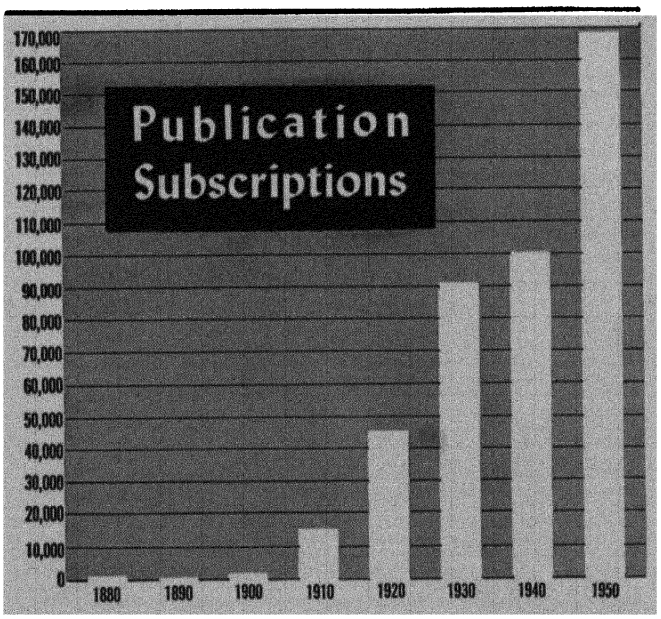
The simple answer to "What is chemistry?" is anything that is in *Chemical Abstracts*. It is not the only answer, and certainly not the only answer to the question "What does the AMERICAN CHEMICAL SOCIETY do?" The ACS publishes four other major journals, the *Journal of the American Chemical Society*, *Industrial and Engineering Chemistry*, *Analytical Chemistry*, and *Chemical and Engineering News*. In addition, there are the ACS Monographs (published for the Society by Reinhold Publishing Corp. under the editorship of William Hamor) now amounting to 111 treatises; *Journal of Physical and Colloid Chemistry*, edited by S. C. Lind; and *Chemical Reviews* edited by Ralph L. Shriner (both journals have been published for the ACS by Williams & Wilkins Co. Beginning in 1952 the Society will take over the publishing operations for the *Journal of Physical and Colloid Chemistry*.); and the newly started series of Advances in Chemistry. Added to these are Abstracts of Papers for national meetings, "Reagent Chemicals, ACS Specifications," and other miscellaneous publications edited by the Washington staff. It can indeed be said that the publication program of the ACS, even if it were not for the meetings and the many other activities, would certainly be enough



S. C. Lind, editor of the *Journal of Physical and Colloid Chemistry*



Editorial staff of the *Journal of the American Chemical Society*



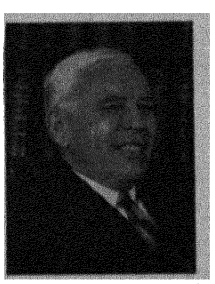
to keep the Society together, and to maintain it in its present outstanding position.

The major ACS publications are "horizontal" journals, where this curious phrase means that the reader interest is by broad subject grouping rather than by industry. All branches of chemistry, at the fundamental and theoretical level, can be published in the *Journal of the American Chemical Society*. All branches of chemical engineering, or of applied chemistry, can be published in *Industrial and Engineering Chemistry*. Fundamental to all chemistry is analysis; *Analytical Chemistry* therefore subserves every single branch of chemistry. All chemists and chemical engineers are interested in news, and *Chemical and Engineering News* brings news from all branches of the chemical world.

Journal of the American Chemical Society

Of the family of journals, the *JACS*, as befits its academic subject matter, is the simplest in structure. It reports new work in chemistry, with emphasis strictly on discovery of new principles without any present thought to the practical application of the discoveries or ideas. It has a respectable history, if not a great antiquity, among chemical publications, dating back to 1879, only three years after the foundation of the Society. Several chemical journals now being published are actually older than this, but not so very many, while a much larger number are younger.

JACS is one of the leading scientific publications of the world. And like the AMERICAN CHEMICAL SOCIETY and everything connected with it, it grows. In spite of the foundation of new journals dealing with this or that specialized branch of chemistry, and while keeping up, even improving, its quality, it has grown since 1900 to 10 times the size (based on word count) it was then, at a time when it was the only journal of the Society! It has a circulation of over 17,000 at a cost of $6.00 to members and $12 to nonmembers. W. A. Noyes of the University of Illinois, whose guidance was invaluable to the Society in so many ways, undertook the editorship of the *Journal* in 1902 and handed it on in 1918 to Arthur B. Lamb. With a small staff on the premises of Harvard University and with the cooperation of about 15 associate editors, Dr. Lamb carried on the *Journal of the American Chemical Society* and made it into what it is today. When he turned over the editorship, in 1950, to W. A. Noyes, Jr., who now carries on the work at the University of Rochester, Dr. Lamb spoke of his particular pleasure in being able to hand over the *Journal* to the son of the man from whom he originally received it, 32 years before.



Arthur B. Lamb

Any new contribution to chemical knowledge may be published in *JACS*. The *Journal* carries a short book review section but is

quite predominantly devoted to scientific papers and to notes and communications to the editor, which are in effect smaller papers, often published for the sake of establishing a priority of discovery. A very interesting example of this was the synthesis of vitamin B_1 by R. R. Williams, whose note in the *Journal* anticipated very shortly the publication of German patents on the same subject.

Papers for the *JACS*, or any of the Society's other journals can be submitted by anyone, not necessarily a member of the ACS. Many excellent papers have been published from chemists in other countries. Whatever the source of the contribution a careful referee system ensures that every paper contains new material that is worthy of publication and that it is well presented. Good referees must have special abilities. They must know the subject of the paper thoroughly, must be able to make well-considered criticisms, neither too harsh or unduly lenient, and, above all, they must be willing to give considerable time for this careful work. The *Journal* has always been able to obtain this willing cooperation.

If an excellent report is received from one referee, the paper may be published at this stage, but often it will go to another referee, and perhaps a third. The comments of all the referees are sent to the editor, who (after toning them down if this is necessary) sends them to the author. Sometimes prolonged correspondence ensues before the paper is in publishable form.

Taking some statistics about the fate of manuscripts, Dr. Lamb reported that of 1300 manuscripts submitted in 1941 "34% were accepted without change; 11% were accepted subject to minor changes or suggestions; 46% were returned to the authors for important revision or abbreviation or both; and 9% were flatly rejected. Putting these statistics another way, we found something acceptable for publication in 91% of the manuscripts." Or putting the same figures yet another way, of the manuscripts actually published, over half had been considerably revised since they were first submitted.

Whichever way the matter is looked at, the results are first class, and *JACS*, since its foundation, represents a record of the achievements of American chemists. To pick only a few of the high spots, one may mention the series of papers by Pauling and others on the nature of the chemical bond and the structure of molecules—the work of Seaborg on the transuranium elements—Lewis on atomic structure and on acid-base systems—Spedding on separation of rare earths by ion exchange—Hammett and Bartlett on mechanism of organic reactions—Mark on polymer chemistry—Richards and Baxter on determination of atomic weights—Harned, Shedlovsky, and MacInnes on physical chemistry of solutions—MacBain on colloidal electrolytes—Gomberg on tautomerism—Kharasch on free radicals—Langmuir on surface chemistry. Many others could of course be mentioned, for in all branches of theoretical chemistry *JACS* has reported fundamental discoveries. The *Journal* has been of incalculable importance to chemistry, and it has been described as "The largest, the most widely distributed, the cheapest, and the best periodical of research in pure chemistry in the world."

Industrial and Engineering Chemistry

But between a learned paper in *JACS*, and the availability to the actual consumer of a new plastic, a new fiber, a new detergent, an improved metallurgical treatment, or a more economical synthesis, a huge number of steps intervene. They are served by the ACS at all levels, and with regard to publications the next to come into the picture is *Industrial and Engineering Chemistry*. If *JACS* represents the old Society, considered as a learned body of savants, on a pattern going back to the 17th century foundation of the Royal Society in England, then *I&EC* represents the new Society, which is rooted in academic science, but concerns itself intimately with the actual translation of theoretical ideas into practice. And it is typical of the ACS that the newer activity is *added to* the older; it does not replace it.

It would be hard to overestimate the importance of *I&EC* to



Harrison E. Howe

chemical development in this country. Scientific papers are there, reporting the original determinations of the data the industrial chemist and chemical engineer must use in their design work. There are also methods of design calculations, nomographs, flow sheets, and other forms of basic information. Many other features have been added, editorials, staff reports, industrial data, facts and figures, special issues devoted to symposia—and all these features of the modern *I&EC* have been added, without subtracting from its original function of being a scientific journal, reporting the results of original research.

I&EC has been fortunate from the beginning in having a series of editors of great energy and vision—W. D. Richardson, 1909–1911; M. C. Whitaker, 1911 to 1917; Charles H. Herty, 1917 to 1921; and Harrison E. Howe, from 1922 to his untimely death in December 1942. The same description certainly applies to the present editor, Walter J. Murphy. He, with James M. Crowe, executive editor, has under his wing two monthly periodicals, a weekly, and the News Service—*I&EC* with D. O. Myatt as managing editor, *Analytical Chemistry* with Lawrence T. Hallett as part-time associate editor, *C&EN* with Robert F. Gould as managing editor, and the ACS News Service with James H. Stack as managing editor. These people run a multi-ring circus. They do it with a personnel of 32 in the Washington office, 15 in New York, three in Chicago, two each in Houston and San Francisco, two in Europe, and four in Easton, Pa., where the magazines are printed. That these people produce so much and do it so well is utterly astonishing!

Although contributed articles, presenting original experimental or theoretical contributions, are still the mainstay of *I&EC*, the publication presents far more than that. In each issue a Staff-Industry Collaborative Report describes a contemporary manufacturing plant in some particular industry. These reports continually give chemists and chemical engineers an opportunity to keep abreast of latest developments in some branch of technology, which may be extremely new (bacitracin, in the July 1951 issue), extremely old (brewing, June 1951), or intermediate (calcium cyanamide, May 1951). The series for the first two years has been published in book form, "Modern Chemical Processes," by the Reinhold Publishing Corp. Since scale-up of reactions from test tube to full production almost always requires considerable pilot plant experimentation (with the striking exception of the wartime work on plutonium for the atomic bomb), a regular feature in each issue is "Pilot Plants," usually a description of some particular installation. The magazine now regularly carries columns specially written by experts in the fields of equipment and design, instrumentation, corrosion, plant management, industrial wastes, atmospheric pollution, safety, industrial hygiene, and materials handling. The annual reviews of unit operations, unit processes, and materials of construction are awaited eagerly by many readers and used constantly as reference material. Each month an editorial calls attention to some development or some aspect of the profession. Every other year there is a special "Facts and Figures" issue presenting the latest chemical statistics, and each issue devotes a considerable part of its space to a symposium (sometimes more than one).

Recent symposia include Ion Exchange, Dispersions in Gases, Radioactive Wastes, Purification of Sugar Juices, and "Information Please," which discussed how to obtain information and how to disseminate it, in applied research, market research, and technical service.

The first symposium ever published was in October 1918 under the editorship of Herty. It was on the Chemistry of Dyestuffs—and it is easy to see its appropriateness at that time. Equally well-timed, at the beginning of the last war were the two sympo-

sia, Rubber for Defense, November 1941, and Compounding and Properties of Synthetic Rubber, November 1942.

The editors of *I&EC* are acutely aware of the many facets to successful chemical production besides the basic chemical reactions involved. This progressive attitude of mind is illustrated by the publication of a series covering the seven geographical areas of the United States, as defined by the Bureau of the Census, dealing with such topics as availability of raw materials in the particular area, present and future markets, labor availability, transportation, and types of possible plant construction—all supplying information that a company would need in determining where to locate new producing facilities. The Southwest was analyzed in the August 1951 issue of *I&EC*. The Pacific Coast area will be covered in the December 1951 issue. Thereafter, two sections will be reviewed each year until all of the seven areas have been studied in detail.

***Industrial and Engineering Chemistry, Chemical and Engineering News,* and *Analytical Chemistry* Editorial Staffs**



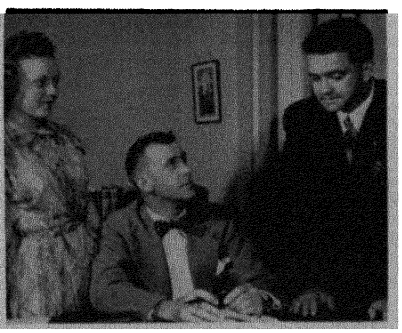
Washington staffs. Seated: Robert F. Gould, James M. Crowe, Walter J. Murphy, D. O. Myatt, and Nell A. Parkinson. Standing: Norma Gabel, Martha Fisher, Margaret Summers, Eileen G. Hoffen, Howard J. Sanders, Hannah Pluess, Edyth Malin, Gordon H. Bixler, Stella Anderson, Robert G. Gibbs, G. Gladys Gordon, Joseph H. Kuney, Kathryn Campbell, Rosemary Norair, Betty Forden, Monica Crawford, Whilden Johnson, Mary Arnone, Ruth Cornette, Irene Hodgens, Katherine Biggs, Cora Ryerson, Rosalie Leimbach, Nena Manley



Easton editorial staff. Betty Kieffer, Mary Carls, Charlotte Sayre, Bertha Reynolds



New York editorial staff. Merritt L. Kastens, Julia Bandini, Harold A. Knight, Ouida Ferree, Harry Stenerson, and John F. Bohmfalk



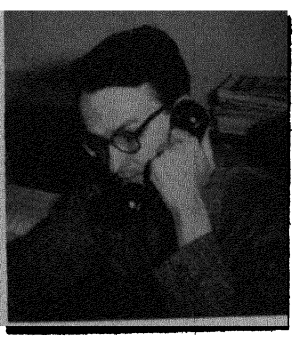
Chicago editorial staff. Irene Reitan, Rodney N. Hader, and Gordon C. Inskeep



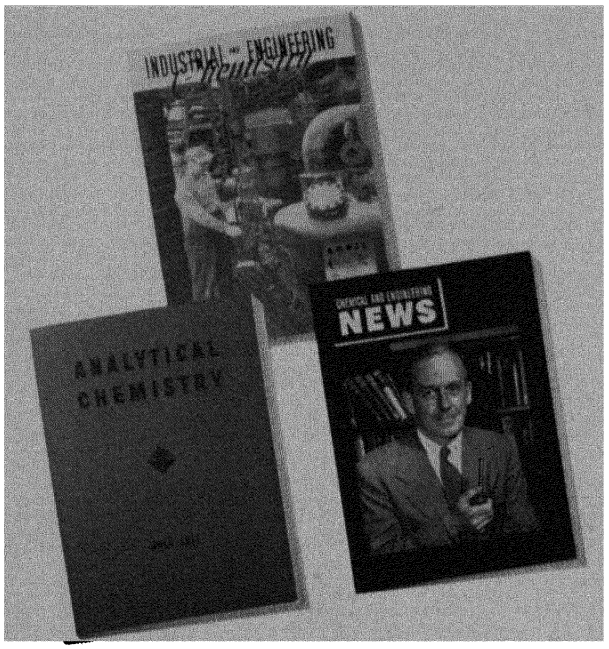
Houston editorial staff. Will H. Shearon and Mary Holmsley



San Francisco editorial staff. Marion Hilliard and William Q. Hull



European office (London). Richard L. Kenyon



Contributing greatly both to *I&EC*'s usefulness to the readers and to the revenue of the Society is advertising, amounting to more than 1300 pages in 1950. The planning of symposia and special issues in advance permits advertisers to place their advertisements in those issues that are particularly appropriate. An attractive layout, the use of color in printing, and an interesting photographic theme on the front covers are modern in style and pleasing to the reader. In many other ways *I&EC* exercises editorial leadership: examples are the symposia on Industrial Wastes, May 1947, and Atmospheric Pollution, November 1949, both of which call attention to important subjects that were once apt to go unnoticed (what is everybody's business is nobody's business). And to mention just one more symposium, the magnificent issue of March 1947 was devoted entirely to fluorine and fluorine compounds, containing papers by a total of 73 authors. It has been estimated that this issue about doubled the industrial interest in these new chemicals, and therefore greatly helped their development into new and useful products. It is interesting to note that when the papers came in there was such a state of confusion in terminology that the editors inserted a special note on Fluorine Nomenclature, thereby following the precept of Lavoisier, and greatly clarifying and facilitating the progress of this branch of science.

On several occasions the outstanding editorial excellence of *I&EC* has been formally recognized. The Symposium on Industrial Wastes (1947) was awarded a first prize in the annual contest sponsored by the magazine *Industrial Marketing*. Again, another first was received in 1949 for the "Facts and Figures" issue, published in 1948. In 1951 a certificate of merit was received from *Industrial Marketing* for the 1950 issue devoted to Facts and Figures about the chemical and chemical process industries.

Although it is not so old as the *Journal*, *I&EC* has in its back pages many a paper of historic, and indeed, of permanent interest. Volume I, No. 1 has the splendid and fundamental paper "The Synthesis, Constitution, and Uses of Bakelite" by its discoverer, L. H. Baekeland; "The Theory of Fractional Distillation" by Warren K. Lewis; and "Industrial Fellowships" by Robert Kennedy Duncan. The latter laid down the broad principles upon which the Mellon Institute was founded. Volume III has "The Electrical Precipitation of Suspended Particles," the announcement and description by F. G. Cottrell of his process of electrostatic precipitation. Volume VI, 1914, has an important paper by B. C. Hesse on "The Industry of the Coal-Tar Dyes." Often it is possible to follow through successive papers showing the stages of development of some subject, for example, the hydrogenation of coal and petroleum: 1925, A Direct Synthetic Plant; 1930, Hydrogenation of Petroleum; 1934, The Hydrogenation of Coal; 1937, Coal Hydrogenation; 1946, German Synthetic Liquid Fuels by Destructive Hydrogenation; 1947, Bench-Scale Equipment and Techniques for Investigation of High-Pressure Reactions; May 1949, Liquid Fuel from Coal, a Staff Industry Collaborative Report describing the large demonstration unit of the U. S. Bureau of Mines at Louisiana, Mo.; October 1949, Fischer-Tropsch Synthesis; January 1950, Hydrogenation of Bituminous Coal in Experimental Flow Plant; August 1950, Liquid Fuel from Coal; November 1950, a progress report on the first year of operation of the Louisiana, Mo., demonstration unit. Such a story illustrates the continuity of the service that *I&EC* has provided to American industry.

I&EC is circulated to about 29,000 subscribers at the rate of $4.50 for members and $5.00 for nonmembers. These subscribers receive roughly 70% editorial matter and 30% advertising matter—reversing the usual percentages of industrial publications. And readers can be sure that the contributions are original and are well presented, for an extremely careful reviewing system, similar to that of *JACS*, is maintained.

Analytical Chemistry

Analytical chemists in earlier years had grown resigned, rather than accustomed, to being the waifs and strays of the chemical profession. Nevertheless, their work is fundamental to *all* branches of chemistry and chemical engineering. As Walter Murphy, editor of *Analytical Chemistry*, expresses it, "Advances in the field of analytical chemistry in the past decade or so have been nothing short of phenomenal, but few outside of the profession are at all aware of this progress. In that period the field of analytical chemistry has undergone profound changes, but these changes have had little publicity and are none too well understood outside of the confines of the analytical laboratory and by research and production departments." Also, "The laboratory technician who works with physiochemical procedures does not necessarily need to understand the basic chemical and physical principles upon which these methods are based. The pure analytical chemist, however, must possess more than a mere working knowledge of instrumentation. Today the analytical chemist must be not only an organic chemist, an inorganic chemist, a physical chemist, a biochemist, a metallurgist, but must also be a physicist of no mean order."

If the respect accorded analytical chemists in the profession has improved greatly in recent years, so that they may almost be said to receive their due, this can be credited to a large extent to the editorial leadership shown by Walter Murphy in *Analytical Chemistry*. When Murphy took over the editorship in 1943, it was *Industrial and Engineering Chemistry—Analytical Edition*. In 1948 it became a separate publication. It carries fundamental articles on analysis, reviewed and edited with the same meticulous care as those in the other publications, and it has the regular monthly features Instrumentation, the Analyst's Column, Crystallographic Data, book reviews, the Analyst's Calendar, Aids for the Analyst, Scientific Communications, and Notes on Analytical Procedures. And it carries editorials which constantly stress the importance of analysis, the dignity of this branch of the profession, and the importance of the teaching of analytical chemistry. One concrete result of this program was the foundation, after an editorial entitled "The Profession of Analytical Chemistry" which appeared in the March 1947 issue of *Analytical Chemistry*, of the Fisher Award in Analytical Chemistry for outstanding work in the field and the Merck Fellowship for advanced study in analytical chemistry.

Chemical and Engineering News

And then there is *C&EN*, the *"Time Magazine"* or *"Newsweek"* of the chemical world. It is a weekly, fully as timely as its

newsstand counterparts, somewhat similar in general appearance, comparable in size and more complicated in layout. It goes to all members of the ACS and to about 10,000 other subscribers, many of them abroad, making total circulation around 75,000. The great majority of the readers of *C&EN* are chemists or chemical engineers, but there the resemblance between them ends, for they may be working in a great variety of different ways. They may be research chemists, analysts, executives, college professors, students, employees of the Government in many capacities, in very large companies, in small companies, self-employed or in consulting work, doing library research, in the sales or purchasing or market research departments, or in many other unexpected positions where chemists or chemical engineers turn up. And a proof that *C&EN* also performs considerable service to many laymen is the list of banks, chambers of commerce, public relations agencies, and others who rely upon it to give them the most accurate and up-to-date information of a world with which they are not familiar, but which is becoming of greater importance to them every day.

Everyone of these people will find something to interest him in *C&EN*. Some will turn straight to book reviews (Beyond the Flyleaf), Industrial Literature, or Government Publications; others to Potomac Postscripts, Wall Street of Chemistry, The Week's Price Changes, Behind the Markets, Process Industries' Outlook, and Chemical Market Prices. Canadian Chemistry will interest some, who may, if they wish, go further afield and read World Wide Chemistry. Some, actually interested in what goes on in the ACS, may read ACS News and The Secretary's Office. Those interested in people find News-Makers as complete an account as can be obtained of all in the profession who have taken new positions; the same readers may also turn to Necrology. They will be joined by many others in reading the short profile of the chemist or chemical engineer whose photograph appears on the cover—a winner of an award, or a new national ACS officer, or one who makes the news in some other way. Many will read the editorials, a constant source of enlightenment about legislation, mobilization developments, possible new taxation, and any other changes that may affect the chemical profession. New Chemicals and Specialties, Containers and Transportation, New Equipment, Industrial Relations, In the Works, and Safety Forum are some of the other regular features, and in addition, there are always several special articles on most varied subjects connected with chemistry, and special issues give programs of meetings, ACS Board of Directors Minutes, and Official Reports. An important feature is Employment Information, with Situations Open (at present large and full of display insertions), and Situations Wanted, divided very properly into ACS members and nonmembers. Members are allowed three free ads when they are unemployed. Otherwise member rate is one half of regular rate. Student affiliates also get the one half rate. This section of *C&EN* is the leading source of employment information in the chemical profession. But, even a reader who should confine himself to conCENtrates, on the two pages following the contents, would be well informed about the latest developments in industrial chemistry. And there is always a one-column feature, News-Scripts, at the very end, where humor is allowed to creep into the official lives of chemists.

The editors of *C&EN* are constantly devising ways and means of serving their readers. For example, the outbreak of hostilities in Korea followed by a broad industrial mobilization effort of the country to meet the threat of World War III also witnessed the inauguration of a new department in the magazine under the title Industrial Mobilization. Week by week, chemical executives can find in this department a well-digested, authoritative story of what is happening, largely but not entirely in Washington, in the country's mobilization efforts.

Before 1943 *C&EN* was *Industrial and Engineering Chemistry, News Edition*, in which form it goes back to 1923. An interesting note was struck by page 1 of Volume 1, No. 1 of the *News Edition*. It begins with a talk given by John E. Teeple before the Bankers Forum in New York on Nov. 22, 1922. The purpose of his talk was to persuade the bankers of the value of research. He declared that the values produced by a research department were greater than the whole of the fixed assets of a plant. "If all of its assets were destroyed they could be speedily replaced; if the whole output of its organized research could be destroyed, 20 years would not suffice to replace it." He drew an example from the potash industry. In 1918 under the stimulus of the potash famine produced by the World War, there were 44 plants in the U. S. producing potash as their main product. Only one of these had a research department. At the time of speaking, 1922, only one of the 44 plants was still in operation, and it was *that* one. This is an example of the type of message that the ACS loses no opportunity of putting forward, through any of its numerous channels of reaching the public.



Air view of Mack Printing Co., Easton, Pa.

The original *News Edition* was a slim little number, often thought of as a mere house organ of the ACS, and generally not kept by libraries more than a year back. This habit all too often persists, although the periodical has changed its character completely. It has done this in the ACS fashion without eliminating its former character, for it still carries information about the ACS, but it has also become a great news organ. Its news character became so important that in its old leisurely style of appearing twice a month it could not bring the news to the chemical profession fast enough, and beginning in January 1947 it became a weekly.

Even before the change to weekly appearance was put into effect, *C&EN* was as up-to-the-minute as any national weekly. There had been a pleasant habit, in the old days, of moving the entire staff up to Woods Hole, Mass., for the summer to escape the heat and humidity of Washington. In the summer of 1945 they were caught short by the utterly unexpected news of the dropping of the first atomic bomb on Hiroshima on Aug. 6, 1945. They jumped into action like hardened newspapermen and -women. A holder-of-the-fort in Washington dictated the Pentagon's news releases over the phone to Woods Hole. The staff worked until early the next morning preparing text to take down to the printer at Easton, Pa., and after much telephoning to Easton the next day, the story came out as an 8-page insert, with illustrations, in *C&EN* for Aug. 10, achieving a scoop on every other technical magazine in the country.

It is not possible to write about the publication program of the ACS without making a deep and sincere bow in the direction of the Mack Printing Co. at Easton, Pa. For many years they have printed *all* the major ACS publications. They have become extremely expert at satisfying the special demands that the chemist is bound to make upon a printer, and they now possess about 9000 special characters for this purpose—benzene rings, double bonds, arrows, double arrows, double-headed arrows, electrons in several shapes, and so on endlessly. And that the relationship between the ACS and the Mack Printing Co. is not merely one of hard-boiled business is shown by the history of the

Journal of Chemical Education. In 1932 when that journal was having financial difficulties, Harvey Mack not only continued to print it, but personally assumed the business management which he rotained for over 10 years. After this he handed it back, as a concern able to pay its way, to the Division of Chemical Education, which continues to publish it.

If chemistry has levels, so also does the AMERICAN CHEMICAL SOCIETY. The original Society, established in 1876 with its one journal started in 1879, represents a scientific society in the old style—learned men reading papers to one another and publishing them. The Society still has this character. But it also has its more modern character as well, that of a professional society, by no means withdrawn from, but right in the middle of, the whole fast-moving technical and business world. Its journals serve the profession from one end of this scale right through to the other. They are not just a random collection of journals, they are an integrated group of journals—by far the best integrated group of technical journals in the world.

What Does the Public Think of the Chemical Profession?

The ACS has to concern itself not only with what its members say, and think, among one another. If it confined itself to providing meetings, journals, and little local house organs and social events, it could reasonably be called an ivory-tower society, doing much less than its full job of publicizing chemistry and promoting the interests of chemists and chemical engineers in every possible way. It must also concern itself deeply with the question, "What does the public think of the chemical profession?"

It is probably safe to answer that the public thinks very highly of the profession. It is also probably true that many chemists and chemical engineers are unaware of this, or realize it only dimly. They should reflect on this once in a while, and consider where they would be if things were otherwise.

It is not easy to compare the present state of affairs with a state of affairs which *might* have been, but did not actually come to pass. It is difficult for us now, in the middle of the 20th century, to imagine how different the word "chemist" sounded 50 years ago, or 75 years ago when the AMERICAN CHEMICAL SOCIETY was founded. Chemists were then, at the best, the followers of a certain academic but rather impotent branch of study, like geologists, entomologists, ichthyologists, or even (which is reprehensible) phrenologists. If a young man at college had the idea that he wanted to devote himself to the study of chemistry, this was regarded as rather unusual; it would be but little more unusual and withdrawn from the actual life of the world if the young man said he wanted to study numismatics. The word "chemist" had connotations entirely different from those it has today.

If we use the word "engineer" we may intend to denote a person whose work is anywhere along a very wide scale. At one end of this spectrum is a highly skilled professional who designs suspension bridges a mile long; at the other end is the operator of a locomotive on a railroad, a fine man, probably, and a skilled man, but not as a rule a college graduate, and not a man whose occupational abilities express themselves in any intellectual way.

If we speak of a "physicist," the connotations are quite different. We then refer exclusively to a college graduate, and probably to a man of high intellectual abilities, with at least a Ph.D., and possibly a whole string of other academic honors as well. Yet we exclude the man who designs a suspension bridge, in spite of the fact that his work is based entirely on physical principles. A man who splits the atom is a physicist, a man who makes electrons turn 'round and dance for him is a physicist, but the man who applies these discoveries does not call himself a physicist. If you went into a shop where the most complex electronic devices were being constructed or repaired and said "Hi, physicist!" the chances are that no one would look up. The real physicist would be in a different part of the building, dreaming up even more extraordinary devices. Once a physicist has found out something useful, he banishes it from the realm of physics.

The word "chemist" has gotten to have a meaning quite different in scope from either "engineer" or "physicist." It is not so broad as to include the man whose abilities are not on the intellectual level, but neither is it so narrow as to exclude the man who puts the principles of chemistry to some practical use. Chemists like to acknowledge fatherhood of their brain children. If you went on to the premises of a large oil company, and had your cry of "Hi, chemist" piped into every corner by a public address system, swarms of people would consider that they were being spoken to. In some building by themselves would be the research geniuses, thinking up ways to make something totally unexpected out of petroleum. Many chemists doing routine analyses, trouble shooting, and other chores would find it proper to answer. Executives, too, would answer; at least the vice president in charge of research, and possibly the president himself. In the sales department many would answer; also in publicity, advertising, technical service, and possibly several other departments. Plant managers would answer. A great many workers about the plant, whose skill corresponds to that of the "railroad engineer" would *not* answer. Of those whose work demands professional training, of the college graduate level or higher, there might be some who would hold out and say "Why don't you call for a chemical engineer?" But of these persons also, the chances are that a large majority would be members of the AMERICAN CHEMICAL SOCIETY.

Right up until the first world war there was probably some lingering, in the public mind, of the 18th century feeling that chemists "toil like asses." But for the most part, the public did not think about chemists at all. World War I made many people chemist-conscious, because of the emphasis, in that horrible war, on "poison gas," which loomed large in the public imagination. It was felt, even then, that the next war, if ever one came, would be fought by chemists. It *was* of course, but in a way different from what was expected, for at that time a chemist was thought of as a rather terrible person who at a moment's notice could have the entire population, men, women, and children, wearing gas masks. The next war, it is true, brought its own horrors, but even before this war broke out, the public attitude toward chemists had enormously changed. By the time the war was through it was abundantly clear that the inventions of chemists are quite predominantly on the positive side of the ledger—DDT, sulfa drugs, antibiotics, antimalarials, plastics, nylon, vitamin-enriched foods—even bubblegum and "bubbaloon." It certainly cannot be said of chemists that "they toil not, neither do they spin"; they both toil and spin—their new synthetic fibers.

This is why it is so difficult to go back to the public idea of "chemist" many years ago, and to figure what *might* have been *if*. If, that is to say, the term "chemist" had continued to be thought of as in "chemist and druggist," or as almost synonymous with "pharmacist." It might have been that the World War I idea of the chemist as a ghoulish figure, bent on humanity's destruction, would have stayed in the public imagination. Many things might have been, IF—there had not been a strong scientific and professional society looking after the interests of chemists, IF there had not been a body continually concerned that the importance of chemists should be properly appreciated, with neither underestimation nor absurd exaggeration. Indeed this is one of the most important of all the achievements of the AMERICAN CHEMICAL SOCIETY. It is also one of the easiest to overlook, for it has been achieved, like a mushroom pushing up the asphalt, by a constant, inconspicuous steady pushing (perhaps occasionally a little pulling), and is very often incidental to

some other objective. In fact it might be said that all of the Society's activities contribute, in some measure, to improving the public estimation of chemists. To single out, in this connection, the American Chemical Society News Service is to concentrate, for the time being, on that activity which contributes most directly, to this end, without "prejudice" (as the lawyers say) to the other activities, which also help.

Technical men, immersed in the work of their laboratories or their plants can as readily be excused for being ignorant of the techniques of news-collecting, as journalists can for being ignorant of the right way to fold a filter paper. All the news that is printed in the newspapers gets there *somehow*, but the routing it and filtering it and digesting it and putting it into suitable form for the reader is a complex business, requiring the work of many people, at numerous levels. The big well known agencies such as AP and UP collect news of the common, political, well-known personal, or man-bites-dog variety. But there are also specialized items in all newspapers, even quite small local ones, and small papers cannot be expected to carry specialists on their staff to deal with such news. They depend upon news releases. And news releases reach them in enormous profusion, from any number of sources. The Department of Agriculture, Bureau of Mines, AEC, and other government agencies are a prolific source of news releases. Trade associations are another. Publicity departments of large companies and educational institutions are constantly on the alert to see that their newsworthy activities are not overlooked. Numerous other groups all strive to obtain for themselves as much mention—favorable mention of course—as they can. A newspaperman's problem is to keep them out of his hair.

ACS News Service

Chemistry probably gets fuller coverage and a better press than any other science. The American Chemical Society News Service has had long experience with this work, for it was started as far back as 1917, the year in which the United States entered the war, and two years after the Germans had introduced chlorine gas in battle, at that time the last word in chemical horror. Already there had been a notable increase in the amount of newspaper space and magazine articles devoted to chemistry, and Dr. Parsons, Secretary of the AMERICAN CHEMICAL SOCIETY, pointed out that the Society "must either take steps to provide authentic information, prepared in a form attractive to the daily press, or else chemistry would suffer from the inclination to overemphasize the sensational development in the science." Julius Stieglitz, at that time ACS President, also saw the same necessity, and wrote "The whole nation's welfare demands. . .that our public be enlightened in the matter of the relation of chemistry to our national life." It may be noted that, from the start,



Staff of ACS News Service. Seated, left to right: Eileen Reilly, Erna Leis, Dorothy O'Brien, Doris Goodwin, and Mary Sullivan. Standing: Robert Norton, James H. Stack, Edward J. Reardon, Roy Avery

two of the principal objectives of the News Service have been to take chemistry out of the dry-as-dust atmosphere of the laboratory and make it sufficiently interesting for the popular press and at the same time to help the popular press avoid making chemistry altogether too sensational through distortion or misunderstanding. Getting off in this way on the right foot at the start, the News Service has become well respected throughout the journalistic world. As for its quantitative success, at first it kept records, using a measure, customary in this trade, which has the dimensions of a velocity, but with extremely small units, inches per year—a snail's pace, in fact. For 1918, this velocity was 5000 inches per year—inches of newspaper space (irrespective of column width) devoted to chemical subjects and obtained through News Service influence. The rate grew rapidly, and by 1923 had reached the respectable figure of 205,000 inches, or 3.23 miles per year, when the keeping of such records was abandoned owing to the high cost of a clipping service for supplying the data. If the figure could be obtained now, it would be astronomical, and even so would not take into account the greatly increased circulation of so many newspapers and magazines.



James T. Grady (third from left), former managing editor of ACS News Service, chats with W. L. Laurence of the *New York Times*, H. W. Blakeslee of the Associated Press, and Gilmore Iden, *U. S. News and World Report*

The ACS News Service, like the AMERICAN CHEMICAL SOCIETY itself, grows both in size and in scope. It does not confine itself to actual discoveries and chemical personalities in the news. To quote from "The ACS News Service—Voice of the Chemical Profession": "Particular emphasis has always been placed by the News Service on the task of making known to the public the viewpoint of the chemist and chemical engineer on current issues affecting the chemical profession. Editorials in the journals, resolutions voted by the Board of Directors, and statements of Society officers on vital problems have been widely reported." In other words, the News Service permits the chemist to speak. Chemists can speak to one another easily enough, through the other activities of the Society, the meetings, and the journals, for the spoken and written word respectively. Chemists discourse in these manners both frequently and eloquently. But outside of these activities chemists are rather inarticulate. This is not a defect in their characters, it is rather a virtue: it could be put this way, that chemists are not a loud-talking bunch, constantly attracting attention to themselves. They need an organization to put their point of view forward. And if the public estimation of a "chemist" has been improved enormously over the past 30 years—well, at least it is possible to see where a large part of the credit for this improvement should go.

The ACS News Service was fortunate, in its early days, in obtaining the services of James T. Grady, for a quarter of a century Columbia University's director of public information. Grady is one of the grand old men of publicity. At a time when "press agent" was hardly respectable, Grady (an old *New York Tribune* man himself) was winning the respect of all newspapermen through his ability and through his realization that the best publicity is obtained not by sensationalism but by playing the truth true. The ACS always was one of his principal interests, for he realized that chemistry had no need of exaggeration. All it needs is for its story to be put squarely before the public. But this needs to be *done* and Grady did it. He succeeded so

well that at his retirement he was elected an honorary member for life of the National Association of Science Writers—a form of recognition which has been granted to only three other men. ACS News Service is now an activity under the directorship of Walter J. Murphy, with James M. Crowe as executive editor and James H. Stack as managing editor. Its annual budget is about $65,000. It uses these funds to such good purpose that it has frequently been studied by other news organizations, who wish to know how it obtained such good results so expeditiously.

In the past six years the ACS News Service has broadened the base of its operations greatly, by paying attention not only to national news, from the national Society, but to local news also. If a chemist reads an important paper before a meeting of the Society, his home-town newspapers get releases on the subject, so that they can report "Home-town boy makes good" or "makes news in chemistry." If a local section holds a meeting, this too will be reported in the local papers, and so will addresses, elections, student contests, and even social events. Most of the local sections have set up their own public relations committee, and the central News Service helps them with guidance in this usually unfamiliar field.

Several sections are active in television. The News Service utilizes every well-known means of mass dissemination of news to the public except the motion picture, and hopes in the not too distant future to add this medium to its program of publicity and public relations.

The atom bomb is the most spectacular piece of news the world has ever seen. Recognizing this, the editors of *I&EC* and *C&EN*, working with the ACS News Service staff, developed the first atomic energy exhibit ever to be built. This project took place in February 1946. Well over a million people saw the exhibit which attempted to describe fission in language understandable to the layman, and to indicate some of the profound changes likely to occur as a result of man's knowledge of how to split the atom. The exhibit was shown in more than 30 cities of the United States, several in Canada, and in Paris at the first meeting of UNESCO.

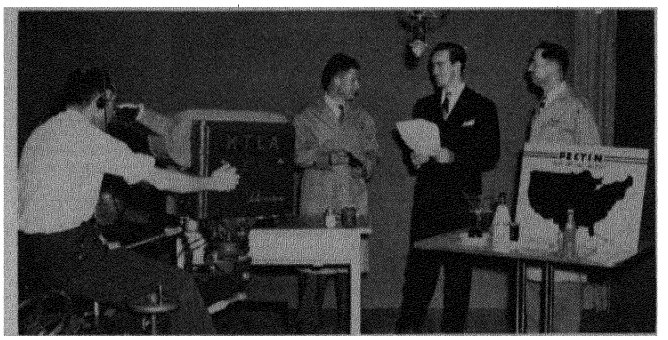
"Headlines in Chemistry" is a weekly radio program on WNYC (New York), carried also on some 80 other stations about the country. Television is not a regular feature yet, but telecasts have frequently been made at national meetings, presentations of awards, and other such chemical events. And yet another activity of the News Service is to act as a clearing house of scientific information for many magazines and radio programs: This is an inconspicuous activity, yet it contributes greatly to the general standard of reliability in science reporting.

The News Service also does international work, in sending news stories to European and Latin American editors. It cooperates with the State Department, which occasionally has chemists or chemical engineers appear on the Voice of America program, and it supplies a bimonthly news report to the Committee on Inter-American Scientific Publication. These efforts can be judged to be very successful. Americans often do not realize the extent to which the first class publicity work, on a very high level, is typically American. This can be briefly indicated, by a tribute paid to the excellence of the work of the ACS News Service by the British weekly *The Chemical Age*, which pointed out that all the world must have a very good idea of what American chemistry is doing, and declared that the average Englishman hears as much about the doings of American chemists as he does about his own fellow Britons.

ACS and the Chemical Profession

The AMERICAN CHEMICAL SOCIETY is not only a Society devoted to chemistry. It is also a Society devoted to its members. Its Constitution and its National Charter say:

The objects of the AMERICAN CHEMICAL SOCIETY shall be to encourage in the broadest and most liberal manner the advancement of chemistry in all its branches; the promotion of research



Television and radio carry the story of chemistry to the public through programs arranged by the News Service and local sections

in chemical science and industry; *the improvement of the qualifications and usefulness of chemists through high standards of professional ethics, education, and attainments;* the increase and diffusion of chemical knowledge; and by its meetings, professional contacts, reports, papers, discussions, and publications, to promote scientific interests and inquiry; thereby, fostering public welfare and education, aiding the development of our country's industries, and adding to the material prosperity and happiness of our people.

Many of the Society's activities contribute to the objective italicized above and this objective is also the subject of special attention in its own right. But before anything can be done about professional status, it is necessary to have some idea of what "professional" means, for it is a concept that is nebulous to many people, including a number of chemists.

Justice Brandeis of the U. S. Supreme Court has given a carefully thought-out definition of a profession as follows:

First. A profession is an occupation for which the necessary preliminary training is intellectual in character, involving knowledge and to some extent learning, as distinguished from mere skill or proficiency.
Second. It is an occupation which is pursued largely for others; and is not pursued merely for one's self.
Third. It is an occupation in which the amount of financial reward is not the accepted measure of success.

A similar definition of "professional employee" appears in the Labor-Management Relations Act (Taft-Hartley Act), but stressing also that the work of a professional involves "the consistent exercise of discretion and judgment" and that "the result accomplished cannot be standardized in relation to a given period of time."

The ACS has a Committee on Professional Relations and Status, and many of the local sections have similar committees. The work of these committees is probably among the least well known to chemists. This is true in spite of the fact that the subject is of the greatest interest to all chemists.

Licensing and Certification

Great attention has been paid by many chemists and chemical engineers to the question of whether chemists should be subject to any form of licensing or certification, or whether there should be optional licensing or certification. The Feb. 10, 1946, number of *C&EN* carried a double-page spread with the title "Should Chemists Be Licensed?" with Gustav T. Egloff on the left-hand page saying "Yes," and Charles L. Parsons saying "No" on the right. This was followed by a most thorough airing of the whole question, with a great number of articles and letters to the editor.

Now it happened that, about this time, there had been considerable discussion of certain fundamental questions about the organization and activities of the Society. It was decided to make a deep study of the opinions of the membership, so that any decisions could be made in an unquestionably democratic manner. John M. Hancock, a close and frequently a business associate of Bernard M. Baruch, and widely known in financial

and business circles, working with McKinsey, Kearney & Co. and Opinion Research Corp., prepared a most elaborate and well-thought-out questionnaire on the organization and policies of the Society. The opportunity was taken to find out the position of the members on the question of licensing. The results of this study, the famous "Hancock Report," were published in *C&EN* Feb. 17, 1947. Some of the conclusions referring to professional relations: (1) "About two thirds (63%) of the members cannot, on open questioning, suggest anything they'd like to see the Society do to improve the income status of chemists that it isn't doing now": (2) "Over a third of the members have not formulated definite opinions on state licensing of chemists, but of the remainder (65%) who do have crystallized opinions three in five (61%) (or 40% of *all* members) oppose any moves in this direction to improve status"; (3) "members react strongly against any ideas to improve their status through unionization—apparently considering such affiliation incompatible with their status as professionals." The statistical answers to all the questions, with critical comment, can be obtained by any Society member on consulting the Hancock Report, which is available as a separate reprint.

It was somewhat disappointing that the questionnaire brought to light considerable ignorance, on the part of some members, about what the Society is doing in getting across to the American people the importance of chemistry in our national life; 24% said the Society was doing a "poor job"; sample comment—"They should supply newspapers with chemical news items." This ill-informed chemist had never heard of the News Service!

A crucial question was "From what you know, do you think the national Society officers are doing a good job, just a fair job, or a poor job in trying to improve the status of chemistry as a profession?": 55% said "good job," 29% "fair job," 9% had no opinion, and 7% said "poor job." These 7% of the membership are invited to go on the committees. There are committees on professional relations and status in many of the local sections—if not, the chemist concerned should start one. He can also write to the members of the national committee, or he can attend their open meetings. And if he has some constructive suggestions, they will certainly be listened to.

One of the most important decisions relevant to the professional status of chemists was that of the National Labor Relations Board when it decided that professional employees must not be forced into a heterogeneous union. This interesting decision was rendered in the Shell Development case. Some employees, members of the CIO-FAECT Union sought to have the FAECT represent both the professional and nonprofessional employees in the Emeryville, Calif., laboratories of the company. Some of the professional employees objected and insisted that if any union or bargaining agency was formed, it must include only those of a professional level, if such a group was to represent the interests of the professional men and women on the staff. It is unnecessary to review at this time the bitter struggle that took place. The AMERICAN CHEMICAL SOCIETY entered the controversy "as a friend of the court." Ultimately the NLRB in Washington overruled a regional decision in California and stated in effect that no professional employee could be forced into a heterogeneous union. This pattern has been followed by the NLRB in other decisions where the conditions were similar to those at Emeryville. It is generally considered that the prompt action of the AMERICAN CHEMICAL SOCIETY has had a profound effect in maintaining the professional status not only of chemists and chemical engineers, but of all people who have had professional training.

Clinical Chemists

In several different states the Society has found it necessary to keep a close watch, through its local section, on legislative action affecting the position of clinical chemists. In a clinical laboratory, where chemical tests are carried out, it has often been proposed that the head of the laboratory, the man whose signature is required over every test result, must be a qualified physician. The Society has always taken the attitude that this work is that of a chemist, sufficiently qualified in clinical chemistry, and that such a chemist has sufficient professional status as to make it quite unnecessary to place him under an M.D.

C&EN has published a series of studies of the economic status of chemists and chemical engineers. Articles and editorials dealing with the professional status of chemists and calling attention to important developments are frequent, and studies are made of the supply and demand situation in the chemical profession.

A very important service supplied by the Society is its work in bringing together employers and prospective employees. In addition to the regular weekly pages in *C&EN* devoted to Employment Information, the Society maintains at its regular meetings, a clearing house where prospective employees register stating their abilities, and interviews with employers are arranged. In addition, some of the local sections maintain employment aids. A question in the Hancock questionnaire brought out that "The Society's job-placement activities are universally applauded by members as serving a vital function."

An important related activity is seeing that chemists and chemical engineers are properly placed in times of war and national emergency. In this, the ACS has always taken the lead. Back in World War I, when nobody in the Government appreciated the importance of technical and highly trained personnel, Dr. Parsons, Secretary of the ACS, did. He took the lead in setting up a survey to find out how many chemists the country possessed. To his surprise and delight, there were found to be as many as 17,000, and Dr. Parson's insistence on having them in positions where their training could be used to advantage, and his success in impressing on the government authorities the importance of chemistry in war, led to the formation of the Chemical Warfare Service (now, the Chemical Corps).

Chemical Manpower In World War II

In World War II the whole country—not only Washington—understood much better the important role of the scientists. (Could this be the result, at least in part, of persistent effort by a great scientific society?) The ACS cooperated with the National Resources Planning Board and the U. S. Civil Service Commission in the preparation of the National Roster of Scientific and Specialized Personnel. In innumerable ways the Society worked (and still works) for the proper treatment of chemists and chemical engineers, not only in their interest, but in the interest of the nation as a whole. For example, in January 1944, ACS President Midgley found it necessary to speak about the disastrous effects on production of war material by the indiscriminate drafting of chemists and chemical engineers. This pronouncement was given wide publicity in the national press. The prestige, and the success, of the ACS were so very great that the Society was found to be carrying the ball not only for its own chemists and chemical engineers but for *all* scientists.

Says Secretary Emery: "General public policies inevitably affect our profession. Seldom are those responsible able from their own experience to weigh the effect of proposals on science and technology. It must be the responsibility of the ACS to see that these are understood. This is one of the most important and burdensome assignments, one about which least is generally known.... However, it is gratifying to the ACS that government officials are turning to us for comments and advice with increasing frequency; that more and more opinions as expressed in editorial pages are considered officially; and that we are asked to carry out assignments in such areas either informally or by contracts. A few examples will show the nature of these matters but not the extent. At the request of the Chemical Corps, a large and strong committee is active in advising it regarding policies and technical matters. A Committee on Liaison with the Department of Defense was created at the request of the Army to be concerned



ACS Student affiliate chapters are active in 272 colleges and universities throughout the U. S. and its possessions

with all matters of mutual interest. The ACS was asked by the National Security Resources Board to develop a plan for proper use of scientific and technical manpower during mobilization and under wartime conditions. It is gratifying to note that some of our proposals (not all, as yet) are recommended for implementation." The role of the ACS, in matters where public policy affects the professional status of chemists, may not be spectacular, but it is one of constant watchfulness and should not be underestimated.

ACS and Education

The question of where chemists come from concerns the ACS. They come, of course, from colleges and universities all over the country, but the ACS is concerned that they shall be well trained; and this for two reasons, first, to advance generally the science and profession of chemistry, and second, because the ACS, as a professional society, has minimum requirements for membership, which include a college degree, or its equivalent, with specialization in chemistry or chemical engineering, and it is necessary to see that this college degree is good enough.

The ACS comes into contact with education through a number of its different activities. A whole division of the Society is devoted to chemical education, and publishes a journal on the subject. Two committees of the Society, the Committee on Professional Training and the Committee on Chemical Education, deal with it in different ways.

The Committee on Professional Training will, on request and without charge, make a careful examination of the type of instruction provided in the department of chemistry in any institution of learning. This is entirely independent of accreditation by any other body, and quite independent of the instruction provided in all other subjects. It has been reported, at times, to be considered something of a nuisance by college presidents, who say that they are subject to accreditation visits by so many different organisations. The heads of the departments concerned, however, take it very seriously. If they pass muster, and are placed on the ACS list, well and good; if not, then they can present an excellent case to the president for increased appropriations. Some 190 colleges and universities have been placed on the ACS list up to June 1951. Many well-known and large institutions are on this list, and also a number of smaller and much less known colleges, some of which have been found to be giving remarkably good instruction.

The Committee on Chemical Education, among its other activities, receives and considers applications for the formation of Student Affiliate chapters. Student affiliation offers a young man, or woman, before graduation, many of the advantages of membership in the ACS. Such a student does not, of course, receive voting or office-holding privileges, but for a very modest fee he receives *C&EN*, and he may subscribe at reduced rates to any of the other journals. He also, in anything like a lively and well-run chapter, has available for him an interesting and profitable series of meetings. Often the local section will cooperate with the student chapter by providing speakers, running competitions, organizing trips to local plants. The student affiliates may work on projects, sponsor radio programs, have social meetings, and also meetings at which the students themselves read papers.

In order to encourage young men and women to join their professional chemical organization at an early age and obtain the benefits which come from such association, the Society allows a one-third discount in dues for any senior or post-graduate student who is a member and who subscribes to one of the Society's publications.

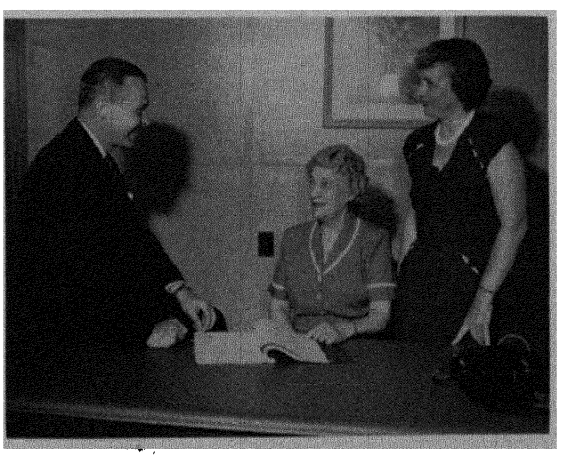
The ACS believes in "catching 'em young." The time to begin preparing for professional life is the time when the profession is being learned. Academic training is carried out well enough—certainly in colleges on the ACS approved list. Through its Student Affiliate Chapters the ACS not only sees to the academic training, but to the professional training, of the young chemists of this country, the chemists of the future.

What Else About the American Chemical Society?

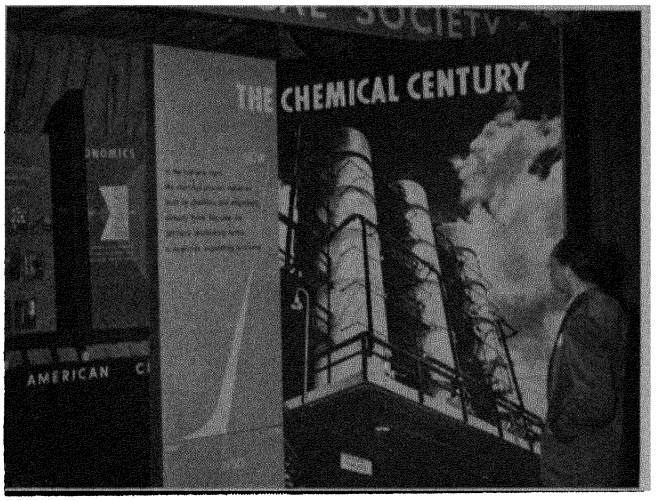
Plenty. But before "plenty" is described let us pause for a moment to dwell on organization—not the Society, but the machinery, so to speak, that makes the Society tick. A member seldom sees the men and women of the Executive Secretary's staff unless he visits the Washington headquarters and is given what is jocularly referred to as "the dollar tour." But it takes the able administrative abilities of Alden H. Emery, Assistant Secretaries George G. Taylor and Ronald M. Warren plus a staff of about 75 people to keep that complex molecule—the AMERICAN CHEMICAL SOCIETY from disintegrating. A professional juggler would pale at the number and variety of objects that the Executive Secretary must help to keep moving in an orderly fashion.

Some, of course, are pretty obvious, such as a Board of Directors, a Council, 20 scientific divisions, 138 local sections, the business side of a huge publishing venture, two national meetings a year, with one of these now the equivalent of two or three meetings as far as arrangements go, literally a hundred committees of one kind or another . . . some, such as the confidential conferences with high officials of government departments where Government is seeking the assistance of the Society, are not so obvious.

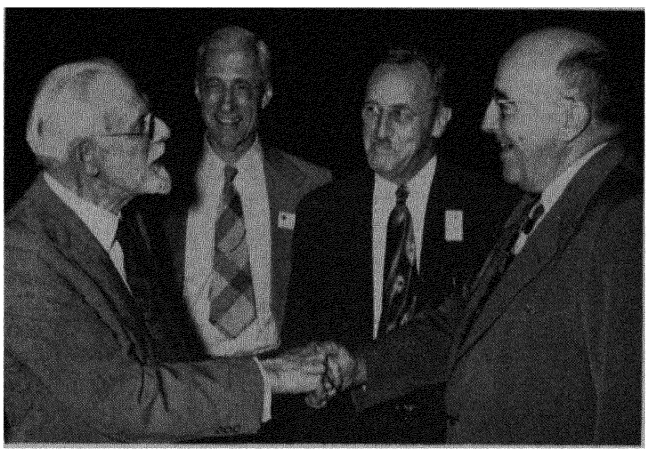
Take one at random—national meetings. When the 15,000 or more chemists and chemical engineers assemble in New York



ACS Committee on Professional Training includes John H. Howard, Bertha H. Goodrich, and Gertrude H. Homer



Award-winning exhibit of ACS at Sixth National Chemical Exposition, Chicago, 1950



Charles A. Kraus, Priestley medalist for 1950, receives congratulations from Joel Hildebrand, Roger Adams, and Robert E. Wilson



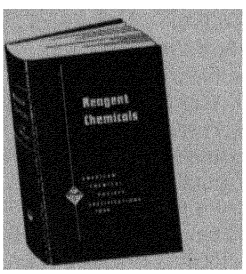
Chemists also have hobbies. An exhibit of paintings at National Chemical Exposition sponsored by the Chicago Section of ACS drew entries from many parts of the world

two weeks hence it would be nothing short of a mob scene except —well, except for a lot of top-notch planning for two years, plus practically faultless execution of duties on the part of more than a hundred individuals whose responsibilities will vary from marshaling the distinguished guests to providing on time, the lantern, the operator, pointer, blackboard, eraser, etc., etc., to the Division of Polymer Chemistry meeting in the New Yorker and the identical equipment to 19 more divisions meeting in perhaps a half a dozen other hotels scattered across the midriff of New York City.

While all this is going on and plenty more, there will be in process in some hotel the biggest employment operation in the city—the Employment Clearing House, which brings employer and employee together without charge to either. Why does it function so smoothly? The temporary employees have been trained for a week ahead by those of the Executive Secretary's office in charge of this activity.

To provide the ACS membership with an efficiently run meeting—one that the members are not conscious is being run because they are completely engrossed in doing what they want to do when they want to do it—takes precise direction and split-second timing usually associated with that which goes on under the "Big Top"—indeed, like Barnum and Bailey-Ringling Bros. The trucks must roll with a wide assortment of equipment before the "show" can go on.

And now back to "plenty." Some few other achievements and activities of the ACS may be taken at random. A quiet, but distinguished event is the publication this year of "Reagent Chemicals," culminating 30 years of effort on the part of some of America's foremost analysts, and giving standard specifications for no less than 177 reagents—with more to follow.



Witness the diversity of ACS operations by exploring such an activity of the Society as the Tour Speakers Service. A major portion of the speakers before the 139 local sections are what are technically known as "tour speakers." The Executive Secretary's office arranges for speakers who will cover sections in a given area. Some tours will cover just a few sections, others may be very extensive, a coast-to-coast proposition. The young lady who directs this particular activity almost literally can recite by heart the U. S. Railroad Guide and its counterpart for the airlines.

An advertiser wants to know how many consultants read *C&EN*. There is a department in the Executive Secretary's office that has such information. Some 25,000 address changes of members and subscribers were made last year and on the average just one week is needed to effect a change while most publishers require six weeks. That is efficiency.

A successful society must be an informed society. One way of dissemination of information is through pamphlets. The very titles serve to illustrate the variety of ACS activities: "It's Your Society," "Films on Chemical Subjects," "Handbook for Local Section Membership Committees," "Manual for Student Affiliate Chapters," "Information for Local Section Officers," and "Publicizing the Chemical Profession"—to mention just a few.

The number of services made available to members are many and varied—witness such a simple yet extremely useful thing as the Photocopying Service. Members of the Society may purchase coupons singly or in books of 10 and with them it is possible to obtain from one place microfilms and photoprints from almost any periodical available anywhere in the United States.

Photocopying Service is a service to the individual member. By virtue, however, of its federal charter, its extensive membership, and its prestige as a national organization, the Society must render services to the nation and its Government. The ACS has exerted an unusual degree of influence in national affairs affecting

chemistry, chemists, and chemical engineers. While it may not engage in any "lobbying" activity, its advice is often sought where pending legislation affecting the natural sciences is under consideration.

And to mention another, entirely different way in which the ACS encourages chemistry, there are the awards administered by the ACS (in addition to those administered by local sections), the ACS Award in Pure Chemistry, the Borden Award in the Chemistry of Milk, the Eli Lilly and Co. Award for young chemists working in biological chemistry, the Fisher Award in Analytical Chemistry, the Fritzsche Award for work in essential oils and related chemicals, the Garvan Medal for women chemists, the Ipatieff Prize for young chemists (under 40) the Paul-Lewis Laboratories Award in enzyme chemistry, the Precision Scientific Co. Award in petroleum chemistry, the Priestley Medal, to recognize distinguished services to chemistry, and the newly founded Scientific Apparatus Makers' Award in chemical education.

Yet again, there may be mentioned such activities as participation in the preparation of the International Table of Atomic Weights: cooperation in the development of better biological stains and their standardization; assembly and regular publication of data on hazardous chemicals and explosives in cooperation with National Fire Protection Association covering subjects such as photography, letter symbols and abbreviations, graphics, and sieves; provision at very low rates of microfilms and photoprints of any technical article published anywhere in the world; study of applicability to literature searching of new mechanical and electronic sorting devices; participation in the program of the American Documentation Institute; and aid to foreign projects of value to American chemists, such as Beilstein and Gmelin. And certainly not least, the AMERICAN CHEMICAL SOCIETY welcomes the foreign chemists who will visit us for the World Conclave which includes, besides the 75th Anniversary Meeting of the ACS, the International Union of Pure and Applied Chemistry and the International Congress of Pure and Applied Chemistry.

For the 100th Anniversary of the ACS—and 200th of the Declaration of Independence—some writer probably will imagine an old-timer transported by time machine to 1976. To facilitate his task, in view of the gigantic changes in the third quarter of the 20th century, he will probably pick an old-timer from not so very long ago—quite possibly from 1951—who will reminisce about the leisurely state of affairs in that year: when there were only about 25 types of synthetic fiber that had reached even pilot plant stage, and wool was still obtained from sheep: when we spoke about "natural rubber" and "synthetic rubber" and gravely made comparisons between the two; when rocket fuel chemists were playing around with firework stuff; when structural metals were limited to a bare handful from the periodic table, aluminum was painfully extracted from bauxite, magnesium had recently arrived, and a few new, exciting metals were waiting just around the corner; when petroleum chemists had just begun to realize that pretty nearly the whole of Beilstein can be made, if required, from petroleum, or else from natural gas; when putting in a double bond, and an oxygen, taking out a side chain or two, and making a few other structural changes in a sterol system, to make cortisone, was a matter of the utmost difficulty and technical skill; when dye chemists plodded along with structural formulas little changed since the original work of the German chemists; when an insecticide a little more potent, or more selective, than DDT was news; when efficient weed killers had just begun to appear; when routine analytical determinations sometimes took many hours; when thousands of compounds had to be tested to find a medium-good antimalarial; when corrosion-resistant materials for many purposes were hard to find; when fluorine was new and exciting; when an unbreakable bottle was a novelty; when wood pulp and other factories actually discharged "waste" into rivers and chemical factories contributed to smog; when the numeral designations of U.S. patents were still in seven figures and the ACS had only 66,000 members . . . what will this chemist think of the chemistry of 1976?

Many of us present at the 75th Anniversary of the AMERICAN CHEMICAL SOCIETY will only have to wait to know the answer.



Chemical Progress

DURING THE 75 YEARS OF THE AMERICAN CHEMICAL SOCIETY

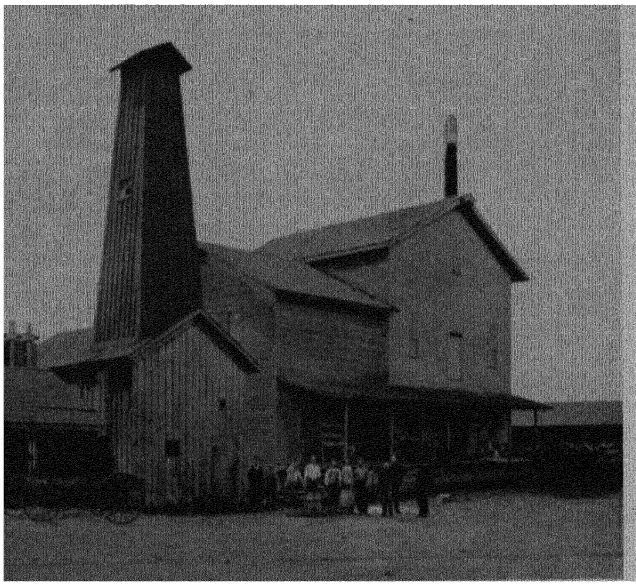
A series of papers in which the development of chemical science and its industrial applications over the past 75 years are reviewed. These papers, originally published in *Industrial and Engineering Chemistry*, February through June 1951, were prepared by historians appointed by the respective divisions of the American Chemical Society. Significantly, the men appointed have all been long active in ACS affairs—men who, in some instances, have been key figures in their divisions since the very beginning.

The scope of each paper includes a discussion of the part the American Chemical Society and its divisions have contributed to the advancement of chemical knowledge and skill. Throughout the series, the sequence in which the histories of chemistry's various branches are presented follows approximately the chronological order in which the respective divisions were established.

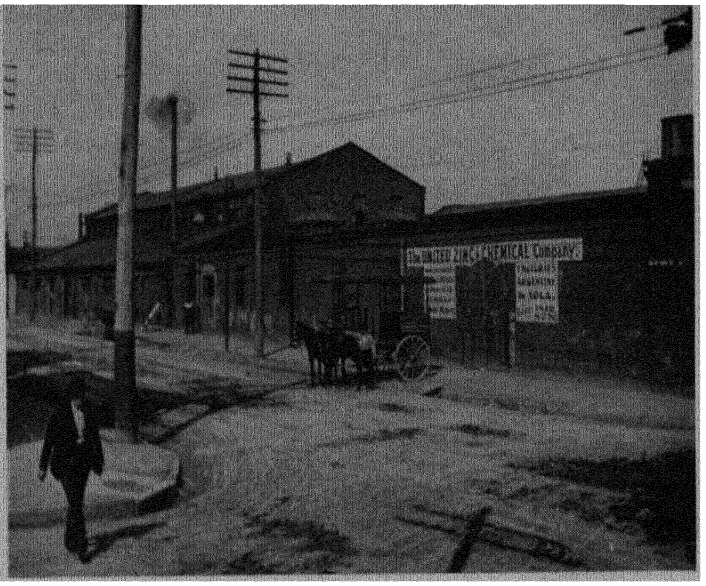
The panoramic survey here unfolded reveals such impressive advances in the development of our science, our industries, and our Society that we believe readers will join with the editors in echoing the statement made by Sir Humphry Davy a century and a half ago: "I hardly know which we ought most to rejoice at—the progress that has been made in natural knowledge or the progress that is to come."

aiding the development of our country's industries

. . . OBJECTS OF THE AMERICAN CHEMICAL SOCIETY



Here at Midland, Herbert Dow first tested his process for recovering bromides from Michigan brines



In 1901, horse and wagon was the only rolling stock of J. F. Queeny, founder of Monsanto Chemical

Physical and inorganic are among the major pillars supporting the entire structure of chemistry

Physical and

L. F. AUDRIETH and
FARRINGTON DANIELS

INORGANIC CHEMISTRY

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THE past quarter century has witnessed the transition of inorganic chemistry from an almost purely descriptive subject to one in which all modern developments of chemistry and physics have found application. This trend, in itself, has made it more difficult to differentiate between inorganic and physical and analytical chemistry, especially since inorganic chemistry furnishes the fundamental body of facts and descriptive material for all branches of chemistry, with the possible exception of carbon chemistry.

The intimate relationship among inorganic chemistry, analytical chemistry, and physical chemistry has long been recognized. These branches of chemical science were not specifically differentiated within the AMERICAN CHEMICAL SOCIETY until recently. The original Division of Physical and Inorganic Chemistry (which included Analytical Chemistry) was established in 1908 and existed as a unit until 1940, when a separate Division of Analytical Chemistry was established. A survey of papers presented at meetings of the AMERICAN CHEMICAL SOCIETY demonstrates, however, that such segregation into specialized subdivisions is largely a matter of circumstance rather than evidence of any real difference among these three branches. The very fact that so many symposia are now conducted at meetings of the AMERICAN CHEMICAL SOCIETY under the joint sponsorship of various divisions is further evidence that such segregation is well-nigh impossible. The trend toward specialization has brought with it the realization that no branch of chemistry is sufficient unto itself and that coordinated effort is more important today in the solution of the problems of chemistry than ever before.

It is unfortunate in many respects that inorganic chemistry has been confused with general chemistry. Actually, general chemistry makes use of the facts of inorganic chemistry in order to develop those generalizations which apply to all of chemistry. Reference is made to this misconception, for it has served to obscure the really great advances in inorganic chemistry in the technological fields. Inorganic chemical technology, metallurgy, and ceramics represent applied fields in which descriptive inorganic chemistry together with analytical and physical chemistry are employed to make possible the production of those commodities which have made chemical science so indispensable to modern living and have made the chemical industry so important a part of our national economy. The body of fact and theory which comprises inorganic, analytical, and physical chemistry is fundamental in chemical engineering, metallurgy, and ceramics, and in such borderline fields as mineralogy, geochemistry, and nucleonics. Yes, even the organic chemical industry depends only in part upon carbon compounds, as is evident from the frequent reference to the fact that air, water, limestone, salt, and coal are its basic raw materials!

It will be impossible to name all workers in the field of inorganic chemistry, especially those whose contributions have been

made during the past 25 years. Accomplishments in the immediate past are difficult to evaluate in terms of their influence on present-day and future developments. Scientific achievements are today rarely the result of individual effort, either in the universities or in industry; research teams have facilitated the more rapid accumulation of factual knowledge and the development of theoretical concepts. Perhaps it would be best to consider scientific progress as a product of the era, rather than a product of the individuals whose names may fortuitously be connected with specific accomplishments. There is no question but that, given the same background of information upon which to build and recognizing the need for the solution of a specific problem—and having at hand essentially the same physical means for attacking a problem—many will arrive at the same answer through the application of the scientific method!

Inorganic Chemistry Before 1900

In presenting a survey of inorganic chemistry since the founding of the AMERICAN CHEMICAL SOCIETY, it is interesting to note that a number of important lines of research and industrial activity were initiated during the period before 1900. These pioneer efforts are discussed first, because they can be shown to have had a marked influence on future trends. The more recent contributions of inorganic chemistry to the advancement of chemical science and to our everyday living as individuals and as a nation

Inorganic Chemistry

are then presented in topical form. The record, even though brief and incomplete, is an impressive one.

The opportunities offered by the vast and then-unexplored mineral resources of the United States served to attract many of the early American inorganic chemists to a study of the composition and structure of minerals and to problems involving the extraction of metal values from them. Even foreign scientists recognized opportunities in the field of mineral chemistry. According to Edgar Fahs Smith, it was Emil Fischer who urged one of his American students to devote himself "to the inorganic field; the great mineral wealth of your country offers magnificent opportunities for research, bound to be of value both from the standpoint of pure science and that of industrial developments."

Frederick Augustus Genth (1820–93), J. Lawrence Smith (1818–83), T. Sterry Hunt (1826–92), William Francis Hillebrand (1853–1925), and Frank Wigglesworth Clarke (1847–1931), all of whom were recognized as outstanding scientists by their election to the presidency of the AMERICAN CHEMICAL SOCIETY, achieved prominence for their work in mineral chemistry. Each one can be acclaimed as a pioneer in the field of inorganic chemistry or analytical chemistry, or as an outstanding mineralogist and geologist. Each was an individual whose success was the result of his own personal effort; only a few "students" were available to aid them in their investigations.

Frederick A. Genth studied the alteration of corundum and determined the composition of vanadinite and other rare minerals. J. Lawrence Smith subjected samarskite and various rare earth minerals to careful analysis and made important contributions to the analytical chemistry of tantalum, niobium, titanium, molybdenum, and tungsten. He was also an authority on meteorites and devoted much effort to the determination of their chemical composition. The J. Lawrence Smith method for the determination of the alkali metal content of silicates is still used today.

T. Sterry Hunt, another past president of the ACS, was the first to propose that charcoal, graphite, and diamond could be regarded as polymorphic forms of elemental carbon. Hunt was impressed by the fact that the physical properties and reactivities of organic compounds differing by successive CH_2 increments varied in a regular fashion. He suggested that similar changes in the composition of minerals might be responsible for observed variations in properties. He even went so far as to make the assumption that the molecular weights of such substances must be very much higher than those admitted for the hydrocarbons and their derivatives and proposed that minerals consist of highly polymeric aggregates.

William F. Hillebrand had studied under Bunsen and at the Freiburg Mining Academy. His work on the "Analysis of Silicate and Carbonate Rocks" is considered to be one of his outstanding scientific contributions. Hillebrand was an analyst par excellence. He later became chief chemist of the Bureau of Standards (1908), where his influence continued to be felt throughout his long period of service in that very important position.

Frank Wigglesworth Clarke, like his illustrious contemporaries, emphasized continually the importance of analysis in mineral chemistry. Clarke may be regarded as the father of geochemistry in this country; he not only determined the chemical composition of many minerals, but from such data developed rational theories to account for the genesis of ore bodies and minerals and traced the alterations which these minerals had undergone in nature. His outstanding text, "Data of Geochemistry," is still a classic in its field.

Clarke compiled one of the first authoritative tables of atomic weights; it was published in the *American Chemical Journal* in 1881–82 and listed some 65 different elements.

The researches of Wolcott Gibbs (1822–1908), Rumford professor of chemistry at Harvard University, on the complex iso- and heteropoly acids, influenced profoundly the thinking and experimental activities of the early mineral chemists. Wolcott Gibbs began his researches in the late 70's. For more than 20 years, he labored unceasingly in characterizing and preparing salts of the complex acids of tungsten and molybdenum and of related heteropoly acids containing arsenic, antimony, and phosphorus.

Edgar Fahs Smith added to the list of oxides which could enter into combination to form heteropoly acids those oxides derived from tantalum, niobium, and the rare earths. However, his contributions extended far beyond this field. Like all the early workers in inorganic chemistry, Edgar Fahs Smith was a careful and thorough analyst. Many of the early atomic weight values were determined by him. He was also one of the pioneers in electro-inorganic analysis.

Interest in the complexity of naturally occurring substances in the mineral kingdom was paralleled by related work on complex compounds of the double halide type. Ira Remsen was attracted by the fact that many "double salts" actually broke up into their constituents in aqueous solution, whereas some so-called double halides, notably the chloroplatinates and the fluosilicates, appeared to be stable. A complete survey of such double halides was made by H. L. Wells and constituted a valuable starting point for all future investigators. James Lewis Howe says about the early work of Remsen, Wells, and Gibbs:

"The work of Remsen, and more particularly that of Wells, laid the foundations and furnishes no inconsiderable portion of the material used by Werner in developing his coordination theory, while the work of Gibbs led to that of A. Rosenheim in the application of Werner's theory to the tungstic and molybdic acid complexes."

The chemistry of the rare earths received considerable attention before the turn of the century. The oxalate method for the separation of the rare earths was first suggested by J. Lawrence Smith. Wolcott Gibbs proposed the method for the determination of average atomic weights of rare earth mixtures from the oxide-oxalate ratio. Cerium was subjected to thorough study by T. H. Norton. Welsbach mantles had come into common use, and large quantities of by-product rare earths were available for use and study. Other pioneer efforts in inorganic chemistry were also being brought to the attention of the chemical public through the medium of the AMERICAN CHEMICAL SOCIETY'S publications.

H. N. Stokes published some outstanding papers on the nitrogen derivatives of the phosphoric acids and the phosphonitrilic chlorides. L. M. Dennis had returned from Europe to begin his investigations on hydrazoic acid and related nitrogen compounds, thus beginning a tradition for research in nitrogen chemistry which was to place the laboratory at Cornell University in a leading position for work in this field. E. C. Franklin and C. A. Kraus (with H. P. Cady) had initiated their work on reactions in liquid ammonia at the University of Kansas, and laid the foundation for some of the most important advances in theoretical and descriptive chemistry, both inorganic and organic. Atomic weight determinations, with attendant emphasis on precise analytical methods, had been undertaken by Josiah P. Cooke, whose efforts were to be reflected in continuing activity in this field by T. W. Richards, and later by G. P. Baxter. E. W. Morley had determined directly the combining ratio of hydrogen with oxygen. W. A. Noyes was shortly thereafter to redetermine this same value, using an indirect experimental approach.

But even more important were the evidences of American engineering genius in developing new metallurgical and chemical processes and in taking advantage of the tremendous resources in fuel, power, and raw materials. The electrolytic process for production of aluminum had been discovered by Hall at Oberlin and made this widely distributed element, a precious metal prior to that time, a readily available and useful material of construction. The alkali-chlorine industry had been established at Niagara Falls and had directed attention to the possibilities of using electrical energy for the production of a wide variety of inorganic chemicals derivable from sodium chloride. The Solvay process for preparation of soda ash had supplanted the older LeBlanc process. Sulfuric acid was being produced from pyrites using the lead chamber process. Phosphatic fertilizers were being produced, although potash and nitrogenous materials, if used at all, were being imported from foreign sources. Glassmaking was still an art.

A young student at Case, Herbert H. Dow, had examined the composition of brines associated with petroleum and had turned his attention to the extraction of bromine from them. He had patented a process for removing the bromine by blowing air through the reaction liquor. From this idea was born a great industry which was the first to use sea water as an important raw material and was later expanded to the production of metallic magnesium (1916).

The American chemical industry and related metallurgical and ceramic industries had at last been established. Yet all American technology was complacent to the extent that no pressures had been applied to bring it into a competitive position with the European industry. Furthermore, it is an undisputed fact that European producers made definite efforts to prevent such competition from developing. The 20th century was ushered in with the promise of continued normal development; it was not suspected that two great world wars would be necessary to spur the American chemical industry toward self-sufficiency, within the realm of available resources, as a national defense measure. However, as is now well known, that is what actually happened during the past 50 years.

The Metallic Elements

The Rare Earth Elements. Reference has been made to the pioneer efforts of mineral chemists in the study of the composition of rare earth minerals. The separation of the individual members of the rare earth group constituted a real challenge to the inorganic chemist and, even today, still offers opportunities for real accomplishment. Many of those who began work in this field soon after the beginning of the 20th century combined their interest in the rare earth elements with an interest in rare metals generally. Outstanding is the work of Charles James who separated the yttrium earths by the fractional crystallization of bromates and was the first to prepare a pure thulium compound. Victor Lenher devoted himself first to rare earth chemistry, but later turned his attention to the chemistry of selenium and tellurium. L. M. Dennis undertook to separate the rare earths by an electrolytic procedure, but later became interested in the chemistry of germanium.

The researches of C. W. Balke initiated the continuing efforts in the chemistry of the rarer metals at the University of Illinois. Work in the rare earth field was continued by Balke's successor, B Smith Hopkins, and led in 1925 to the announcement of the discovery of the last of the missing rare earth elements, No. 61, which was named illinium. The chemical and spectroscopic evidence seemed straightforward, but attempts to concentrate this elusive material were unsuccessful. During the course of these studies, however, a substantial supply of pure rare earth compounds was accumulated; new methods of concentration were developed and evaluated; rare earth metal amalgams and anhydrous halides were prepared by new procedures. Atomic weights of several rare earths were redetermined. Work in the rare earth field is today being continued at Illinois by G. Therald Moeller.

Among the outstanding present-day authorities on rare metals are H. E. Kremers (rare earth metals and alloys, but more recently distinguished by success in the growing of large single crystals from the fused state), Edward Wichers (platinum metals at the Bureau of Standards), L. F. Yntema (who developed the method for separation of europium and ytterbium from the other rare earths by electrolytic reduction of the trivalent ions to the divalent state), F. H. Driggs (production of metallic thorium and uranium by fused electrolysis), P. W. Selwood (who first proposed that a liquid-liquid extraction procedure be employed for the concentration and separation of the rare earths, but has since become the leading authority on magnetochemistry, especially in the application of this technique to the study of the structure of catalysts and surfaces), L. L. Quill (who with Pool demonstrated that the bombardment of neodymium in the cyclotron produces an isotope of element 61 and proposed that the element be named cyclonium), and D. W. Pearce (who appears to have been the first to attempt separation of rare earths by the ion exchange technique).

One can only marvel at the patience and fortitude of the investigators who carried out rare earth separations by laborious fractional crystallization procedures. Hundreds and even thousands of fractionations were sometimes necessary to approach the chemical and spectroscopic purity that was essential to a study of the chemistry of the individual elements. This method might still be the only procedure (except for those few instances in which the elements were found to exist in different valence states), had it not been for the emphasis on rare earth research by the discovery that these elements are among the principal fission products of uranium and plutonium. Groups of

scientists working under the direction of G. E. Boyd at the Oak Ridge Laboratories, and later with F. H. Spedding at the Ames Laboratory at Iowa State College, succeeded in effecting separations by using newly developed synthetic organic exchange resins. Their work was disclosed at the Symposium on Ion Exchange Separations held in connection with the September 1947 meeting of the AMERICAN CHEMICAL SOCIETY.

The Oak Ridge work led also to the separation and positive identification of a radioactive isotope of element 61 by J. A. Marinsky and L. E. Glendenin. The element was officially given the name promethium.

The Transuranium Elements. The synthesis of six transuranium elements by nuclear reactions and the study of the chemical properties of these elements have become a major activity in numerous government-sponsored laboratories, where hundreds of chemists and physicists are making a concerted attack on one of the most recently discovered frontiers of science. New techniques for handling these radioactive elements have been developed. Every scientific tool available to man has been pressed into service. The inorganic chemist made his greatest contributions in preparing materials of highest purity—for instance, uranium compounds—in the extraction of such materials from the naturally occurring mineral sources, in metallurgical procedures designed to yield various metals in pure form suitable for use in the atomic reactors, in the production of moderators of highest purity, and in the separation of fission products.

Discovery of the Transuranium Elements

Name	Symbol	Atomic No.	Discoverers
Neptunium	Np	93	McMillan and Abelson
Plutonium	Pu	94	Seaborg, McMillan, Wahl, and Kennedy
Americium	Am	95	Seaborg, James, and Morgan
Curium	Cm	96	Seaborg, James, and Ghiorso
Berkelium	Bk	97	Thompson, Ghiorso, and Seaborg
Californium	Cf	98	Thompson, Street, Ghiorso, and Seaborg

Other Rare Elements. Other "rarer elements" have also been the subject of outstanding achievement on the part of American chemists. The early efforts of F. P. Venable on the chemistry of zirconium and of C. L. Parsons, a guiding figure in the activities of the AMERICAN CHEMICAL SOCIETY for almost 40 years, in directing attention to the interesting properties of beryllium and its compounds, have borne fruit in the technological developments which have made these elements and their compounds useful articles of commerce. To C. W. Balke must be given credit for introducing tantalum and niobium to the industrial world. The production of tantalum as a powder by electrolysis of fluoride melts and its subsequent fabrication into sheet, tube, and massive form following the methods used for tungsten and molybdenum, contributed significantly to the further development of processes of powder metallurgy for the fabrication of new and unusual alloys of the common metals.

The discovery of germanium dioxide in certain zinc ore residues obtained from the Franklin Furnace, N. J., mines, led L. M. Dennis to undertake a thorough investigation of the preparation and chemical properties of germanium and its compounds. This work has resulted in the recent discovery of very interesting electrical properties of the metal. Research covering the chemistry of germanium, as well as of silicon and boron, has been continued at Cornell by A. W. Laubengayer and his students.

Many of the rarer metals have become commercially available in limited quantities. Indium can be electrodeposited from solution. Gallium has been isolated from bauxite ore residues. Most significant, however, is the production of titanium in the massive state as a light, strong, corrosion-resistant element. Titanium may well be the wonder metal of the future. Conventional metallurgical procedures had failed to yield it. However, now it is obtained from titanium chloride by reaction with magnesium. If the history of aluminum is any guide, imagine what the future holds for its sister element, titanium!

More Common Elements. Numerous processes for the production of metals have been discovered and many of these methods commercialized in America. Reference has already been made to the production of aluminum, tantalum, niobium, indium, and gallium. Magnesium was first produced in this country in 1916 by utilizing the magnesium-containing brines at Midland, Mich. The need for tremendous quantities of magnesium to supply war needs caused the erection of a huge plant at Freeport, Tex., employing sea water as the source of raw material. The Downs cell for production of sodium, by electrolysis of a mixture of sodium chloride and melting point depressants, such as calcium chloride, superseded the older Castner process. This electrochemical development made sodium available in substantial quantities for use as a powerful chemical and metallurgical reducing agent, for the expanded production of the cyanide and peroxide, and contributed to the development of the oxide and hydride as valuable new inorganic chemicals.

Hydrogen and Hydrides

The isolation and characterization of deuterium by H. C. Urey and coworkers stimulated contemporary studies of the concentration of deuterium oxide, the preparation of both organic and inorganic deutero compounds, and the exchange reactions between hydrogen compounds and both deuterium and heavy water. Use of biologically active deutero compounds in a study of metabolic processes represented pioneer attempts to employ "tagged" atoms in such investigations.

L. M. Dennis first prepared the simpler hydrides of germanium by use of the Stock procedure. W. C. Johnson developed a greatly improved method (applicable also to silicon), involving the reaction between the magnesium alloys and ammonium salts dissolved in liquid ammonia. Johnson used a similar method to prepare arsine; he also succeeded in effecting the alkylation of arsine, using ammonia as the solvent. Hydrides of lithium and calcium are now commercially available and are finding application as metallurgical reducing agents, hydrogen sources, and chemical intermediates.

The investigations of H. I. Schlesinger and his students (among them, H. C. Brown and N. Davidson) on the preparation and properties of the boranes and their derivatives are outstanding. The continuing researches at the University of Chicago have led to the preparation of such compounds as the borohydrides and the aluminohydrides, some of which are now commercially available. Their use as powerful reducing agents has opened up a whole new approach to organometallic chemistry. Chemical reactions of the hydrides of boron are being studied in particular by A. B. Burg and his students. The structure of the boron hydrides is still a puzzling problem. The protonated double-bond theory of K. S. Pitzer, together with electron diffraction studies by S. H. Bauer, represents the most recent contributions in this field. The boranes and the metallohydrides have also been proposed for use as specialty fuels and as hydrogen sources.

The Nonmetallic Elements

Oxygen, Oxides, and Hydrous Oxides. The commercial availability of liquid oxygen has already led to improvements in the metallurgy of iron, in oxygen's further use in permissible explosives, and in specialty fuel combinations. The early studies by O. Maass on highly concentrated hydrogen peroxide represent fundamental contributions which led eventually to the production of this chemical on a substantial scale. The 90% product containing no stabilizer is now shipped in pure aluminum drums. W. C. Schumb and coworkers studied the decomposition kinetics of the concentrated material. It may be anticipated that per-

oxides, peroxy compounds, and salts of peroxy acids will be subjected to more extensive investigation and evaluation.

The fundamental work of H. B. Weiser and W. O. Milligan on the colloidal character and structure of the hydrous oxides and hydroxides of the elements represents a borderline physicochemical approach to such systems. The early studies of various hydrated (or hydrous) oxide gels, especially silica gel (W. A. Patrick, T. H. Norton, V. Lenher), paved the way for use of these materials as catalysts, mixed oxide catalysts, catalyst supports, adsorbents, and ion exchange agents.

Knowledge concerning the behavior of oxide systems at higher temperatures is of vital importance in the manufacture of glass, abrasives, and refractories. The work of W. A. Weyl, A. Silverman, and K. Fajans in using structural and theoretical approaches to define the behavior of oxide systems is especially significant.

Liquid Ammonia and Nitrogen Chemistry. The investigations begun by E. C. Franklin and C. A. Kraus at the turn of the century on the behavior of liquid ammonia as a solvent had a profound effect on the development of inorganic and theoretical chemistry. Their researches directed attention to the use of nonaqueous solvents as media for chemical reactions and influenced markedly the development of concepts dealing with acid-base relationships. In proposing a "nitrogen system of compounds" based upon ammonia as the parent solvent, Franklin made possible systematic organization of the chemistry of both inorganic and organic nitrogen derivatives.

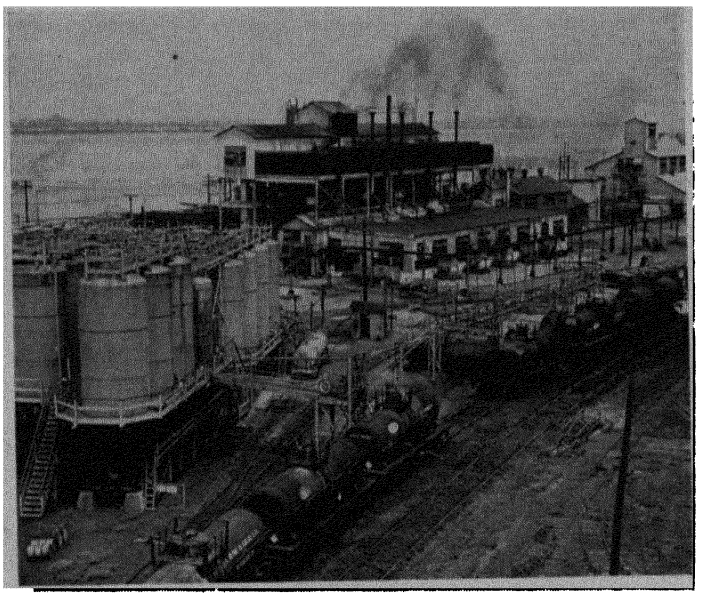
Franklin and his students devoted most of their experimental efforts to a study of chemical reactions in liquid ammonia. Synthetic procedures leading to ammono compounds were shown to involve reactions of ammonolysis and ammonation, strictly analogous to those of hydrolysis and hydration. Metallic amides were shown to be bases in liquid ammonia; ammonium salts, to behave as acids. Kraus investigated solutions of the alkali metals in liquid ammonia, and as early as 1907 advanced the solvated electron theory to account for the physical and chemical properties of such metal-ammonia solutions. Studies of reactions of the alkali and alkaline earth metal solutions with various metallic ions to yield metals, alloy phases, or polyanionic complexes have brought to light some of the most striking reactions in the whole field of chemistry. Kraus was also the first to make use of liquid ammonia to synthesize organometallic compounds.

Use of liquid ammonia as a solvent for reactions involving ammonolysis, electrolysis, reduction, metathesis, and synthesis has been the subject of investigations by F. W. Bergstrom, A. W. Browne, W. C. Johnson, W. C. Fernelius, L. F. Audrieth, C. B. Wooster, G. W. Watt, G. B. L. Smith, H. S. Booth, J. Kleinberg, and H. Sisler. So great was the amount of published work on liquid ammonia chemistry over the years following the first comprehensive treatment of the subject by Fernelius and Johnson in the *Journal of Chemical Education* (1928–30) that annual reviews later appeared in this same publication from 1933 to 1940, prepared by G. W. Watt and collaborators. Special phases of liquid ammonia chemistry were also subjected to comprehensive treatment in articles published in *Chemical Reviews*, especially by W. C. Fernelius (ammonolysis, alkali amides), F. W. Bergstrom (heterocyclic nitrogen compounds), and G. W. Watt (reductions by metal-ammonia solutions).

Study of nitrogen compounds was stimulated markedly by experimental confirmation of the analogies set up by Franklin. A. W. Browne was specifically interested in the hydronitrogens and, with his students, undertook investigation of hydrazoic acid and the azides, the azidodithiocarbonates and hydrazine. Browne's early work dealing with the preparation of hydrazine by ammonolysis of the sulfate, and his studies on the oxidation of hydrazine and on hydrazine as a solvent, together with the researches of F. C. Gilbert on the thermodynamic properties of hydrazine and its compounds and on the autoxidation of hydrazine, are of special interest at the present time because of the possible use of this hydronitrogen as a specialty fuel.

Attention has also been given to the ammono derivatives of sulfuric and phosphoric acids, whose systematic study has been undertaken principally by Audrieth and his students. Sulfamic acid, NH_2SO_3H (Du Pont), and its salts are now widely employed; potentialities of other sulfur-nitrogen compounds such as sulfamide are recognized. Among the phosphorus-nitrogen compounds worthy of special mention are the phosphonitrilic chlorides, $(PNCl_2)_x$, which exist in a variety of polymeric forms. These polymerize still further on heating to give the "inorganic rubber," a typical elastomer.

Phosphorus and Sulfur. The significant advances in the chemistry of these two elements have been made by the inorganic chemical industry. The first electric furnace for the production of elemental phosphorus was set up at Niagara Falls in 1904 (Oldbury). Since that time, the production of phosphorus has become a major industry, the element being used for the manufacture of phosphorus pentoxide, phosphorus tri- and pentachlorides, and phosphorus sulfides. However, the phosphatic fertilizer industry had already enjoyed phenomenal growth by the turn of the century and even today on a tonnage basis represents one of the largest and most important chemical operations.



The nitric acid installation at the Repauno plant of E. I. du Pont de Nemours & Co., Inc.

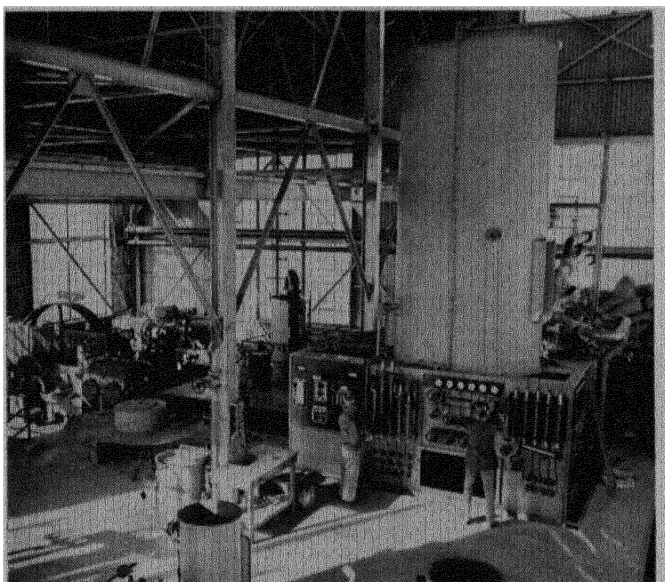
R. E. Hall's discovery in 1932 that the glassy metaphosphate can be used to prevent formation of boiler scale gave added impetus to the development of the poly- and metaphosphates. Pyro- and triphosphates are now widely employed in soap and detergent compositions. It is only recently that some consideration has been given to the mechanism of formation of poly- and metaphosphates from the simple hydrogen orthophosphates. Structural concepts have been used to show how the polymerization of simple phosphate tetrahedra leads to ring, chain, and polymeric metaphosphate aggregates. The work of E. P. Partridge and his associates of the Hall Laboratories has done much to make knowledge more generally available in this complex field. Significant also are the contributions of R. N. Bell and associates (Victor Chemical Works Laboratories) in demonstrating that the strong phosphoric acids are mixtures of various poly- and metaphosphoric acids.

Solutions of the metaphosphate glasses have recently been studied by J. R. Van Wazer, who succeeded in fractionating such systems to separate the polymeric aggregates. The ionic-molecular weights of particles in such polymetaphosphate solutions average between 10,000 and 20,000; the various fractions range

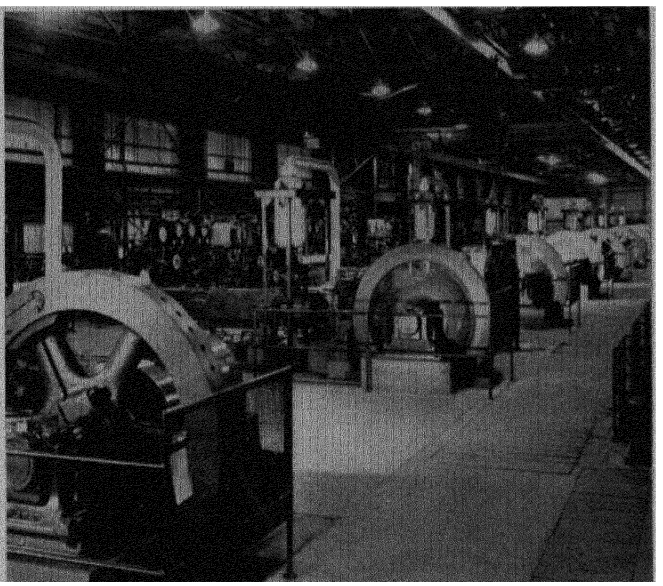
from simple trimetaphosphate units to aggregates whose average ionic-molecular weight exceeds 50,000.

The development by Herman Frasch of a simple process for making available the tremendous gulf sulfur deposits very markedly influenced the development of the chemistry of sulfur compounds, specifically the production of sulfuric acid—first by the lead chamber process and later by the more modern catalytic processes. Sulfuric acid must still be considered our most important chemical commodity. Of outstanding interest is the development of stabilized sulfur trioxide under the trade name Sulfan (General Chemical Division, Allied Chemical and Dye Corp.).

Sulfur dioxide is potentially available in tremendous quantity. Its use as an extractive solvent and as a solvent medium has been the subject of intensive investigation in industrial laboratories.



Here oxygen is extracted from the air at —305° F. Operators are at controls of rectification column



Circulators and panel boards at the ammonia plant of Spencer Chemical Co.

The fascinating possibility of producing mixed inorganic-organic polymers by the sulfur dioxide–olefin reaction has been subjected to fundamental study by C. S. Marvel and coworkers.

Many of the simpler sulfur compounds, such as sulfur chloride, thionyl chloride, sulfuryl chloride, the metallic sulfides, and the polysulfides, have found wide industrial application. Again, inorganic chemical technology is chiefly responsible for the production of these materials on a substantial scale and for our knowledge concerning their properties and uses.

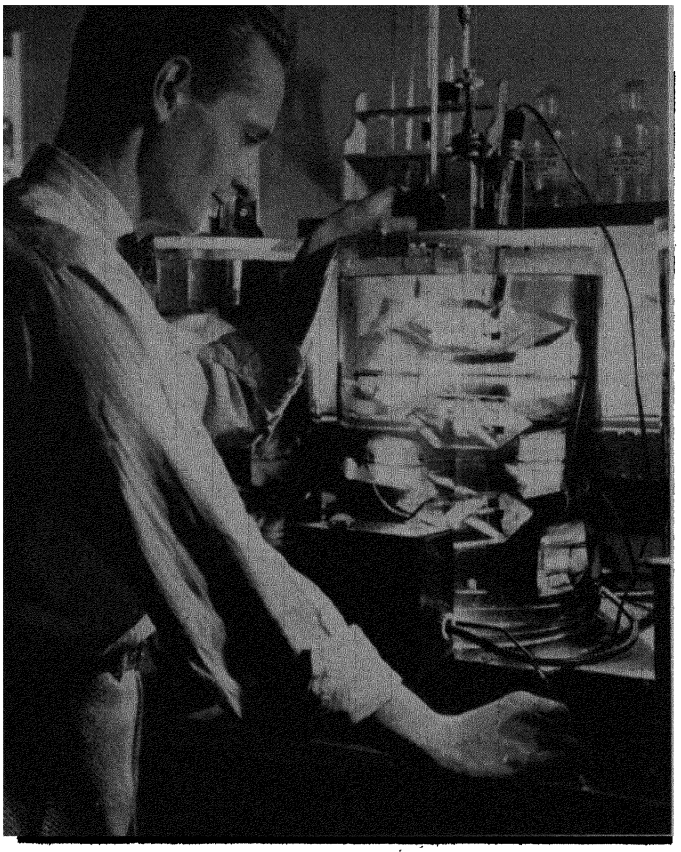
The Halogens. Significant contributions have been made in developing technologically the chemistry of the halogens and their compounds. Early interest was manifested in the development of cells for the production of fluorine from various potassium fluoride–hydrogen fluoride mixtures, representing operations at low, medium, or high temperatures (L. M. Dennis, G. H. Cady, W. C. Schumb, J. H. Simons, and others). Laboratory and commercial cells for the generation of gaseous fluorine are now obtainable; elemental fluorine is available in cylinders. Use of elemental fluorine for the preparation of fluorides has been studied by Schumb and coworkers. H. S. Booth and his students have used the Swarts reaction (fluorination with antimony trichloride–antimony pentachloride) for the preparation of nonpolar fluorides and mixed halofluorides of phosphorus, silicon, germanium, and sulfur. Cady had prepared such unusual compounds as FNO_3 and $FClO_4$. Willy Lange has continued work on the characterization of mono-, di-, and hexafluophosphoric acids and their salts. H. S. Booth, D. R. Martin, H. C. Brown, and A. W. Laubengayer have made important contributions to the chemistry of boron trifluoride and its coordination compounds.

J. H. Simons and coworkers have studied reactions in anhydrous hydrogen fluoride. A significant development is the electrolytic fluorination of many types of organic compounds in anhydrous hydrogen fluoride—a process which is now in the pilot plant stage. The work of A. F. Clifford in applying the Lewis concept to acid-base relationships in anhydrous hydrogen fluoride represents an outstanding fundamental contribution.

Production of electrolytic chlorine has been supplemented by nonelectrolytic chlorine processes, especially the nitrosyl chloride process (Solvay), involving the interaction of nitric acid and sodium chloride. American accomplishments in the alkali-chlorine industry have included the development of distinctive cells (Vorce, Hooker, and Nelson) and their modifications for the production of electrolytic bleach, chlorates, and perchlorates. Particular reference is made to the original studies of G. Frederick Smith, which led to the commercial production of perchloric acid and to use of various perchlorates as drying agents. Both sodium chlorite and chlorine dioxide are now available for a variety of industrial uses (Mathieson Chemical Corp.).

Need for more bromine led to the erection of a plant in 1930 at Wilmington, N. C., for bromine extraction from sea water, using a process based in part upon the original Dow patent. Recovery of iodine from certain California oil well brines has made the nation independent of foreign sources.

The coordinate bond, involving the interaction of an electron pair donor with an electron pair acceptor, is now recognized as the basis for many chemical phenomena, notably those which lead to the formation of solvates and complex ions in general. Reference has already been made to the early researches of Wolcott Gibbs and E. F. Smith on the iso- and heteropoly acids and of Remsen and Wells on the complex halo-metallates. T. W. Richards and D. W. Horn investigated the stability of copper(II) ammines; D. W. Harkins became interested in the preparation and properties of a variety of cobalt(III) complexes. H. I. Schlesinger prepared the complex fluorides of the platinum group elements. More interest was manifested subsequently in the physicochemical behavior of complex ions, especially by A. B. Lamb and his students, who determined the base strengths of a large number of cobalt ammine hydroxides and the acid



Synthetic crystals used in electronic equipment are grown at the Bell Telephone Laboratories

strengths of various aquated and partially aquated metallic ions. These researches on cationic acids are important, in retrospect, for they furnished the experimental material to implement the teachings of the protonic theory of acids and bases. The phenomena of the cationic aggregation of simple aquated metal ions to yield complexes of increasing ionic-molecular weight of colloidal dimensions were interpreted by A. W. Thomas as involving the formation of hydroxo- and oxo-linkages (olation and oxolation).

Outstanding are the studies which have been carried out by J. C. Bailar, Jr., and his students on the stereochemistry of the metal ammines and in the development of new and improved preparative procedure for the complex compounds of cobalt(III), chromium(III), platinum(II), and platinum(IV). Notable among these researches is the accomplishment of Walden inversions among certain optically active cobalt complexes and the development of a new and useful method for the resolution of optically active organic acids by employing cobalt(III) complexes containing optically active coordinated groups. The chelating effect of modified Schiff bases has been studied by M. Calvin and by Harvey Diehl in the preparation of cobalt complexes which are capable of reversibly absorbing and desorbing molecular oxygen. The preparation of carbonyls and nitrosyls of the transition elements has been the subject of extensive investigation by A. A. Blanchard and his students.

The industrial applications of complex compounds are numerous. Dyes, such as the phthalocyanines, metallic lakes, and metal conjugates with azo derivatives, represent useful pigmenting and coloring materials. Complex metal cyanides, pyrophosphates, and tartrates are the solutes used in metal refining and plating operations and in the extraction of metal values from complex ores. The tanning action of cationic complexes of chromium and zirconium and of the anionic metasilicate and metaphosphate complexes represents special cases where olated and oxolated polymeric species are effective, even though simple ions exert no such action. The sequestering action of water-softening agents, such as the polyphosphates and polymetaphosphates (R. E. Hall and J. R. Van Wazer), is caused by the formation of very stable metal chelate complexes.

Complexing agents are employed as metal deactivators for the stabilization of petroleum products, hydrogen peroxide, and hydrazine and for the preservation of fats and oils; traces of metallic ions greatly catalyze the autoxidation and deterioration of such products. The effectiveness of complexing agents in reducing the metal ion concentration is an even more fascinating problem in evaluating the influence of trace elements upon biological processes, in general. It is conceivable that some plant growth regulators which are complexing agents owe their action to a decrease in the metal ion concentration considered necessary for normal development.

There are numerous applications of complexing agents as indicators and as specific and extremely sensitive reagents in the qualitative detection and quantitative determination of metallic ions.

The process of solvation must be considered in any theory which purports to account for the behavior of electrolytes in solution. The early work of H. C. Jones, who first attempted to account for the anomalous behaviors of concentrated solutions of electrolytes by the binding of water by ions, is particularly interesting in this connection. The hydrogen bond (W. H. Rodebush and W. M. Latimer) was at one time believed to represent an example of coordination through hydrogen. This phenomenon is now regarded as representing dipole orientation, even though the hydrogen bond is defined as a linkage through hydrogen of two electronegative atoms. Solvation of anions in very acidic solvents may represent examples of hydrogen bonding. There is no question but that the water in crystal hydrates, such as $MSO_4.7H_2O$, is in part hydrogen bonded to the anion.

Acids, Bases, and Nonaqueous Systems

The early work of Franklin and Kraus on reactions in liquid ammonia stimulated the study and investigation of many other potential solvents, such as hydrazine (A. W. Browne), hydrogen sulfide (J. A. Wilkinson), sulfuric acid (J. Kendall, A. W. Davidson), acetic acid (J. B. Conant, N. F. Hall, A. W. Davidson), formic acid (A. W. Davidson, H. I. Schlesinger), phosgene (Germann), selenium oxychloride (V. Lenher, G. B. L. Smith), and hydrogen fluoride (J. H. Simons). Much of this work was undertaken to extend the solvent system concept of acids, bases, and salts (E. C. Franklin) to media other than water and ammonia. Many such systems of compounds were actually proposed and subjected to experimental study. For all hydrogen-containing solvents, it was soon recognized that the solvated proton might be looked upon as the characteristic acid species—but the base analogs were different for each solvent. The mass of experimental material accumulated by those interested in nonaqueous solvent chemistry not only made a more generalized theory necessary, but did, in fact, furnish the basis for the Brønsted-Lowry protonic theory. Outstanding among American investigations are the studies by J. B. Conant and N. F. Hall on "superacid solutions" in which acetic acid was employed as a solvent. These studies pointed the way to the utilization of acetic acid in preparative inorganic and organic chemistry and in analytical chemistry.

The protonic concept was also limited in its scope, as it disregarded nonprotonic solvents and neglected completely technically important high temperature reactions. With the development of the modern theory of valence, it was possible for G. N. Lewis to propose a generalized electronic theory according to which an acid is defined as an electron-pair acceptor and a base as an electron-pair donor, while neutralization is considered to involve the formation of a coordinate covalent bond. The general utility of this concept is now recognized and has been shown not only to apply to inorganic reactions in a wide variety of nonaqueous solvents, but also to explain satisfactorily many organic

reactions which are acid- or base-catalyzed (W. F. Luder). Both the protonic concept and the Lewis electronic theory have been extended to cover high temperature reactions (L. F. Audrieth, A. Silverman) such as characterize many of our very important phenomena in ceramics and metallurgy.

Preparative Inorganic Chemistry

To many chemists, methods for the production of inorganic chemical commodities are conventionally represented by simple equations which any freshman can reproduce. To a limited extent the "chemistry" is simple, but the "test tube" attitude toward inorganic chemistry is hardly justified when these same simple reactions are carried out on a technical scale. It is paradoxical, however, that inorganic synthesis represents an exceedingly difficult field, largely because of its variety and versatility. Few reactions can be regarded as standardized type reactions corresponding to those which are so common in organic chemistry. Furthermore, there are no simple criteria for purity except through analysis. The number of reference sources which can be consulted for information on the preparation of inorganic compounds is limited. Only during the past 15 years has a real effort been made to fill these gaps in the scientific and technical literature with the publication of the "Inorganic Syntheses" series dealing with preparative inorganic chemistry. This American project has attracted world-wide attention and has done much to stimulate interest in preparative inorganic chemistry, both industrially and academically.

More than background and training in inorganic chemistry are required to prepare many of the special classes of inorganic substances. A few examples may be cited to emphasize this point. The metallurgy of rarer metals demands both an intimate knowledge of the chemistry of the respective elements and familiarity with the techniques of electrochemistry and with operations at higher temperatures. Preparation of the ultrapure materials needed for use in atomic reactors and in nuclear energy projects calls upon every known physical and chemical procedure for elimination of impurities. So many complex compounds consist of organic molecules coordinated with the inorganic central atom that only those with adequate background in organic chemistry can hope to succeed. This is certainly also true of the inorganic-organic polymer field. Both W. I. Patnode and E. G. Rochow, two of the men largely responsible for the development of procedures for the manufacture of the silicone resins, are inorganic chemists.

The synthesis of a new and unusual inorganic compound always brings up the age-old question of "how and what to name it." The National Research Council Subcommittee on Inorganic Nomenclature, under the chairmanship of W. C. Fernelius, and in cooperation with E. J. Crane and A. M. Patterson, has handled a number of controversial issues with dispatch. The Stock system of representing the oxidation state of an element by the Roman numeral designation has been adopted. Recommendations of the Commission on Inorganic Nomenclature of the International Union of Chemistry, whose American representative is A. Silverman, have been approved for the most part by the National Research Council group. Columbium is now officially called niobium, but tungsten remains tungsten. Rules for the naming of coordination compounds have been standardized.

Structural Inorganic Chemistry

Man has always attempted to extend his vision beyond the limits of his senses. To accomplish such an objective, he has had to resort either to instrumentation to magnify matter and thus permit him to see in detail that which is beyond normal definition, or to his imagination in depicting the structure of matter in terms of forms, models, or concepts that characterize behavior of visible and ponderable units. We speak of "chains of atoms linked together," the "bonds" between them, the "packing" of ions considered as "spheres" with definite "radii," of "layer" lattices. The carbon atom is pictured as a "tetrahedron" capable of sharing "corners," "edges," and "faces." Geometrical configurations are developed to make it possible for us to envisage the manner in which the fundamental particles of matter are joined together. Logic teaches us that external crystalline form must be a manifestation of the way in which such fundamental particles have been brought into combination. Such structural arrangements become reasonable concepts when subjected to study using various analytical and physical methods, especially those involving the diffraction or reflection of x-rays, of electrons (and of neutrons), or of molecular beams, much as visible light is reflected or diffracted.

Structural concepts are to most of us much more satisfying than abstract mathematical and physical pictures. It thus becomes simpler for us to consider properties of matter in terms of particles with form and dimensions. Yet, recognizing that matter is electrical in nature, we do employ concepts of charge and size to account for the attraction and/or repulsion between such particles in developing our knowledge concerning the nature of the chemical bond and the architectural design of matter. Structural chemistry is today as important to the inorganic chemist in duplicating and improving upon the accomplishments of nature as it has been for the past 75 years to the synthetic organic chemist in his efforts to build complex molecules from simple carbon compounds. The achievements of American chemists in developing structural inorganic chemistry have been outstanding during the past 35 years.

G. N. Lewis and Irving Langmuir were quick to adapt the findings of European chemists to present a static model of the atom which might explain the formation of chemical compounds, by either the sharing or transfer of electrons. Physical properties of covalent (nonionic) and ionic compounds fitted in nicely with such a picture. The independent development in America in 1916 of the powder diffraction method by A. W. Hull, which made it possible to study the structure of matter by x-ray diffraction, and the recognition of the existence of ionic, covalent, metallic, and molecular lattices (as well as intermediate lattices) in the solid state, was offered in further support of the Lewis-Langmuir proposal. The idea of coordinate covalence—i.e., bonding between electron-pair donors and electron-deficient ions or molecules—and of the effective atomic number concept represented extensions of the octet theory by N. V. Sidgwick in England. Crystal structure studies by the x-ray method led to the characterization of individual ions and atoms on the basis of size and to the assignment of ionic and covalent radii (on the assumption that individual particles could be considered as spheres). Bond distances could, therefore, be determined or calculated. Assigned ionic radii were shown to vary with the charge. Interatomic distances were also shown to differ, depending upon the single, double, or triple bond character based on formal valence considerations, but redefined in terms of the corresponding number of electron pairs involved in such linkages to conform with the teachings of the octet theory.

However, when calculated and experimentally determined values were found to deviate from each other -that is, depart from anticipated additivity—it became necessary to present an explanation of these differences. Linus Pauling promulgated the resonance theory based upon the premise that actual structures could be considered to be an average of all possible electronic forms; Kasimir Fajans advanced the concept that interaction of particles of differing size and charge results in deformation or polarization. Particles with indicated formal charges could no longer be considered as spherical; bond distances were thus shortened. The more deformable the ion, the more covalent (nonionic) the resulting compound. In effect, therefore, ionic and covalent states represented the ideal extremes, with all pos-

sible variations reflected in partial ionic character determinable on the basis of the relative electronegativities (Pauling).

Application of the x-ray diffraction method to solids was materially facilitated by the development of the Coolidge x-ray tube. American pioneers in this field include A. W. Hull, R. W. G. Wyckoff, W. P. Davey, and G. L. Clark. Methods of x-ray and electron diffraction must be regarded as the fundamental experimental tools in the elucidation of the structures of both organic and inorganic molecules.

The theory of directed bonds, as implied in the tetrahedral configuration of the carbon atom in aliphatic hydrocarbon derivatives, was shown to be applicable to silicon and phosphorus in silicates and phosphates, and to many other highly polymeric oxides in the solid state (S. B. Hendricks, L. Pauling). The postulated existence of ring structures, chains, sheet, and three-dimensional polymers based on arrangement of such primary tetrahedral XO_4 units, opened up a whole new approach to one of the most difficult and baffling problems in the whole realm of chemistry—the nature of silicate minerals. While 4-coordinate bonds are more easily visualized in building up such structures, success has also been achieved in applying this approach to simple hexacovalent units—for instance, in the cobalt ammines—and to the complex iso- and heteropoly acids of molybdenum and tungsten (Pauling).

The quantum theory has been applied by Pauling in the development of a more fundamental concept of directed bonds which thus determine configuration and structure. Fajans has further refined his original ideas of deformation and polarization with presentation of the "quanticul" theory.

The importance of structural concepts in leading to a clearer understanding of the nature of the chemical bond is emphasized in Pauling's inspiring 1947 Richards' Medal address, under the title "Unsolved Problems in Structural Chemistry." It is significant that the structural approach over a period of 25 years has been responsible for many of our most important theoretical advances. It will doubtlessly be responsible for many more significant advances in the years ahead.

The Future

The future is bright and promising for the inorganic chemist and for the field of inorganic chemistry. Real contributions will be made in the borderline fields—in nucleonics, in metallurgy, and in ceramics. The horizon in classical descriptive inorganic chemistry had been much too limited, because consideration had been given only to those environmental conditions covering ordinary ranges of temperature and pressure and to reactions in water and in a few nonaqueous solvents. The development of new modes of travel, possibly by rocket propulsion, will necessitate study and extension of our physical laws to behavior at very low and very high pressures and temperatures. Increasing demands will be made upon the inorganic metallurgical chemist and the inorganic ceramic chemist for lighter and stronger metals and alloys, for superior refractories and abrasives, and for more stable inorganic coatings to withstand the rigors and changes in temperature which may be met in superstratospheric or even interplanetary flights.

The modern age of inorganic chemistry has had as its major objective the investigation of inanimate nature in an attempt to improve upon that with which nature has furnished us. New gem stones of surpassing beauty and brilliance have been produced by laboratory methods. Quartz is produced by hydrothermal synthesis. Bentonite films, synthetic micas and glass wool for fabrics and insulation have been made. High temperature-resistant ceramic coatings, new abrasives superior to most of those found in nature, lighter and stronger metals, alloys, and materials of construction are the products of research and development and represent accomplishments of tremendous importance. Realization that there are certain fundamental building blocks which make up most of the mineral world has led to the development of structural inorganic chemistry. Structural chemistry has furnished the investigator with a working hypothesis to help him build the larger and more useful inorganic materials from simple molecules and ions. It is in the field of inorganic polymer chemistry that even greater future developments may be anticipated.

Perhaps even more challenging will be the further study of the effects of trace metallic constituents in biological processes, whether these pertain to the human, animal, or vegetable world. Many of the very complex organic molecules found in nature are built around some common inorganic element—magnesium in chlorophyll, iron in hemoglobin, or cobalt in one of the vitamin B_{12} complexes. The pharmacological action of many drugs may be associated with their ability to remove trace elements necessary for the existence of harmful organisms, or with the tendency for these same compounds to facilitate the transfer of such elements into the cell fluid. Certainly, the catalytic effect of such trace elements on biological processes is a problem of tremendous importance and can be solved only by real cooperation between specialists in inorganic and organic chemistry and the life sciences.

Importance of Nuclear Chemistry

The inorganic chemist of the future will pay more and more attention to nuclear chemistry—first, in order to characterize and employ properly the newer synthetic elements, and secondly and more importantly, to make it possible to utilize effectively in all branches of chemical science the large number of artificially radioactive materials which are now available. Separation, purification, and handling of such materials require specialized skills and thorough knowledge of inorganic chemistry. With fissionable elements as the power sources of the future, it will be necessary to depend upon the inorganic chemist to solve problems involving not only the production and purification of the energy-containing materials but also the disposal of waste products.

Inorganic chemical technology will continue to advance as more and more research chemicals are found to have industrial and everyday uses and as changing of raw material supplies and process developments bring about the rediscovery of long forgotten inorganic chemicals. It may be anticipated that even more attention will be paid by the inorganic chemical industry to the production of useful compounds of the nonmetals, especially those which occur abundantly in nature's mineral resources, such as chlorine, sulfur, phosphorus, nitrogen, and especially silicon.

Academic and industrial progress will demand a continuance of the cooperative effort which has manifested itself throughout the whole 75 years of the existence of the AMERICAN CHEMICAL SOCIETY. Inorganic and analytical chemistry have been closely allied from the very beginning. Because chemical phenomena are governed by the environmental conditions which limit a particular observation, it is important to recognize the contributions that can be made by physical chemistry in achieving the objectives of modern inorganic chemistry. In the future, cooperative effort will be more important than ever, if the solutions to the many intricate problems of today are to help build a better world of tomorrow.

Acknowledgment

The author wishes to express his sincere appreciation to his colleagues, J. C. Bailar, Jr., Virginia Bartow, and George L. Clark for their help and advice in the organization and presentation of the material on inorganic chemistry. He is also indebted to W. C. Schumb of the Massachusetts Institute of Technology and to L. L. Quill for their kindness in reviewing the manuscript.

PHYSICAL CHEMISTRY

FARRINGTON DANIELS
University of Wisconsin, Madison, Wis.

THE year 1887 is generally accepted as the date of the emergence of physical chemistry as a separate branch of science. This was the year of the founding of the *Zeitschrift für Physikalische Chemie*, which was soon to include classic papers on the electrolytic dissociation theory by Arrhenius, van't Hoff, and Ostwald, on rates of reaction by Arrhenius and Ostwald, and contributions from Nernst, Raoult, Roozeboom, and others. Nernst's textbook on "Theoretische Chemie" was a standard throughout the world for two decades for the training of physical chemists and served as a pattern for some of the early American textbooks. Certainly for the 25 years from 1875 to 1900 physical chemistry was distinctly a German science, but from 1900 on it developed rapidly in this country, and, after about 1910, the large majority of American physical chemists took their Ph.D's in American universities. However, through many postdoctoral fellowships in Europe, generously supported by the Rockefeller Foundation, and through the work of such leaders as Debye, Svedberg, Brønsted, and Bodenstein, Europe continued to exert an influence on the development of physical chemistry in America.

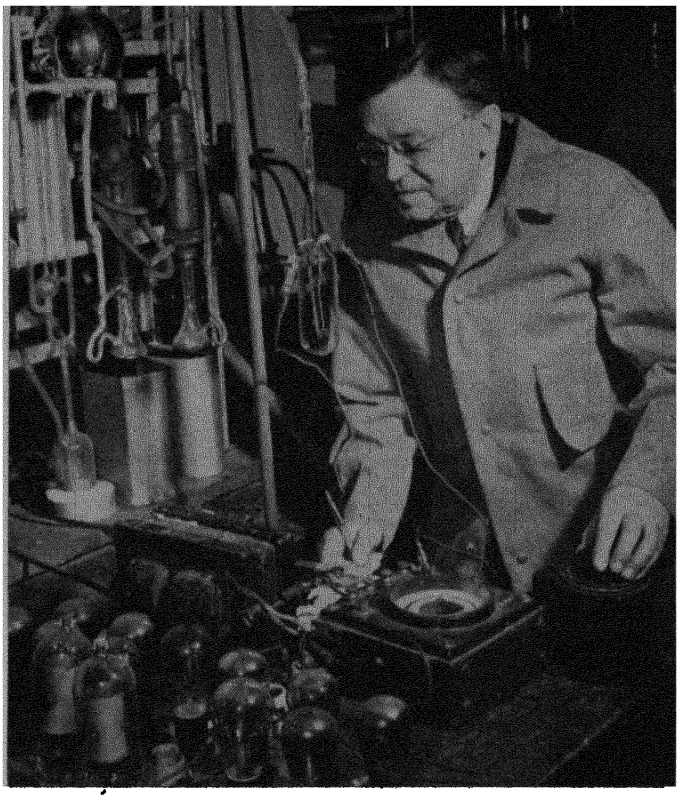
At the turn of the century T. W. Richards at Harvard became a leader of physical chemistry, emphasizing for a quarter of a century accurate measurements on materials of high purity. His work included thermochemical and electrochemical measurements, measurements of compressibility, and the exact determinations of atomic weights, for which he received the first Nobel Prize in Chemistry awarded to an American.

No American has had greater influence on the world development of physical chemistry than G. N. Lewis, as is evident from his contributions to chemical thermodynamics and molecular structure, together with the records of achievement of the men who studied under him at the University of California.

Many other physical chemists, most of whom are still living, have shaped the course of physical chemistry. The growth of a new science such as this is largely intertwined with the lives of its pioneers, but various other influences have played a part in directing the development of physical chemistry.

For many years after its emergence as a separate branch of science, physical chemistry was largely concerned with the study of dilute aqueous solutions, the determination of molecular weights, and the measurements of osmotic pressures. The most active researches and lively controversies centered around the Arrhenius electrolytic dissociation theory. The influence of organic chemistry was strong, and emphasis was placed on molecular weights in the gas phase and in solution, on refractive index and rotation of polarized light, and on those measurements which could be used to connect physical properties with molecular structure. The Arrhenius theory is now known to apply only to weak electrolytes, most of the important molecular weights have been determined, and osmotic pressure turned out to be a rather unsatisfactory method for studying ionic solutions.

There are several examples in which the influence of other branches of science and the practical applications of physical chemistry have served as stimuli in the development of this basic science. The separation of salts from complex mixtures in the Stassfurt deposits stirred the development of phase diagrams and the phase rule. The chemical industries' need to increase the yield and purity of products led to intensive work on the determination of equilibrium constants and on reaction rate measurements, chemical kinetics, and catalysis. The Haber process for the production of ammonia from atmospheric nitrogen in 1913 is an example. The growth of the petroleum industry in America was responsible for great improvements in fractional distillation, and for the accumulation of much exact thermodynamic information concerning the hydrocarbons. The two world wars



At Westinghouse, H. C. Rentschler dissolves oxygen in strip of zirconium enclosed in glass tube

with their demands for critical materials and munitions also played their part in directing the course of physical chemistry.

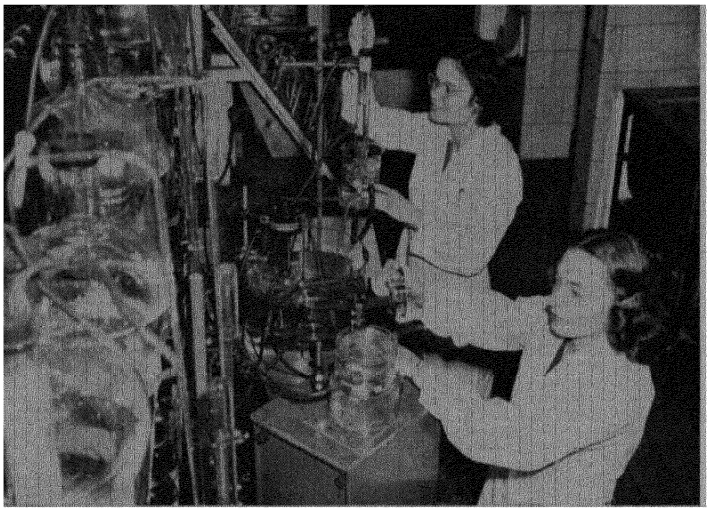
The growth of physical chemistry has been affected by the practical demands of organic chemistry, chemical engineering, and analytical chemistry, but still more by the theories and techniques of physics. The discovery of radioactivity and the concepts of isotopes, atomic numbers, and nuclear structure have been followed quickly by new activities in physical chemistry. The quantum theory, the x-ray study of crystals, the Debye-Hückel theory of strong electrolytes, the Raman and infrared spectra, and many other new findings of the physicists have influenced greatly the development of physical chemistry.

In the field of physical chemistry itself the steady growth of chemical thermodynamics with the understanding of free energies and activities has been very fruitful, as has the growth of our understanding of molecular structure through the use of the electron pair concept and the electron theory of valence. Progressive improvement of apparatus has been helpful in the growth of physical chemistry and each advance which permitted going to higher or lower temperatures, or higher or lower pressures, and each refinement which permitted one more decimal point in precision have opened up new frontiers for quick exploration.

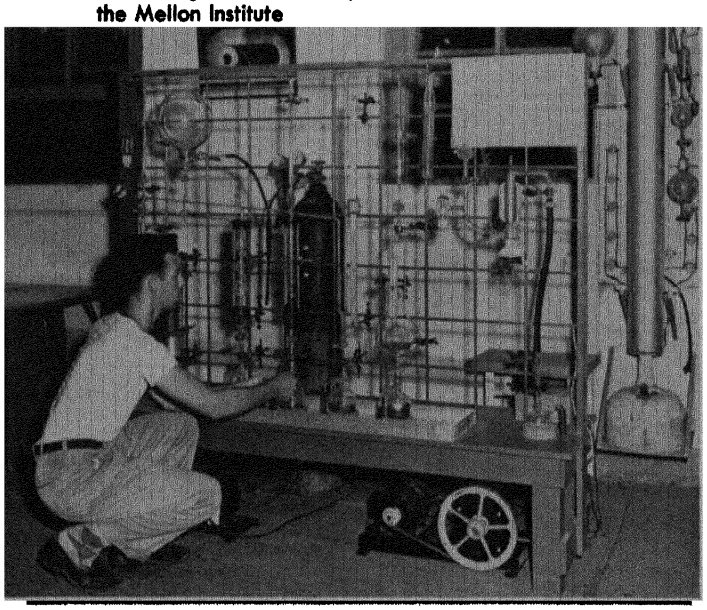
The interpretation of molecular structure through measurements of dipole moments, infrared and Raman spectroscopy, and electron diffraction has been a notable advance which finds practical application in calculating equilibrium constants and reaction rates.

One of the newer trends lies in the recognition and calculation of the various forces which attract molecules together. As the quantitative mathematical laws for these attractions are developed, it may be possible to predict more concerning deviations from ideal gas laws, the nature of viscosity, the properties of liquids and solutions, and the velocities of chemical reactions.

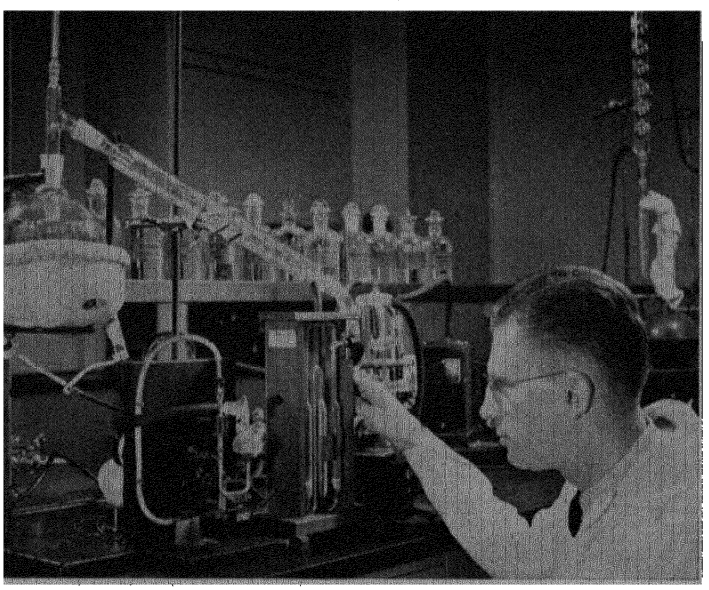
It is interesting to note the rise and fall of interest in the different branches of physical chemistry. Often early success in a limited field has led to unwarranted extrapolation to wider areas, sometimes with sobering failures. Vigorous attempts were



Measuring surface activity of various cationic detergents at the Mellon Institute



Determining specific surface of fine particles in Georgia Tech micromeritics laboratory



Operating vacuum distillation apparatus at research laboratory of Firestone Tire and Rubber

made to carry over the Arrhenius theory of electrolytic dissociation to strong electrolytes and concentrated solutions, but the Debye-Hückel theory in the mid-1920's showed that the Arrhenius theory could be important only for weak electrolytes. The oxidation-reduction potentials of inorganic chemistry were so successful that they have been carried over with moderate success to organic chemistry. Again, the ionic mechanisms which have been so successful in inorganic reactions are now feeling their way into organic reactions. The radiation hypothesis in chemical kinetics prominent in 1920 has had perhaps the most meteoric rise and fall. The prediction of reaction rates seemed not too far around the corner in the early '30's, but at the threshold of the '50's there is painful realization of the fact that although simple elementary uni- and bimolecular reactions can sometimes be calculated, the ordinary chemical reaction is frightfully complex because it is composed of so many of these simple reactions going on at the same time.

Along with the changing emphasis it is interesting to note also the changing methods. Until the first world war research in physical chemistry was largely a product of the universities, where apprenticeship training of graduate students was the main purpose and the laboratory staffs were small and intimate. Now a great deal of research is done also by scientists and teams of scientists working together in the industrial laboratories, government laboratories, and research institutes. Most of these laboratories are well equipped with apparatus and service facilities, so that the physical chemist is spared much routine work and can devote more of his time to his direct research. The research teams often include experts from different fields, with the result that researches can be carried on more effectively in the area between two or more sciences. In the second world war such dramatic results were obtained through programmatic research by teams of scientists that we sometimes forget that the stockpile of fundamental research was drawn on very heavily, and that such stocks of pure and theoretical research are continuously needed in order to advance also the practical applications which are so dependent on them.

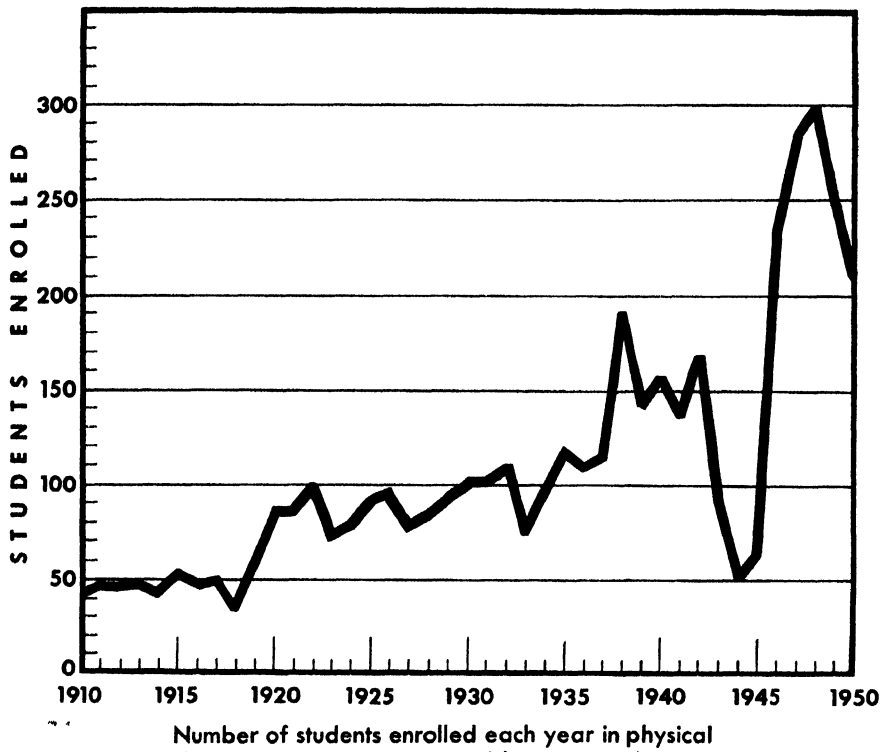
Glimpses of the Past

This survey is being written in 1951. Twenty-five years ago W. D. Bancroft prepared a similar survey of physical chemistry, as did Louis Kahlenberg 50 years ago. We can get a view back into the preceding century by reading a paper written by G. C. Caldwell in 1892. All three of these historical reviews were published in the *Journal of the American Chemical Society*.

Caldwell summarized the historical development of chemistry in America and recorded the number of papers published each decade from 1820. J. P. Cooke lectured at Harvard and wrote a book on "Chemical Physics" in the 1860's. He foreshadowed the periodic table of Mendeleev and looked forward to the prediction of the properties of undiscovered elements. Also in the 1860's Storer wrote his "Dictionary of Solubilities" and Clark published a book on the "Constants of Nature" containing a table of boiling and melting points, densities, and specific heats. Researches were published on volatile hydrocarbons and on apparatus for the fractional condensation of volatile liquids. Caldwell classified the contributions in chemistry, but did not mention physical chemistry nor the classical work of Willard Gibbs at Yale on chemical thermodynamics.

In 1901, Louis Kahlenberg wrote: "The words 'physical chemistry' too frequently call to mind simply molecular weight determinations and theories of very dilute solutions which are only remotely connected to human welfare. It is hoped that physical chemistry may fully realize its high aspirations to promote the welfare of mankind, and that it will demonstrate its right to full recognition in all our higher institutions of learning."

In his 1905 review of physical chemistry F. G. Cottrell discussed the progress of the prior decade in the study of heterogeneous



Number of students enrolled each year in physical chemistry courses at a midwestern university

equilibria and phase diagrams, electrolytic dissociation, the theory of dilute aqueous solutions, and the quantitative treatment of reaction velocities and homogeneous equilibria. He felt that attention should now be directed to aqueous solutions of higher concentrations and to nonaqueous solvents. He reported on progress in the determination of molecular weights but observed that "reaction velocities are at a standstill" and noted the developments taking place in physics and sensed their impending influence on chemistry. He concluded, "As fast as what we term physical chemistry is reduced to definite laws, it ceases to directly concern the physical chemist proper and becomes the tool and the method of the specialist in other fields."

In 1926 W. D. Bancroft gave a 50-year historical review of physical chemistry and after summarizing the advances in the different branches concluded "another thing that the physical chemist must do, because he is apparently the one with the pioneering spirit, is to develop the borderlands between physical chemistry and the other sciences."

Interesting glimpses of physical chemistry may be obtained not only from these quarter-century historical reviews, but also from some of the annual retiring addresses of the presidents of the American Chemical Society which have been recorded in the Society's publications. For example, James F. Norris in 1925 and 1926 toured the country stressing the importance of intensified research on petroleum and petroleum products. He predicted that American chemistry would develop petroleum chemistry and the hydrocarbon derivatives as German chemistry developed coal tar chemistry and benzene derivatives. His predictions have been abundantly verified.

When the American Chemical Society was founded in 1876 there was nothing classified as physical chemistry in this country or elsewhere. Twenty-five years later, in 1901, we get a picture of physical chemistry in the United States through the report of the Census Committee of the Society. The committee, consisting of Charles Baskerville, Louis Kahlenberg, Charles E. Munroe, W. A. Noyes, and Edgar F. Smith, sent out a questionnaire (a forerunner of many questionnaires to follow in later years) to all professors of chemistry in every institution of learning in the U. S. A. Two hundred replies were received. Kahlenberg wrote: "A conservative estimate shows that the buildings and floor space devoted to chemistry have increased 25-fold in the 25 years from 1876 to 1901. There were but few laboratories in 1876 but now [in1901] no institution attempts to teach chemistry without some laboratory equipment."

Nearly 40 universities and colleges reported the teaching of physical chemistry and the total number of students taking physical chemistry in 1901 was nearly 500. The reported enrollments were as follows: Harvard University 73, University of Michigan 40, Massachusetts Institute of Technology 30, Ohio State College 25, University of Kansas 25, Creighton College at Omaha 24, University of Wisconsin 24, Cornell University 23, and Stanford University 19. Case School of Applied Science, Louisiana State University, Iowa State College, Sheffield Scientific School at Yale, and Tufts College each reported 15 and the remaining universities less than 15.

Data on the growth of physical chemistry in the United States since 1901 are not readily available, but perhaps a rough idea of this growth can be obtained as a sample from information available at one midwestern university (the University of Wisconsin). The above graph indicates the number of students taking physical chemistry each year.

Branches of Physical Chemistry

Through all the tracing of the growth of physical chemistry it is well to remember that there are two fundamentally different approaches to the study of physical chemistry, and that each is important. The statistical or thermodynamic approach is based on mass behavior and the observations of large quantities of material. Even a millionth of a gram-molecule of a chemical substance, which is about as small an amount of material as the chemist ordinarily works with, contains 6×10^{17} molecules. This number is so enormous that the laws of probability and statistics can be applied with accuracy. The other approach is to predict the behavior of the large mass from the behavior of the individual. Centering attention on individual atoms, molecules, photons, and electrons one can make important predictions using the concepts of atomic and molecular structure and quantum theory and generalizations of organic chemistry.

Physical chemistry covers many different branches with many different origins. It is perhaps best in this brief historical review to handle each of the branches separately. The histories of inorganic chemistry, analytical chemistry, and colloid chemistry are being covered by other reviewers.

Thermodynamics and Thermochemistry. Probably the broadest, most fundamental, and most advanced branch of physical chemistry is that of chemical thermodynamics. Physicists and engineers have used thermodynamics for over a century and the first and second laws were fully established before 1876, but widespread practical application to chemistry falls within the period of this history. The fundamental principles and the differential equations for much of chemical thermodynamics were worked out correctly but obscurely by Willard Gibbs in the early 1870's and published in the *Transactions of the Connecticut Academy of*

Sciences, where they lay dormant until Roozeboom and some of the German physical chemists took the matter up two or three decades later. Gibbs made no mistakes, and many a young student enthusiastic with a new idea is disappointed to find that Willard Gibbs had the same idea long before.

Because heat can be measured easily and quantitatively, early efforts were made to connect heat with chemical affinity and chemical equilibrium. The first effort by Berthelot was oversimplified and his generalization met with failure. Gradually it came to be realized that so-called "free energy" is the energy that is chemically significant. The van't Hoff equation and the Gibbs-Helmholtz equation showed the relation between heat of reaction, temperature, and chemical equilibrium.

A significant advance was made by Haber in his "Thermodynamics of Technical Gas Reactions," translated by A. B. Lamb and published in this country in 1908.

The third law of thermodynamics, according to which for chemical calculations the entropies of pure crystals are taken as zero at the absolute zero, was developed slowly over the first few years of the twentieth century. Starting with observations by T. W. Richards on the temperature coefficient of galvanic cells and a brilliant hypothesis of G. N. Lewis, Nernst produced a satisfactory law for calculating chemical equilibria from a few physical constants. Further developments were made by Sackur and others. Then G. N. Lewis with Gibson and Latimer and other associates, in the years from 1910 to 1920, fully established the use of the third law of thermodynamics in chemistry. These workers emphasized the practical use of calculating entropy changes during chemical reactions from a knowledge of the heat capacities of reactants and products all the way down to absolute zero. By combining the entropy changes thus obtained with the heat of reaction they found it possible to calculate the change in free energy of the reaction and hence the equilibrium constant.

The complete acceptance of the third law took time, because in a few reactions the calculated equilibrium constants did not agree with those which were determined directly in the laboratory. One difficulty with the synthesis of methanol was resolved by a redetermination of the heat of combustion of pure methanol. Still other objections disappeared when an extension of low temperature calorimetry almost to the absolute zero revealed the fact that in calculations involving hydrogen, it is necessary to include a previously neglected term for the entropy change involved in the change of two different types of molecular hydrogen—ortho- and para-hydrogen. This was discovered by Giauque and H. L. Johnston and simultaneously by Bonhoeffer and Harteck.

The importance of determining absolute entropies led to great activity in low temperature calorimetry. Among those who determined heat capacities accurately to very low temperatures were Nernst and Eucken and others in Germany, Latimer, Giauque, and many others at the University of California, Parks at Stanford, Huffman at the Bureau of Mines, Brickwedde and others at the National Bureau of Standards, and Aston at Pennsylvania State College. Most of this work was done on organic compounds. Measurements on inorganic compounds have been made by Kelley and are useful in metallurgy and in ceramics. Brewer has recently collected a large number of thermodynamic data in these fields.

Outstanding in the development of calorimetry at temperatures close to absolute zero has been the work of Giauque at the University of California, making use of the adiabatic demagnetization of gadolinium sulfate, which in 1933 yielded a temperature of 0.25° K. For this work Giauque received the Nobel Prize in chemistry in 1949.

One of the challenges of physical chemistry has been the determination of the precise heats of reaction, many of which are obtained indirectly through exact measurements of heats of combustion. The first systematic calorimetric work was done by Berthelot and Thompson in Europe. From 1900 to 1928 T. W. Richards directed an extended program at Harvard on precise calorimetry, covering heats of combustion, heats of neutralization, and heats of solution. For the past 25 years a splendid program of exact combustion calorimetry has been carried out at the Bureau of Standards under the general direction of F. D. Rossini. With the cooperation of the American Petroleum Institute the physical and thermodynamic properties of many pure hydrocarbons have been measured with high precision. Parks at Stanford and Huffman at the Bureau of Mines also have made important contributions. Kistiakowsky has measured with high accuracy the heats of hydrogenation and reaction of of some of the unsaturated organic compounds.

Precise measurements on heats of mixing and heats of dilution have been made by T. F. Young, Gucker, and several others. Emphasis has been placed also by Sturtevant and others on the heat of slow reactions.

The entropies of inorganic substances and particularly those of the ions in aqueous solution have been the object of a considerable amount of research by Latimer since 1921.

The concept of activities proposed by G. N. Lewis was a distinct advance in the exact use of free energies and other thermodynamical data. Another concept stressed by Lewis was that of partial molal quantities. This simple application of calculus brought out clearly the influence of changing concentration on the physical properties of solutions and reconciled many previously discordant data.

The importance of free energies of chemical substances and the calculation of exact equilibrium constants from indirect physical chemical data and thermodynamics was brought out also by G. N. Lewis. One of the first examples was concerned with urea in 1912.

The influence of salts on the solubilities of other salts in the hands of A. A. Noyes and others supplied data for calculating activities of salts in aqueous solutions.

Publications by Lewis and his associates in the 1910's were followed in 1923 by the monumental book, Lewis and Randall's "Thermodynamics and Free Energies of Chemical Substances," which probably has had more influence on the development of physical chemistry than any other single publication.

The data on chemical thermodynamics up to 1930 were collected by Randall and others in the International Critical Tables.

In 1932 the helpful book on the "Free Energies of Organic Compounds" was published by Parks and Huffman.

Another milestone in the literature of heats of reaction and thermodynamics data was the publication in 1936 of Bichowsky and Rossini's "Thermochemistry of the Chemical Substances," which included all the reliable data of the inorganic compounds and the simple (3-carbon) organic compounds.

For the past few years a very valuable and complete collection of the thermodynamic functions of the hydrocarbons has been edited under the direction of Rossini.

A review of recent thermochemical data is given by Rossini in the first issue of *Annual Review of Physical Chemistry* (1950).

Steady progress in the field of molecular structure led to the prediction of heat capacities of the simpler chemical compounds down to absolute zero through electron displacement, molecular rotation, and interatomic motions. Quantum mechanics and statistical mechanics had developed simultaneously, so that by the middle 1920's it became possible to determine partition functions and through these to calculate thermodynamic quantities and chemical equilibria. Classic contributions to this field were made by Giauque and his associates starting in 1929. Books by R. C. Tolman were influential.

Thermodynamic quantities were quickly calculated for diatomic and triatomic molecules, and now with added information from Raman and infrared spectra the study has been extended

to reasonably complex molecules, notably hydrocarbons. The equilibrium constants calculated from spectroscopy and partition functions are usually capable of greater precision than are those calculated from chemical equilibria, but until the values have been checked by other measurements there is always a chance that there may be a considerable error due to incomplete information concerning the correct assignment of the modes of vibration within the molecule. The uncertainties concerning free rotation around a bond were resolved by Pitzer and others.

Electrochemistry. In 1887 Arrhenius proposed his famous electrolytic dissociation theory (after having it rejected once for his Ph.D. dissertation). Ostwald showed that an excellent dissociation constant can be calculated from the degree of dissociation. Hittorf studied the relative rate of migration of the positive and negative ions and established simple quantitative relations. The whole field of electrolytic conductance seemed complete and eminently satisfactory at the turn of the century.

However, when these successful methods were applied to the aqueous solutions of inorganic salts (strong electrolytes) and to nonaqueous solutions, the simple relations were no longer valid. Kahlenberg, once an enthusiastic follower of Arrhenius and Ostwald, became a vociferous skeptic and pointed out that the velocity of the ions as well as the number of ions was a factor in the electrical conductance and that dissociation constants of salts and strong acids and bases could not be calculated from measurements of conductance alone. The debates from 1900 to 1910 became intense. In 1909 at a joint meeting of the AMERICAN CHEMICAL SOCIETY and the newly organized Chemistry Section (C) of the Association for the Advancement of Science G. N. Lewis gave a paper on "The Use and Abuse of the Ionic Theory." In 1921 Lewis and Randall brought out the concept of the ionic strength which depends on both the concentration of the ions and the ionic valence. With the aid of this relation they were able to predict solubilities in mixed electrolytes and to show that the number of charges rather than the specific chemical nature of the ion is important.

The idea of interionic attraction in solutions of electrolytes was developing rapidly. In 1912 in England Milner proposed a theory of strong electrolytes which assumed nearly complete dissociation. Sutherland, Ghosh, Noyes, and MacInnes contributed additional ideas. In 1923 in Germany Debye and Hückel developed their classical theory which explained quantitatively the behavior of strong electrolytes on the basis of complete dissociation and interionic attraction depending on the charges of the ions, the diameter of the ions, and the dielectric constant of the medium. A. A. Noyes, who had been the leader of quantitative studies of electrolytes in this country, first at the Massachusetts Institute of Technology and then at the California Institute of Technology, supported this theory immediately and showed how successfully it could be applied to a large mass of experimental data. In dilute solutions the Arrhenius theory is very satisfactory for weak electrolytes and the Debye-Hückel theory for strong electrolytes.

Studies of electrolytes had been limited largely to aqueous solutions—and water is a very abnormal solvent. More recently a great deal of work has been done on nonaqueous solutions, and the electrical behavior can be fairly well predicted from theories propounded by Onsager and Fuoss based on the work of Kraus and his associates and others.

Another property which is used in calculations of the properties of electrolytic solutions is that of transference numbers, which depend on the relative migrations of the ions. MacInnes and his associates have been active in this field for the past 30 years.

The exact relations between the current passing through a solution and the weight of material deposited at the electrode have been studied throughout the whole 75-year period, and Faraday's law proposed in 1834 is now one of the most firmly established and exact laws of physical chemistry.

The study of the voltage of electrodes immersed in solutions of electrolytes is another branch of electrochemistry, equally important and perhaps more practical than the study of the electrical conductance of solutions. Nernst in 1889 proposed a mathematical formula for calculating electrode potentials which was immediately applied with great success to concentration cells and to cells with gas electrodes. The hydrogen electrode and its substitute, the glass electrode, for measuring hydrogen ion activities has been, perhaps, the most useful of these electrodes. Sörensen in 1909 introduced the term "pH" and J. H. Hildebrand in 1913 emphasized the ability of the hydrogen electrode to solve problems of acidity. This technique has found large application in analysis, in biochemistry, and in industry. Harned has been active in studying the properties of electrolytes and the accurate measurements of the potentials of electrodes.

The concept that oxidation and reduction are due to the removal and addition of electrons led to the use of electrode potentials for measuring the relative oxidizing and reducing power of the positive and negative ions and organic solutes. Important in the early development was the work of Peters in Germany in 1898 on the observed and calculated potentials of mixtures of ferrous and ferric ions. Through the 1910's and 1920's exact values for most of the electrode potentials were determined. These have been collected and evaluated by Latimer. They find wide use in quantitative as well as qualitative calculations of thermodynamics and equilibria in solutions. James B. Conant pioneered in applying these electrochemical data to organic reactions.

Gases, Crystals, Liquids, Solutions. Industrial demands for high pressures in the production of ammonia, alcohols, and hydrocarbons have been responsible in part for the improvements in equations of state which give the pressure, temperature, and volume relations for gases. The Beattie-Bridgman equation published in 1928 gave more exact values than earlier equations but at the price of five empirical constants. The virial equation giving a series of correction terms to the ideal gas law appears to be very promising both as a useful equation and as one in which theoretical significance is being found for the constants. Improved equations of state were found to be necessary for industrial catalysis at high pressures and for calculations on ballistics during World War II. Extremely practical for calculating the behavior of gases at high temperatures and pressures are the Hougen and Watson charts, which are based on graphical interpolation of reduced temperature, pressure, and volume as calculated from the critical constants.

The theoretical interpretation of crystal lattices through x-ray diffraction by von Laue and by Bragg starting in 1912 opened up a whole new field which in this country has been developed to a high degree of usefulness by Hull, Wyckoff, Davey, G. L. Clark, and others. In the study of microquantities of the compounds of the transuranium elements in the atomic energy program great progress was made by Zachariasen—for example, a brief x-ray exposure gave final answers as to the purity of plutonium or neptunium, the state of oxidation, and the presence of oxides mixed with halides. Thermal analysis from heating and cooling curves is being applied successfully for identification of impurities in laboratory crystals and rocks. The study of fluorescence and thermoluminescence is revealing the importance of chemical impurities and physical imperfections in the lattice of crystals.

Although much more complicated than the structure of gases or crystals, the structure of liquids has responded to intensive research during the past 15 years. X-ray studies have revealed structures which have yielded to theoretical interpretations. Viscosity behavior has been explained by Eyring on the basis of activation energies and theories of absolute reaction rates.

The assumption of the existence of "holes" in the liquid gives satisfactory explanation for many of the properties of liquids.

The study of solutions of electrolytes is a special subject which has already been discussed. Hildebrand has made a special study of the principles of solubility of nonelectrolytes summarized in his monographs of 1936 and 1950. Kirkwood has been successful in the quantitative mathematical description and interpretation of the properties of solutions.

Practical demands for the separation of liquids, particularly in the petroleum industry, have led to great improvements in distilling columns by Fenske and many others. The distillation of liquid mixtures in the laboratory with apparatus having the equivalent of 30 and more theoretical plates has made possible the purification of organic materials to a much higher degree than was possible 20 years ago. Constantly expanding data on the properties of a great many azeotropic mixtures have led to a more intelligent handling of distillation problems. The application of physical chemical principles to the distillation of liquids and solids under high vacuum by Hickman has led to separation of complex organic molecules on a large scale.

The selective extraction of a dissolved substance from one solvent into a second solvent immiscible with the first is being used very successfully with the help of packed columns similar to those used for fractional distillation. Selective adsorption using Tswett's chromatographic technique is finding wide practical use.

Chemical Kinetics. The mass law of Guldberg and Waage had been formulated and careful rate measurements had been made before 1876 on a few reactions such as that of potassium permanganate with oxalic acid. Arrhenius, and Ostwald in 1887, measured the hydrolysis of esters accurately and expressed the rate mathematically as a second-order reaction. The inversion of cane sugar was found to be a first-order reaction, and A. A. Noyes reported the reaction between ferric ion and stannous ion as a third-order reaction. Nernst and others accumulated data on several reactions whose rates could be expressed by the simple formulas of calculus. In 1889 Arrhenius proposed his classic formula for the influence of temperature on the rate of chemical reactions. This originally empirical formula still holds with surprising accuracy over a wide range of conditions for many reactions, even those of a complex nature.

For 20 years, from the middle '90's to the middle 1910's, chemical kinetics was inactive and comparatively uninteresting. Laboratory measurements were made on many reactions, chiefly organic reactions, but the science suffered for lack of a stimulating hypothesis. Then in 1918 the work of Perrin in France, Trautz in Germany, and Lewis in England culminated in the so-called radiation hypothesis, according to which radiation from the walls of the containing vessel rather than molecular collision is the source of chemical activation energy. Hope was raised for the prediction of reaction rates, but was quickly dashed as eager scientists seeking to prove the hypothesis turned up data which disproved it. Though erroneous, the radiation hypothesis stimulated advance.

Going back to an elaborated collision hypothesis, the facts were satisfactorily explained without recourse to radiation, and predictions were made by O. K. Rice, Ramsperger, Hinshelwood, and Kassel that unimolecular gaseous reactions would give specific rate constants which fall off at low pressures. Many reactions involving the high-temperature decomposition of organic vapors apparently supported these predictions, but most of them have since been disqualified because of wall complications or side reactions not detected by the method of measurement then used. Among the tests of theories of chemical kinetics were studies on the decomposition of gaseous nitrogen pentoxide by Daniels and Johnston in 1921 and on solutions of nitrogen pentoxide by Eyring and Daniels in 1930. Careful studies of the kinetics of certain gas reactions have been made by Kistia-



Research worker measures viscosity of petroleum lubricants at Gulf Research and Development Co.



Capable of magnification of up to 100,000 diameters, this electron microscope is vital aid to physical chemists

kowsky. The falling off of the rate constant at low pressures in unimolecular gas reactions still remains an open question, theorists insisting that it must be present and some experimentalists doubting that it has yet been proved in the laboratory in the range of pressures amenable to direct measurement. Most simple chemical reactions, however, involve several steps, and if a single step can be really unmasked and isolated the pressure effect may show up. The primary step in the decomposition of N_2O_5 is the break into NO_2 and NO_3; some recent experiments reported by Ogg and by Johnson may provide evidence for this predicted pressure effect on this reaction.

It became generally accepted in the 1920's that in slow reactions the only molecules to react are those which receive an extra amount of energy, the activation energy. Usually this comes from collisions of the rapidly moving molecules, but it can come from an outside source such as light. Attempts were made to calculate this activation energy (defined as E in the Arrhenius equation, $k = se^{-E/RT}$) from physical chemical constants. The most important attempt was the proposal of Eyring in 1931. This method, known as the semiempirical method, received a good deal of attention in the 1930's, but it rested somewhat insecurely on some oversimplified approximations and it involved a large amount of computation, with the result that it has not been extensively used during the past decade. Chemical kinetics is still waiting for a simpler and better method for determining activation energy, which is by far the most important factor in predicting reaction rates.

The other constant in the Arrhenius equation (the so-called frequency factor) was calculated successfully by Eyring in 1935 by a statistical mechanical method which has come to be known as the theory of absolute reaction rates. The method was based in part on concepts suggested by Brønsted, Rodebush, LaMer, Wigner, Polanyi, Evans, and others. This calculation of the frequency factor is satisfactory if there is available sufficient information regarding the activated complex, formed by a combination of the reactants as a precursor to reaction, and if correct assignments can be made to the modes of vibration of this complex.

Chain reactions constitute a separate branch of chemical kinetics which has become of increasing importance. The products of the first step in a series of reactions are able to react with the reactants and give a rate of reaction much higher than that of the initial step. The first important example was the photochemical combination of chlorine and hydrogen as interpreted by Bodenstein.

Many organic reactions, particularly at high temperatures, involve free radical chains in which CH_3, C_2H_5, OH, H, and similar molecular fragments play a part. Evidence for the existence of such free radicals rests on the experiments of Gomberg in 1900 on triphenylmethyl in solution, on evidence for radicals such as OH, CN, and CH_2 from band spectroscopy, and on calculations of quantum mechanics on the stability of these radicals.

In 1925 H. S. Taylor provided the first evidence of a free radical chain in the hydrogenation of ethylene photosensitized by mercury vapor. In 1929 Paneth introduced the removal of metallic mirrors as a technique for testing for the presence of free radicals in gases. In 1934 Frey found that butane decomposed very slowly at 525° C., but that methyl radicals caused by the introduction of a little mercury dimethyl greatly accelerated the reaction. In the same year Sickman and Allen found that the photodecomposition of acetaldehyde was much faster at 300° than at room temperature, because at the higher temperature a chain reaction is possible. F. O. Rice made an intensive study of the aliphatic free radicals starting in 1929 and in 1934 published with Herzfeld an important paper showing how chain reactions can sometimes appear to be first- or second-order reactions, and how the length of the chain and the concentration of free radicals can be estimated from kinetic data.

Reaction rates in solution are easier to study than in the gas phase. They have been studied carefully by Brønsted, Bray, Kilpatrick, LaMer, Scatchard, Livingston, Amis, and others during the past 25 years. The ionic strength of the solution has played a part in these calculations, but its importance in certain reaction velocities was challenged in 1950 by Olson. The transition from gas phase kinetics to kinetics in solution has been investigated in the case of nitrogen pentoxide. Moelwyn-Hughes in England has made an extensive study of the kinetics of reactions in solution. Hinshelwood in England has directed many researches on chemical kinetics of gaseous reactions. Hammett has carried out researches on the kinetics of organic reactions, emphasizing the entropy of activation as related to the acidity of the solution and the molecular structure of the reactants. The kinetics of enzyme reactions has been studied by P. Wilson, B. Chance, and others.

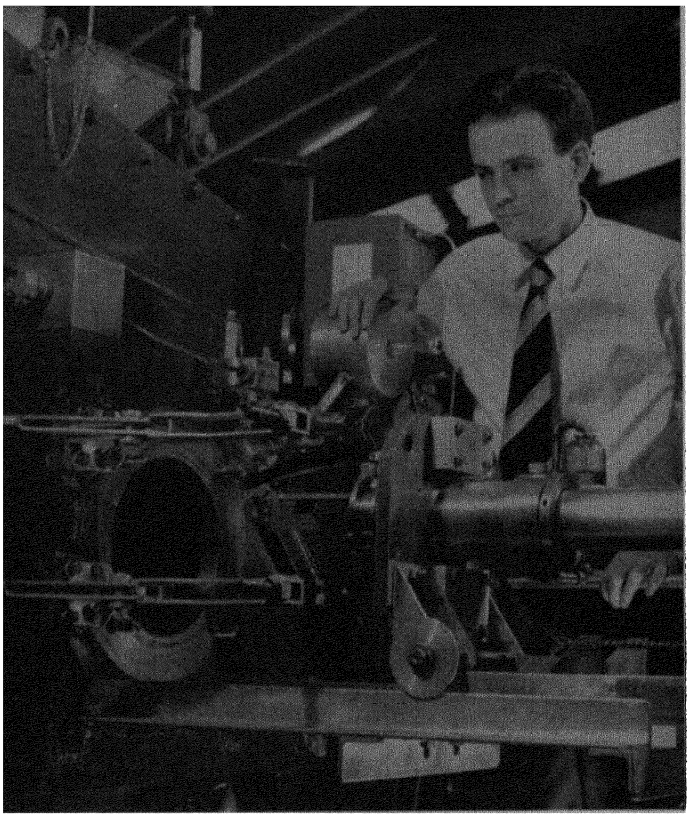
During the world war from 1941 to 1945 much of the fundamental research effort in kinetics was transferred to the kinetics of propellants and explosives, and this material is just now beginning to make its appearance in the chemical journals.

A considerable part of photochemistry may be regarded as a branch of chemical kinetics. Active in this field have been Bodenstein and Bonhoeffer in Germany, Norrish in England, and H. S. Taylor, W. A. Noyes, Jr., P. A. Leighton, Rollefson, Daniels, and several others in this country. Some of the early work in photochemistry was handicapped by an erroneous idea that one molecule should react for each photon of light absorbed, but it is fully realized now that one molecule is activated for each photon and there are many secondary reactions which follow and mask the primary process with its simple one-to-one relation. Photochemistry with its improvements in methods for producing and measuring monochromatic light is providing an excellent means for sifting out the primary reaction and unraveling some of the complications of chemical kinetics.

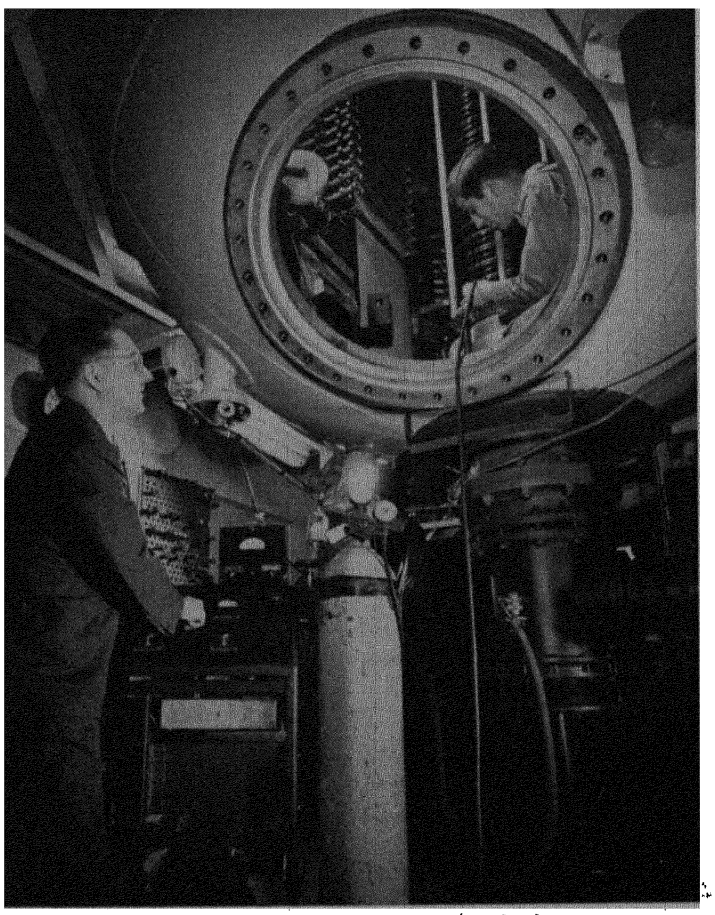
The measurement of the maximum energy efficiency in the photosynthesis of growing algae has been an active field. Most American workers find a maximum efficiency of 25%, but Warburg and his associates report a 60% efficiency. These high values are of little practical concern as yet, however, because a farmer in the northern part of the United States can store in agricultural crops only about 0.1 to 0.2% of the annual sunlight striking a given plot of land.

Catalysis is an important branch of chemical kinetics, but the art is still ahead of the science. H. S. Taylor at Princeton University has been a leader in the theoretical studies of surface catalysis. Work in heterogeneous catalysis was sponsored through the 1920's and 1930's by committees of the National Research Council which issued annual reports. Rapid advances have been made by Adkins and others in the empirical hydrogenation of organic compounds under pressure. The demands in petroleum cracking have led to the large scale use of surface-active catalysts in industrial chemistry. Brunauer, Emmett, and Teller developed an important theory of adsorption in 1938.

Molecular Structure. The great achievements of structural organic chemistry had a marked influence on the development of physical chemistry during the first two thirds of our 75-year period. Measurements of refractive index, density, optical rotation, and absorption spectra were useful to the organic chemist in establishing the arrangement of atoms within the molecule, and in turn the materials and the facts of organic chemistry were helpful to the physical chemist in establishing and testing his theories. Important new tools have been developed by the physical chemist during the past 25 years. Dipole moments calculated from measurements of dielectric constants at different temperatures, or at different dilutions, were shown by Debye in 1924 to be significant in interpreting the shapes of molecules and the arrangements of atoms from which certain chemical and physical properties can be predicted. J. W. Williams and C. P. Smyth have been prominent in measuring



University of California scientist, studying production of mesons, adjusts cyclotron target



Two Westinghouse scientists check for leaks in vacuum system of atom smasher

dipole moments and applying them to structural chemical problems. High speed centrifuges and electrophoresis apparatus are being applied to similar problems at the University of Wisconsin and elsewhere.

Electron diffraction patterns produced by passing a beam of electrons through a gas at low pressure have given important information concerning the spacing of atoms in the molecule. Wierl in Germany in 1928 and Pauling, Schomaker, Brockway, and Bauer have been among those active in developing this field. X-ray diffraction patterns in gases and vapors have been helpful also.

Infrared absorption spectra are due to atomic displacements in the molecule, and they have been very helpful in determining molecular structure. In many cases specified spectral bands can be associated with definite bonds, and so infrared spectroscopy has become of considerable importance in the identification and analysis of organic compounds. Coblentz in 1905 at the Bureau of Standards was one of the first to map the infrared spectra of many organic compounds, and Warburg and Leithauser studying the nitrogen oxides in Germany in 1909 were perhaps the first to use infrared spectroscopy for analysis. Much of the recent development has come in the laboratories of the petroleum industry.

In 1928 in India Raman discovered that atomic motions within the molecule can be studied also from measurements of the scattering of monochromatic light—the Raman effect. Many physicists and physical chemists turned quickly to these measurements and in a surprisingly short time Raman spectra had been determined for thousands of compounds. These data have been helpful in determining molecular structure. They can be used on substances dissolved in water, a significant illustration being a study of the electrolytic dissociation of nitric acid by Redlich and Bigeleisen in 1943.

Magnetic moments, their determinations, and application in chemical problems have been stressed in the last few years by Selwood.

In 1925 Franck proposed a diagram showing how the energy of a pair of atoms changes as the distance between them is varied. It was elaborated by Condon, and Morse showed how to calculate the curves from laboratory constants. These curves have found important applications in the calculations of statistical thermodynamics and kinetics.

Atomic Structure. In 1911 Rutherford proposed the nuclear theory of the atom to explain the extreme scattering of alpha-particles. Thompson had previously discovered the electron, and Rydberg had called attention to the sequence of numbers in the periodic table. In 1914, using measurements of x-ray wave lengths, Moseley showed the importance of atomic numbers. With this background of the English physicists, G. N. Lewis in 1916 announced his theory of the cubical atom (dating back in notebook form to 1902) and the concept of the electron pair. Lewis built up his atoms in the periodic table through concentric cubes, with the outer cubical shell partially or fully filled. Kossel in Germany in 1916 proposed a similar model with concentric circles. Langmuir expanded these ideas of atomic structure and emphasized the octet and the periodic table. Bohr in 1913 and Sommerfeld developed a theory of electron orbits.

At a symposium of the American Chemical Society in 1924 Lewis and Millikan held a lively debate on the relative merits of the cubical and elliptical-orbit atoms.

The relative merits of the particular models were to become less important, but the concept of the electron pair proposed by Lewis and the explanation of the periodic table and his emphasis on the behavior of polar and nonpolar compounds have all become of great importance in the development of physical chemistry and parts of organic chemistry. The different kinds of forces that hold atoms together, the chemical and physical properties of compounds, and the relations expressed by the periodic table have been provided with a useful theory.

The concept of the hydrogen bond, proposed by Lewis, Huggins, Rodebush, and Latimer, as well as the proton theory of acids and bases proposed by Brønsted, by Lowry, and by Bjerrum has been helpful in using molecular structure to predict physical chemical behavior. A still more general theory of acids based on donors and acceptors of an electron pair was proposed by Lewis in 1923.

Pauling and others have advocated the concept of resonance to explain the stability of certain types of organic substances.

Microwave spectra offer the newest means of studying molecular structure. The development of radar during the war provided the physical chemist with new means of producing radio waves of very short wave length, which are absorbed specifically by certain molecules. E. Bright Wilson and others have been active in this field.

Nuclear Structure. The discovery of radioactivity by the Curies and Becquerel in 1898, the fitting of the new radio elements into the periodic table, and the discovery of isotopes started one of the most sensational developments in all science. Most of this work was done by physicists in England, France, and Germany. Boltwood of Yale and McCoy of Chicago did some of the early work on the chemical elements associated with radioactivity. In 1913 Richards and Lembert dispelled the last doubts concerning the existence of isotopes by proving that the atomic weight of lead varies, depending on its origin from uranium or thorium. Lind carried out important researches on alpha-particles and radon and wrote a monograph on "The Chemical Effects of Alpha Particles and Electrons" (1921 and 1928). His work was a forerunner of some of our present-day work on the effects of intense radiation. The heavy chemical elements at the end of the periodic table were disintegrating spontaneously into lighter elements and helium, but it was supposed that no laboratory devices could effect nuclear disintegration. Then in 1919 Rutherford obtained evidence of the artificial disintegration of nitrogen by bombardment with alpha-particles. In 1932 the neutron was discovered by Chadwick. It was used shortly after by Joliot and Curie and by Fermi to transmute most of the chemical elements into other elements differing only slightly in weight.

Harkins was an early investigator of atomic nuclei in this country. He separated the isotopes of chlorine by the fractional distillation of hydrogen chloride and studied many branching alpha-ray tracks. In his speculations he emphasized the importance of the packing effect, proposed regularities in the stability of the elements, and hinted at a unit of matter which was later to become identified as the neutron.

In 1939 came fission. Hahn and Strassmann bombarded uranium 235 with neutrons. Because they had available the chemical techniques for detecting traces of barium and iodine and other metals, they were able to make this remarkable discovery, which was first dramatically interpreted by Meitner and Frisch as being due to the splitting of the uranium nucleus into two new nuclei of about half the original weight.

Then came with surprising speed the large scale development of atomic energy, making use of the loss of weight which accompanies fission, and the creation of energies which are millions of times greater per gram of material than can be obtained from the most violent chemical reaction. This new military potential was accompanied by something unlooked for in science—secrecy, with its potential danger to continued free research and industrial development.

The use of atomic energy for the generation of industrial electricity has been given a low priority in comparison with military and naval development since 1947, but in all such developments physical and inorganic chemists play an important part. The radiation damage to the materials of an atomic furnace, the chemical processing of the atomic fuel, and the disposal of radioactive waste material are among the most important problems. Until an actual pilot plant is built and tested which generates power on a significant engineering scale, it will not be possible to predict under what conditions atomic energy may be a future competitor with coal.

For the present, the chemist's interest in nuclear structures and nuclear energy rests chiefly in the use of isotopes. Naturally occurring radioactive lead was used by Hevesey and Paneth as a tracer in chemistry as far back as 1913, and by Hevesey in biology in 1923, and it was recognized that in these isotopic tracers lies the fulfillment of an old dream of tagging atoms and following their course through chemical reactions and biological processes.

Until 1932 isotopic tracers were largely limited to heavy, naturally radioactive elements, but then Urey discovered deuterium, the heavy isotope of hydrogen, for which he received the Nobel Prize. This powerful new research tool quickly found many new uses as an isotopic tracer. Soon afterward the production of radioactive elements by neutrons from radium-beryllium sources, cyclotrons, and other ion accelerators with millions of electron-volts made many elements available in minute quantities for tracer research. However, the use of isotopic tracers in research did not reach its present scale of activity until radioactive isotopes began to be produced in large quantities by the nuclear reactor at Oak Ridge and were made available at moderate prices by the Atomic Energy Commission.

Heavy isotopes of nitrogen, carbon, and other elements, all traceable by mass spectrometer, are used as well as radioactive isotopes. Both are being applied in many different ways in physical chemical operations, in the study of the mechanism of chemical reactions, and in a rapidly expanding program in biology and medicine.

Development of Apparatus

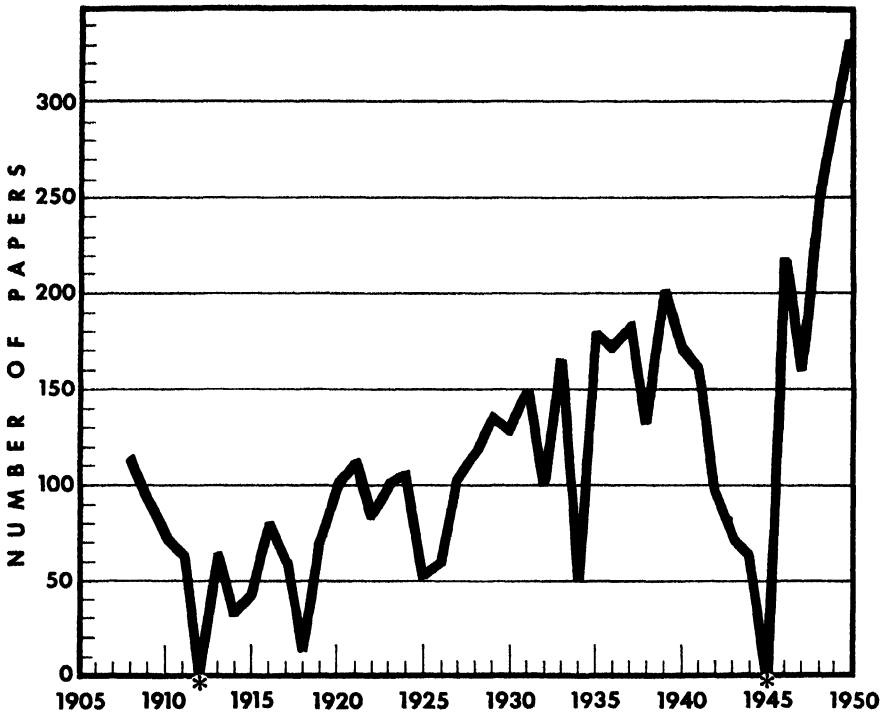
Nowadays no one can look back over the development of a science like physical chemistry without being impressed by the part which improved apparatus and new instruments play. At the turn of the century in 1901 a well equipped laboratory for the teaching of physical chemistry had perhaps a gravimetric balance, a microscope, a refractometer, a polarimeter, and a simple spectroscope. The thermostats, good to a few tenths of a degree, were controlled by the expansion of a mercury column which regulated the flow of gas into a small flame which heated the bottom of the tank, and the stirrer was connected to a large horizontal windmill operated by hot air from a gas flame. Wheatstone bridges were made from resistance boxes and resistance wire mounted on a meter stick which required hours of time for calibration. Weston standard cells were not bought; they were made by the assistant or as a special project by an advanced student. Glassblowers and mechanicians were unheard of—everyone did his own glassblowing and shop work. Progress in the laboratory and in research was slow, but resourcefulness and self-reliance were developed.

T. W. Richards between 1900 and 1927 was one of the first to emphasize the importance of improved apparatus, pure materials, and precise measurements in physical chemistry. He and his associates perfected techniques in calorimetry and in the measurement of density and other physical chemical properties. Washburn between 1915 and 1934 and later Grinnell Jones and Shedlovsky improved the accuracy of measuring conductance measurements through the design of cells and bridges and other accessories.

Many of the new research tools have been mentioned in earlier sections, but the importance of electrical apparatus and electronic devices deserves particular attention. Electrically heated, controlled, and stirred thermostats are now among the first requirements of any physical chemical laboratory. Electric rheostats, electrically driven vacuum pumps, electric furnaces,

and even electrically driven calculating machines are too common to mention. The development of the electron tube spurred by commercial radio in the past 25 years has provided physical chemistry with a wide variety of useful instruments such as relay controls, sources of current for conductance measurements, photoelectric cells, electron microscopes, Geiger counters for measuring radioactivity, and apparatus for determining dielectric constants. One of the striking developments of recent years has been the use of photoelectric cells in colorimetry and absorption spectroscopy and the widespread application of Beer's law to analysis in the visible region of the spectrum, in the infrared, and in the ultraviolet. Mercury and sodium lamps have become readily available as light sources.

Modern refrigerators for temperatures below freezing, cheap dry ice for temperatures to −80°, and liquid air for temperatures to −180° are easily procurable. These and an enormous variety of purified organic and inorganic chemicals and many compressed gases in steel cylinders we now take for granted, without realizing that earlier workers had to spend much more time in getting ready to carry out their experiments than is required at present.



Number of papers presented each year in the Division of Physical and Inorganic Chemistry. (*Denotes no national meeting of the American Chemical Society)

Much of the improvement in apparatus is due to developments by the apparatus manufacturing companies. They have come a long way since 1901 when Kahlenberg sent out a questionnaire to all professors of chemistry reading as follows: "Do you find that you can secure apparatus made in the United States of as good a grade as formerly imported? Are not most of the dealers mere importers?" Potentiometers for electrochemical cells, hydrogen electrodes and thermocouples, recording potentiometers, glass electrodes, Wheatstone bridges, galvanometers, infrared spectrographs, mass spectrometers, and optical instruments have all been greatly improved in accuracy, reliability, and ruggedness.

Importance of Mathematics

Mathematics, including the study of higher mathematics, is essential for a proper understanding of physical chemistry, but American physical chemistry at the turn of the century got off to a bad start. According to L. Kahlenberg in 1901, "Physicists need higher mathematics. Physical chemists need only arithmetic." For the first decade of the 20th century most instructors in physical chemistry tried to avoid calculus, and during the second decade still more effort was sometimes expended in using awkward arithmetical methods than would have been required to learn the simple calculus which is needed for elementary physical chemistry. Some physical chemists looked wistfully at the ability of certain physicists to express complex laboratory facts in mathematical language and thus show the way to the fundamental laws. Books on mathematical preparation for physical chemistry became available in the third decade, and by the 1930's practically no institution admitted students to physical chemistry unless they had had a standard course in calculus.

The new desire for mathematical preparation was illustrated in 1931 when a Symposium on Mathematics in the Service of Chemistry was organized for the meeting of the American Chemical Society. The organizer of the symposium demurred when he found that a room on the eighth floor seating 125 had been assigned to the symposium; but when long before opening time elevator traffic became completely jammed, another room was found to hold the 800 people who crowded in.

Calculus was enough for elementary physical chemistry, but the development of statistical mechanics and quantum mechanics has called for continuously better and better preparation in higher mathematics and theoretical physics. Statistical methods for treating data in physical chemistry are coming belatedly into use.

The next advance in mathematical application to physical chemistry will probably lie in the greatly expanded use of calculating machines, differential analyzers, and electronic integrators. In curve fitting and statistical mechanics the calculating machine is already invaluable, but much more can be done in the future in the field of chemical kinetics and the prediction of reaction rates. The machines can solve the equations of the many intermediate reactions which are usually found in any chemical reaction that is sufficiently well explored. Only a few chemical reactions are so simple that their kinetics can be handled in complete detail by the standard methods of calculus.

There is danger, though, that the pendulum may be swinging too far. Higher mathematics is often necessary, but it is no substitute for accurate experimentation and logical thinking, nor must it be used to bury fundamental postulates nor to impress the reader. The physical chemist has a challenge, because he must not only use his mathematics correctly but he is handicapped by the requirement of relating it to actual experimental systems.

THE DIVISION OF PHYSICAL AND INORGANIC CHEMISTRY

The American Chemical Society by 1903 had grown to such a point that recommendations were made to organize a Section of General and Physical Chemistry and a Section of Inorganic

Chemistry. Meetings were held semiannually in different cities and the number of contributed papers varied from about 20 to 50 in each of the two sections.

At the general meeting on December 30, 1908, the Council of the Society authorized a new combined division to be known as the Division of Physical and Inorganic Chemistry. Shortly after, January 1, 1909, with G. N. Lewis presiding, the organization was effected and Charles H. Herty was elected chairman and Harry C. Jones secretary. Bylaws were drawn up and later amended in 1935, 1937, and 1949.

The activities of the division have consisted largely in receiving, evaluating, and accepting papers for oral presentation at the general meetings of the Society, organizing symposia of timely interest, and inviting speakers on particular topics.

An effort has been made to nominate officers representing the different fields—physical, inorganic, colloid, and analytical chemistry. In 1927, however, the Division of Colloid Chemistry was organized as a separate division and in 1940 a Division of Analytical Chemistry was split off.

The Division of Physical and Inorganic Chemistry has always been one of the largest and strongest of the Society. It has tried to meet its responsibilities to the different groups within the division by organizing special symposia and grouping contributed papers of similar interest. Two or three simultaneous sessions have been necessary. This three-ring circus has its disadvantages and it throws much work on the officers of the division, but it has been reasonably successful.

The list of all the chairmen and secretaries of the Division of Physical and Inorganic Chemistry is given in the accompanying table.

Officers of the Division of Physical and Inorganic Chemistry, 1909–1951

Year	Chairman	Secretary
1909	C. H. Herty	W. D. Bancroft
1910	E. C. Franklin	S. L. Bigelow
1911	H. P. Talbot	S. L. Bigelow (R. C. Tolman pro tem.)
1912	W. Lash Miller	R. C. Wells
1913	S. L. Bigelow	R. C. Wells
1914	G. A. Hulett	H. N. McCoy
1915	G. A. Hulett (E. P. Schoch pro tem.)	H. N. McCoy (S. J. Bates pro tem.)
1916	I. Langmuir	James Kendall
1917	H. P. Talbot	E. B. Millard
1918	S. L. Bigelow	W. E. Henderson
1919	W. E. Henderson	W. A. Patrick
1920	W. D. Harkins	H. N. Holmes
1921	H. N. Holmes	S. E. Sheppard
1922	S. E. Sheppard	R. E. Wilson
1923	R. E. Wilson	Graham Edgar
1924	Graham Edgar	H. B. Weiser
1925	A. E. Hill	G. S. Forbes
1926	H. B. Weiser	G. L. Clark (F. E. Brown pro tem.)
1927	G. S. Forbes (G. L. Clark pro tem.)	Victor K. LaMer
1928	G. L. Clark	W. V. Evans
1929	Victor K. LaMer	Farrington Daniels
1930	Ward V. Evans	H. H. Willard
1931	Farrington Daniels	W. A. Noyes, Jr.
1932	H. H. Willard	D. H. Andrews
1933	W. A. Noyes, Jr.	N. H. Furman
1934	D. H. Andrews	J. W. Williams
1935	N. H. Furman	H. L. Johnston
1936	J. W. Williams	H. S. Booth
1937	H. L. Johnston	George Scatchard
1938	H. S. Booth	G. F. Smith
1939	George Scatchard	H. C. Urey
1940	G. F. Smith	W. C. Fernelius
1941	J. G. Kirkwood	R. E. Gibson
1942	W. C. Fernelius	O. K. Rice
1943	R. E. Gibson	T. F. Young
1944	O. K. Rice	P. M. Gross
1945	T. F. Young	Henry Eyring
1946	T. F. Young	Henry Eyring
1947	P. M. Gross	Martin Kilpatrick
1948	Henry Eyring	J. C. Bailar, Jr.
1949	Martin Kilpatrick	Milton Burton
1950	J. C. Bailar, Jr.	Glenn T. Seaborg
1951	Milton Burton	F. A. Long

The national meetings of the Division of Physical and Inorganic Chemistry have been an important factor in the development of chemistry, not only through the oral presentation of papers and the holding of symposia but fully as much through the opportunities offered for informal, personal discussions between physical chemists attending the meetings. Of great importance, of course, are the final publications in the scientific journals. Much credit belongs to the three editors of the *Journal of the American Chemical Society* during this period of growth—W. A. Noyes, A. B. Lamb, and W. A. Noyes, Jr. The *Journal of Physical and Colloid Chemistry* under the editorships of W. D. Bancroft and S. C. Lind and the *Journal of Chemical Physics*, started by H. C. Urey, have been helpful also in making available the results of research.

At intervals a new field in physical chemistry develops so rapidly that the average scientist cannot keep up with it. Fortunately, men are usually found who are willing to take time off to summarize the new material for the benefit of those who have had less experience with it. The *Chemical Reviews* and the AMERICAN CHEMICAL SOCIETY Monographs have kept pace with this responsibility, and the new *Annual Review of Physical Chemistry* will be helpful. The large publishing companies, too, have contributed to the development of physical chemistry by publishing advanced texts and monographs which draw together in more usable form the farflung developments of the science.

An over-all picture of the growth of physical and inorganic chemistry in the AMERICAN CHEMICAL SOCIETY is obtained from the number of papers indicated in the graph on the previous page. Both physical and inorganic chemistry papers are included, but the total number was reduced in 1927 when the Division of Colloid Chemistry split off and again in 1940 when the Division of Analytical Chemistry was organized as a separate division.

Conclusion

This history is so short that it can mention only a few of the men whose work is important in the field.

Physical chemistry is no older than many of us who read these pages. It has grown out of free and untrammeled fundamental research and the world-wide exchange of ideas. The detailed researches, taken individually, may seem to have narrow interest, but taken together they have made a science which has been basic to other sciences and to much of the technological development that is responsible for the great productivity of our nation. Each year in the United States some 10,000 students of physical chemistry, trained in an understanding of chemical behavior and of the methods of science, leave our universities to apply themselves to new investigations and to new practical problems of tremendous importance to the world in which we live.



Advertisement extolled the merits of American Cream Soap, guaranteed to take the drudgery out of wash day

Organic Chemistry

H. L. FISHER

National Research Council, Washington, D. C,

Once Wöhler refuted the old vital force theory, there was no stopping the creative ingenuity of the organic chemists

UP TO a century before the founding of the AMERICAN CHEMICAL SOCIETY, there were very few organic compounds known. Acetic acid, alcohol, sugar, and soaps were familiar to ancient peoples, indigo and alizarin were used in dyeing by the Romans and Egyptians, and Tyrian purple by the Phoenicians, and in the sixteenth century benzoic and succinic acids were discovered. Then in the latter part of the eighteenth century, the Swedish chemist Scheele isolated several organic acids from natural sources—tartaric, lactic, hydrocyanic, citric, malic, oxalic, and gallic. He prepared mucic acid from lactose and obtained glycerol ("sweet oil") from olive oil. Chemistry was awakening as a science and organic chemistry was arising as a vital part of it.

Interest in organic compounds increased, as indicated by the isolation of a number of substances chiefly of biological origin. Lavoisier proved that many of them upon being burned gave carbon dioxide and water, which indicated that they contained carbon and hydrogen. The chemistry of carbon compounds was taking shape.

In the meantime, the strange theories of phlogiston and caloric were being disposed of. Then in 1828 Wöhler prepared urea from ammonium cyanate and thus upset the theory that a "vital force" was necessary to produce organic compounds. As one writer put it, "Wöhler stood upon the threshold of a new era in chemistry as he witnessed 'the great tragedy of science, the slaying of a beautiful hypothesis by an ugly fact.' "

Berzelius is usually credited with giving the name "organic" to these new substances, although there is evidence that von Schelling of Jena in 1798 originated the term. Berzelius fought a hopeless battle for his theory of electronegative and electropositive radicals. His theory was probably better than his evidence. Then there arose the theory of types, which was of great value in the development of the science. This concept continues to this day in what is now known as the structural theory. The idea of valence slowly developed from Dalton's models, and in 1857 Kekulé and Couper independently arrived at the tetravalency of the carbon atom. A few years later, Kekulé announced the great concept of the ring structure of benzene, and then (1874) van't Hoff and Le Bel independently described the theory of the position of atoms in space—stereochemistry.

Thus, at the time of the founding of the AMERICAN CHEMICAL SOCIETY, organic chemists were already at work isolating organic compounds, determining their structures, studying their properties, and synthesizing known and new organic compounds. Chemical journals were expanding rapidly with detailed reports of their discoveries. It is no wonder that thoughtful American chemists were feeling the urge to establish their own society and their own journals.

The first paper read at the first regular meeting (May 4, 1876) of the Society after its foundation on April 6, 1876, was by Hermann Endemann, entitled "On the Determination of the Relative Effectiveness of Disinfectants." The secretary noted

that "the discussion of [the paper] closed at a late hour, on which account the papers by P. Casamajor and I. Walz were laid over till the next meeting." It was many years before time limits were placed on the presentation of papers at ACS meetings. At that same regular meeting there was adopted "Rule I. No vote of thanks shall be passed to any member of the Society for any paper or communication read before the Society."

In the next five meetings of the Society, June to October 1876, five papers were given on petroleum: "Kerosene Oil," "Explosions and Method of Testing Petroleum Oil," "Pennsylvania Petroleum," "The Quantitative Determination of Naphtha in Crude Petroleum," and "On Galician Ozokerite and Ceresine." So organic chemistry got off to an auspicious start in the meetings of the Society, even though the programs might now be considered somewhat one-sided. Interest is often a product of contemporary happenings.

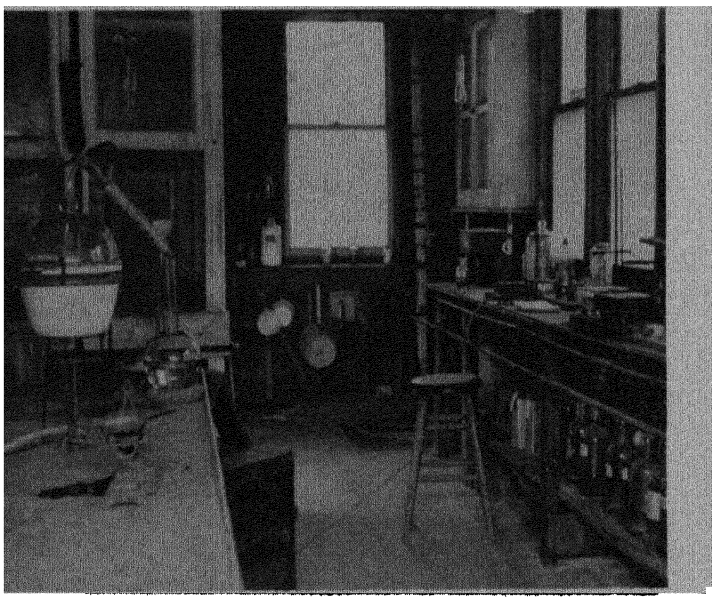
The first paper printed in the first volume of the *Journal of the American Chemical Society*, 1879, related to analytical organic chemistry: "A Method for the Detection of Artificial or Dextro-Glucose in Cane Sugar, and the Exact Determination of Cane Sugar by the Polariscope," by P. deP. Ricketts, Ph.D.

The Crucial Years, 1876–1890. Organic chemistry, especially abroad, was moving forward rapidly. During this period, Emil Fischer prepared hydrazines and used them to isolate and identify sugars as osazones. He also synthesized glucose. Friedel and Crafts perfected their synthesis of aromatic derivatives. Witt formulated his chromophore-auxochrome theory of color and gave new life to the work on dyestuffs. Baeyer synthesized indigo, proclaimed his strain theory, and did an enormous amount of work on the constitution of benzene. Tilden observed the polymerization of isoprene (from turpentine) into a rubberlike material. Victor Meyer isolated thiophene and also demonstrated the stereoisomerism of nitrogen. Kjeldahl published his method of determining nitrogen in organic substances. Laar described the "continued oscillation" of a hydrogen atom between two positions in certain molecules, naming the phenomenon "tautomerism." Claisen worked out syntheses from acetoacetic ester. Furthermore, Ladenburg carried out the first synthesis of an alkaloid, *d*-coniine from α-picoline, and, of industrial interest, Chardonnet produced "artificial silk" from nitrated cotton. Cross and Bevan made a similar product by their viscose process.

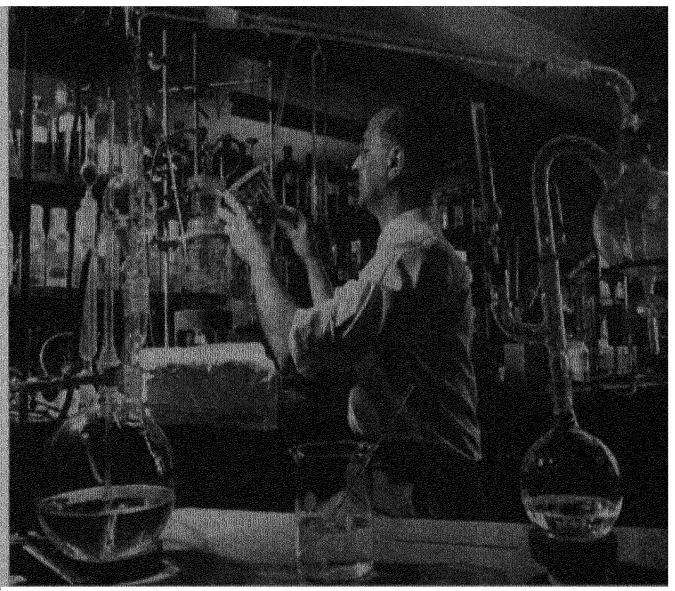
At first, scientific accomplishments in this country were not as striking as those abroad, but American organic chemists were making substantial progress. It must be remembered that the first graduate institution in which students of chemistry could obtain advanced instruction in this country, Johns Hopkins University, was not established until 1876.

Work reported in the first four volumes of the *Journal of the American Chemical Society* covered, in addition to a wide range of analytical and inorganic subjects, organic articles on new dyestuffs, derivatives of toluene and phenanthrene, illuminating gas from wood, thiocarbanilide, heptylene from heptane (from *Pinus sabiniani*), tannic acid, crystalline dextrose, bone oil, and composition of elephant's milk.

Some of the organic work of this period was published in the *American Chemical Journal*, which was founded in 1879, the same year as the *Journal of the American Chemical Society*. For example, the *American Chemical Journal* contained papers on the discovery of "benzoic sulfinide" (saccharin) by Remsen and Fahlberg, Chittenden's pioneer work in physiological chemistry, Osborne's on crystalline proteins, Conestock and Kleeberg's on nitrogen and oxygen ethers of compounds containing the grouping —NHCO—, contributions to the chemistry of camphor by W. A. Noyes, Stieglitz's work on imido esters, Kohler's on unsaturation, and Dakin's principle of β-oxidation in biochemical transformations. After this journal reached its fiftieth volume, it was merged with the *Journal of the American Chemical Society* in 1914.



Corner of Baekeland's laboratory in Yonkers, N. Y., complete with distillation apparatus, pots, and pans (1910)



Modern organic laboratory at Beltsville Research Center, where chemist is at work on new insecticide

Abroad, Emil Fischer continued to make historic contributions to organic chemistry. After his remarkable work on the sugars, he cleared up much of the chemistry of the purines and then laid the foundation for the chemistry of the proteins. Thiele stated his partial valence theory and its applications. Grignard discovered the most prolific method of synthesizing organic compounds, the Grignard reaction. Werner proposed his coordination theory, Sabatier gave the chemical world the catalytic method of hydrogenation, and Walden discovered the stereochemical inversion that carries his name.

In this country, the great organic experimenter Nef accomplished an enormous amount of work on the course of many chemical reactions, including those to demonstrate his theory on the existence of divalent carbon. Takamine isolated adrenaline, Gomberg discovered triphenylmethyl and established that carbon

exists in a trivalent form (explained more recently by the theory of resonance). Arthur Michael accomplished the first synthesis of a glycoside (salicin) (1883) and made many investigations bearing on the fundamental laws and theory of organic chemistry.

The Second 25 Years of the ACS, 1901–1926

During this period, organic chemistry grew rapidly, especially after World War I. This growth can be measured, in part, by comparing the number of students who received the degree of Ph.D. In the four years 1898 to 1901, 113 students were awarded this degree in chemistry, and of these only nine were in organic chemistry, an average of 2.25 a year. However, in the school year 1925–26, 256 students were awarded this degree in chemistry, and of these 98 were in organic chemistry. When Svante Arrhenius was awarded his doctor's degree at Uppsala in 1884, a laurel wreath was placed on his head and a cannon boomed the advent of another doctor of philosophy. If this custom had been followed in this country when organic and other chemists were being turned out in large quantities as doctors of philosophy, some of our universities at graduation time would have been noisy places, indeed.

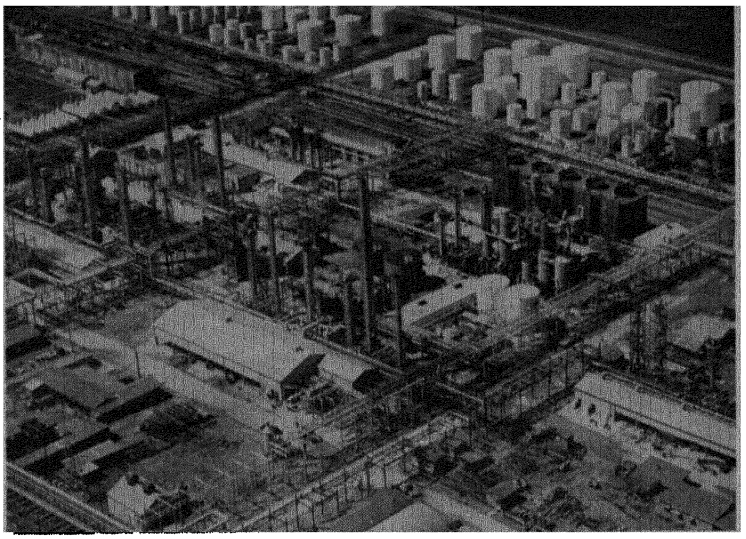
The chemistry departments of prominent universities were improving or building new laboratories, and students with graduate training had little difficulty in obtaining positions as teachers or research chemists in industry.

Organic chemists were doing a great deal of research in the synthesis of compounds and some were even criticized for "just filling up Beilstein." However, these Beilstein synthetic compounds very soon became of wonderful service, as organic and physical chemists applied the principles of physical chemistry to obtain an understanding of type reactions and to determine the structure of compounds and their rates of reaction. Industrial organic chemistry was expanding rapidly, and organic chemists helped much to bring compounds out of the test-tube stage into the plant, especially during the war when German supplies were cut off. Dyestuffs, pharmaceuticals, cosmetics, solvents, photographic chemicals, compounds for the rubber and paint and varnish industries—all were in great demand during World War I. Organic chemistry boomed.

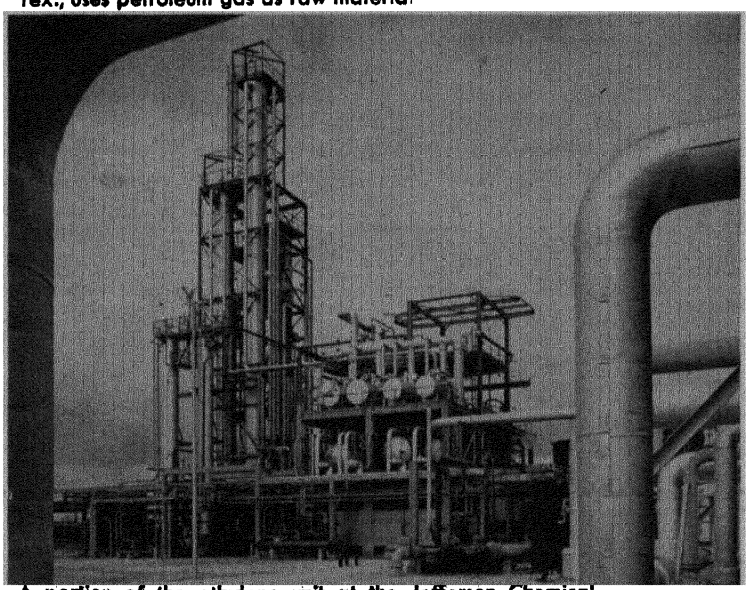
In this country, chemists had depended almost entirely on Germany for their supplies, especially organic chemicals. When the war halted these shipments, C. G. Derick of the department of organic chemistry at the University of Illinois organized a vacation class in 1916 to prepare organic chemicals in somewhat larger quantities than those ordinarily synthesized in the regular laboratory courses. The chemicals prepared in this way were used by the department the following year. He left university work shortly afterwards, and Roger Adams, his successor, took over and enlarged the work and thus helped many organic chemists at Illinois and other institutions. In order to make the chemicals available to a wider group, a central clearinghouse was needed, and E. E. Reid and the writer were appointed by the Division of Organic Chemistry as a committee of two to find a solution to the problem. While they were beginning their work and visiting possible interested companies, C. E. K. Mees of the Eastman Kodak Co. announced at a meeting of the division in 1918 that his company had decided to begin the preparation of organic chemicals, to purify chemicals obtained from industrial chemical companies, and to supply the American market. This service was of great benefit to organic research workers and has continued to the present time.

Out of the work at the University of Illinois grew the publication of detailed practical methods of preparing organic compounds, first in a series of pamphlets, then in those exceedingly useful annual volumes of "Organic Syntheses."

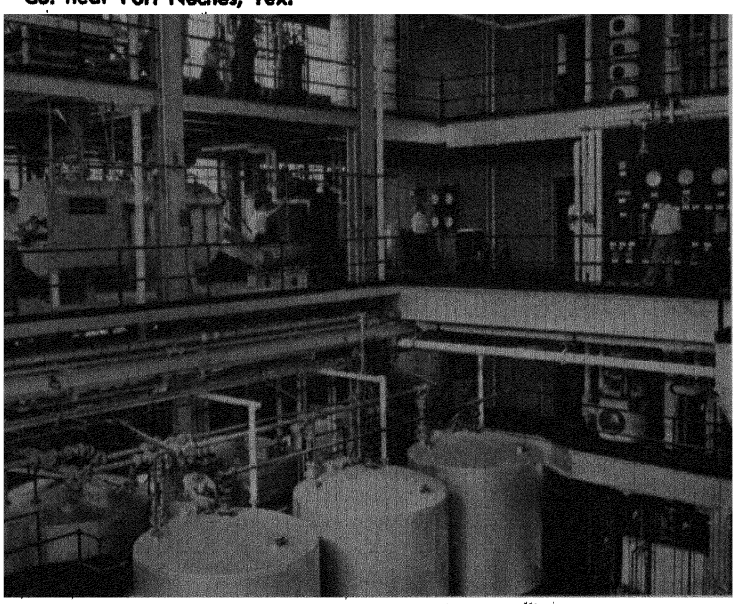
Again, let us take a look at the work of organic chemists abroad. Harries discovered the ozonides and their value as a means of locating double bonds. By this method, Harries



Shell Chemical's giant synthetic glycerol plant at Houston, Tex., uses petroleum gas as raw material



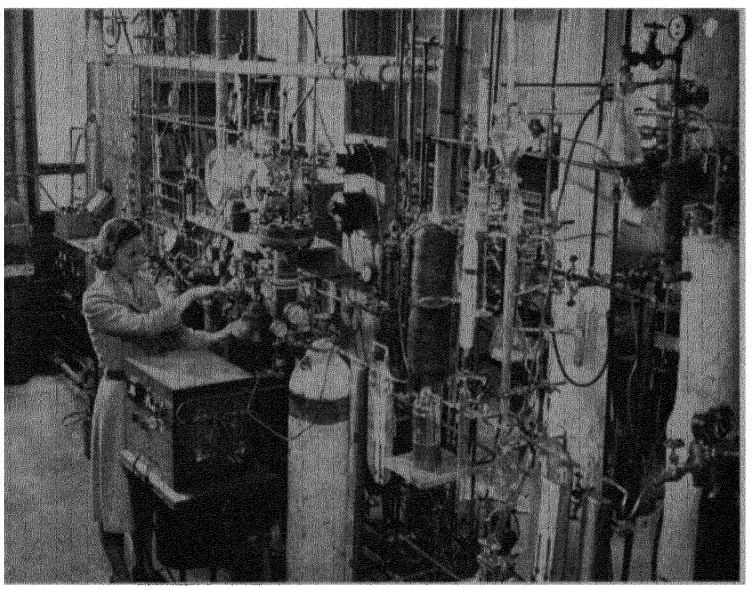
A portion of the ethylene unit at the Jefferson Chemical Co. near Port Neches, Tex.



Department of Agriculture pilot plant at Peoria, Ill., tests new processes for making alcohol from farm products

unraveled the chemical nature of the rubber hydrocarbon. At the Eighth International Congress of Applied Chemistry in New York in 1912, Perkin discussed, with demonstrations, the work of English chemists on the synthesis of rubberlike products from butadiene and isoprene. In 1915 Ostromislensky published his famous work on the synthesis of butadiene and isoprene and their polymerization to synthetic rubbers. Willstätter did his notable work on the constitution of chlorophyll and the anthocyans; P. Ehrlich prepared salvarsan; Pregl performed his important service for organic chemists by perfecting methods of microanalysis; Ruzicka and also Butenandt synthesized hormones; Haworth formulated sugars as chiefly δ-oxides or pyranose derivatives; Ruzicka synthesized multimembered carbon rings; and Harington synthesized thyroxin, which had been isolated 10 years before by Kendall in this country.

And in this country, P. A. Levene at the Rockefeller Institute for Medical Research solved the riddle of the nucleic acids (the first paper on organic chemistry heard by the writer, in New York, 1910) and other biologically important substances; Marston T. Bogert at Columbia University synthesized many substances in the fields of nitrogen heterocycles, dyestuffs, and terpenes; Treat B. Johnson at Yale University similarly synthesized numerous compounds in the pyrimidine and purine fields; C. S. Hudson of the Bureau of Chemistry of the U. S. Department of Agriculture announced his rules of isorotation, outlined the configuration of sugars (including α- and β-isomers), and synthesized many sugar derivatives; E. P. Kohler of Harvard University advanced the theoretical understanding of addition reactions; W. A. Noyes of the University of Illinois worked on the problem of positive and negative valences; and Julius Stieglitz of the University of Chicago not only contributed to our knowledge of molecular rearrangements but also applied physicochemical methods to the solution of other problems in organic chemistry. S. P. Mulliken of Massachusetts Institute of Technology brought out remarkable books on the identification of organic compounds. This series has had a usefulness and influence far greater than originally expected.



Research worker at the Mellon Institute delves into complex problem in organic chemistry

In 1915 W. L. Bragg came to America from England and gave lectures on the structure of compounds as determined by x-ray analysis. His lectures and demonstrations were particularly interesting because they confirmed many conclusions previously reached by organic chemists, especially with regard to the cyclic structure of crystalline benzene and naphthalene.

Division of Organic Chemistry. Up to and through the thirtieth meeting of the Society held in Providence, R. I., June 21 to 23, 1904, there were only general sessions at each ACS meeting. In other words, there was only one program which occupied one or more sessions. Many members were becoming restive; an industrial chemist was not interested in listening to papers on biological, organic, or physical chemistry, and vice versa. At the meeting of the Council at Providence, it was moved that "it is the sense of the Council that at the Philadelphia meeting the Society should meet in part in general session and in part in sections." Therefore, at the Philadelphia meeting, December 28 to 31, 1904, according to the record in the *Proceedings*, there was a general session and then "the general session adjourned and the Society met in sections at 11:30 A.M. and again at 2:30 P.M." Papers were presented in five sections—Physical Chemistry; Agricultural, Sanitary, and Physiological Chemistry; Industrial Chemistry; Inorganic Chemistry; and Organic Chemistry. James F. Norris was chairman of the Organic Section.

The practice of meeting in sections evidently was successful, because the Society continued to meet in general session followed by sectional sessions. The chairmen of these Organic Sections were Marston T. Bogert, Buffalo, June 22 to 24, 1905; Charles F. Mabery, New Orleans, December 29 to January 2, 1905–06; G. B. Frankforter, Ithaca, June 28 to 30, 1906; A. S. Wheeler, New York, December 27 to 31, 1906; J. Bishop Tingle, Toronto, June 27 to 29, 1907; Julius Stieglitz, Chicago, December 31 to January 3, 1907–08; Wm. McPherson, New Haven, June 30 to July 2, 1908; and S. F. Acree, Baltimore, December 29 to January 1, 1908–09.

At the meeting of the Organic Section, December 30, 1908, it was voted to petition the Council of the Society for a Division of Organic Chemistry. The Council having granted this petition, the division was given a temporary organization, December 31, by the election for one year of a chairman, Richard S. Curtiss, and a vice chairman and secretary, Ralph H. McKee. The Division of Organic Chemistry met officially as a division at the Detroit meeting of the Society, June 29 to July 2, 1909. At the same time President Whitney appointed J. F. Norris, S. P. Mulliken, and William McPherson as a committee to report on the constitutionality of the bylaws of the division, and these were shortly afterward passed by the Council.

At this point, it is desirable to quote from Secretary Parsons' history of the divisions in the Golden Jubilee Number of the *Journal*.

> In no country but our own have the pure and applied chemical scientists been able to work together in one organization with mutual appreciation and without serious jealousies. This is one of the chief secrets of the success of the AMERICAN CHEMICAL SOCIETY, which was brought about through the wise foresight of President Bogert, who clearly foresaw that the Society was likely to disintegrate unless some method was devised by which specialists in various branches of chemistry might gather together in essentially autonomous meetings. Accordingly, he inaugurated the divisional system, establishing first the Division of Industrial and Engineering Chemistry, followed gradually by others... No wiser step has been taken in the Society's development than the organization of the divisional system.

More Chemistry. Before leaving this second 25-year period, it would be well to mention a few more advances in chemistry that occurred during that interval. War chemicals, specifically mustard gas, were developed and put into large scale production. Two other compounds, chlorodihydrophenarsasine (adamsite) and chlorovinyldichloroarsine (lewisite), were developed by and named after two university professors, Roger Adams and W. Lee Lewis. It seems odd that it fell to the lot of two gentlemen of the classroom to develop two such obnoxious war chemicals, but "C'est la guerre."

It was also in this general period that Thomas Midgley, Jr.,

who was trained as a civil engineer, discovered the use of tetraethyllead as an antiknock compound. This chemical is important not only because of its effectiveness but also because after over 25 years it still is paramount in its field and evidently has no competition. Its discovery was the result of a highly systematic search for organometallic compounds that are derivatives of elements in a particular part of the periodic system.

J. B. Conant determined oxidation-reduction potentials, especially in the quinone group, and studied the relation between structure and the rate of reaction of certain organic compounds. R. R. Renshaw increased our knowledge of organic onium compounds. F. C. Whitmore prepared organomercuric compounds, and Henry Gilman improved methods of using the Grignard reaction.

G. N. Lewis paid a real tribute to the work of organic chemists when he wrote, "Structural organic chemistry, although developed without mathematics, except of the most elementary sort, is one of the very greatest of scientific achievements... It is this system of structural chemistry that served chiefly as my basis when I advanced my theory of valence." Irving Langmuir developed Lewis' theory further emphasizing the importance of electron octets in the basic mechanism of chemical reactions. Langmuir also demonstrated the physical condition of long-chain acids and soaps on the surface of water with the hydrophilic carboxyl and the corresponding salt in the water and the hydrocarbon chains extending outward from the surface in a monomolecular layer, the thickness of which corresponds to the number of carbon atoms in the chain.

The Third 25 Years of the ACS, 1926–1951

Organic chemistry covers many fields, and naturally it became the mother of several offspring which evolved into divisions of the Society. These are the Divisions of Biological, Cellulose, Gas and Fuel, High Polymer, Industrial and Engineering (in part), Medicinal, Paint, Varnish and Plastics, Petroleum, Rubber, and Sugar Chemistry. Accordingly, the names of many investigators and their work are found in the histories of these special branches instead of in this history of the mother science.

Science is considered to be impersonal by some people, but to the writer it is very personal. Who can think of induced electric currents without thinking of Faraday, of the law of gravitation without Newton, of penicillin without Fleming, of triphenylmethyl without Gomberg? It is difficult, therefore, to discuss the advancements in chemistry without at least mentioning the chemists who made them. However, it must be said that in the past 25 years there have been many changes in scientific methods and in the methods of scientists. Now laboratory work is done much more than ever in groups. Modern apparatus and group efforts have made it possible to produce wonderful results in a short time. Cooperation is the watchword. A biochemist in Hungary, Szent-Györgi, isolates a very large and unheard-of amount of vitamin C and generously sends it to an organic chemist in England, Haworth, who, with the assistance of a group of trained associates, determines its structure and then synthesizes it—all in the matter of months.

What are some of these differences in laboratory apparatus and methods? Even half a century ago, there was no borosilicate laboratory glassware, no or very little silica apparatus, no glass equipment with standard-taper ground-glass joints, no simple cheap vacuum pumps, no molecular stills, no stainless steel, no pH meters, no this, no that. Microanalytical methods were not yet devised to speed up work on very small quantities of material. There were practically no machines for making rapid calculations.

How then can all the chemical achievements of the past 25 years be appraised and how recorded in the brief space allotted? The problem is difficult. About all the writer can do is to make a survey and try to pick out what appears to him to be the high spots of the American scene. These will appear differently to different people, and the author will be criticized whatever material he chooses. Also, the selection will depend partly on his fallibility as a human being and upon the course of his life and contacts.

In the first 25 years of the Society, organic chemistry was concerned largely with benzene and its derivatives—namely, aromatic chemistry. Some of the types studied had complicated structures, but, because they usually crystallized well and could be readily purified, they lent themselves to the processes then known for the study of compounds. Many a mess went down the sink or into the waste jar because it seemed too difficult to handle. As time went on and organic chemistry came into its own in this country, chemists turned toward some of the "neglected" chemicals and also to such cheap raw materials as natural gas and petroleum, alcohol, and other products of fermentation. Thus aliphatic chemistry grew and later far overshadowed aromatic chemistry.

National Symposium of Organic Chemistry. At the beginning of this third 25-year period, American organic chemists began to feel that they wanted more time for meetings than was provided at the two national meetings of the Society for the discussion of papers and organic problems in general. To fill this need, the National Symposium of Organic Chemistry was organized. The first meeting was held in Rochester, N. Y., December 29 to 31, 1925, under the chairmanship of Marston T. Bogert. About 175 members were present. The meeting was so successful that the symposia were continued every other year at about the same time until the ninth program in 1941, after which no more were held until 1947 because of the war. After the first program, the speakers at the symposia were chosen by ballot from lists proposed by the membership of the division and its executive committee. Usually about 15 papers were presented. Attendance quickly doubled and then almost trebled, reaching 488 at the ninth meeting. The tenth symposium was held in Boston, June 12 to 14, 1947, and the eleventh in Madison, Wis., June 20 to 22, 1949.

It seems worth while to mention some of the papers given at these symposia because they indicate the type of chemical work carried out and the fields of the authors. Several Nichols and Willard Gibbs medalists were also among those who gave papers.

WALLACE H. CAROTHERS. Polymerization, with Special Reference to the Polyesters.
C. S. MARVEL. Hexa-Substituted Ethanes Containing Acetylene Groups and Some Reactions of Vinylacetylene and the Synthetic Rubber Program.
F. C. WHITMORE. I. Intramolecular Rearrangements. II. The Mechanism of the Polymerization of Olefins.
E. C. BRITTON. The Hydrolysis of Aromatic Compounds.
L. F. FIESER. Phenanthrene Derivatives Related to Natural Products.
VINCENT DU VIGNEAUD. The Hormones Challenging the Organic Chemist.
R. R. WILLIAMS. Chemistry of Thiamine.
E. A. DOISY. Vitamin K. Assay, Isolation, Constitution, and Synthetic Compounds.
RUDOLPH SCHOENHEIMER. Chemical Reactions of Constituents of Normal Animals Studied with Isotopes.
KARL FOLKERS. Chemistry of Vitamin B_6.

At the Organic Symposium in Rochester, 1936, announcement was made that the division would sponsor a new publication, *Journal of Organic Chemistry*.

A few words more about the Organic Division. At the beginning, each secretary held office for two years, then there was one three-year period, and a four-year period, and starting with 1925 the secretaries have been elected to serve for five years each.

Chairmen of meetings always had difficulties in keeping some speakers from taking too much time. The officers of the division attempted to solve the problem by the use of an alarm clock, set to give a two- or three-minute warning. It helped, but did not always solve the problem. Nieuwland, who worked in acetylene chemistry and often had explosions in his laboratory, never got used to the alarm. He always jumped at the

sound, even when he was looking at the face of the clock. Later, scheduled programs did solve the problem of overtime speakers.

The first joint session of the division with other ACS divisions was held at Milwaukee, September 5 to 9, 1938. There were several joint sessions with the High Polymer Forum, beginning at Atlantic City, April 8 to 16, 1946, and through the New York meeting, September 15 to 19, 1947. At Chicago, April 19 to 23, 1948, there was one double meeting of the division—that is, two concurrent sessions; another double meeting at Atlantic City, September 18 to 23, 1949; four concurrent sessions at Philadelphia, April 9 to 13, 1950; and five concurrent sessions at Chicago September 3 to 8, 1950. At this last meeting, 165 papers were read—the largest number on record.

From programs of the Organic Division the following indicate the progress of our science in this country. The order is chiefly chronological.

R. H. KIENLE. The Polyhydric Alcohol–Polyhydric Acid Reaction. I. Glycerol-Phthalic Anhydride.

T. MIDGLEY JR., and A. L. HENNE. Organic Fluorides as Refrigerants. One of these was demonstrated with the characteristically superb showmanship of the senior author.

F. O. RICE. The Thermal Decomposition of Organic Compounds into Free Radicals.

H. T. CLARKE. Vitamin B_1. The Sulfur-Containing Moiety.

L. G. S. BOOKER. Cyanin Dyes.

R. C. ELDERFIELD and W. A. JACOBS. The Structure of the Cardiac Aglucones.

M. S. KHARASCH. "Normal" and "Abnormal" Additions of HBr to Ethylene Derivatives.

LEE IRVIN SMITH. Studies on Vitamin E, the Structure and Synthesis of α-Tocopherol.

ROGER J. WILLIAMS. Present Status of the Chemistry of Pantothenic Acid.

Mention is also made of hydrogenation and hydrogenolysis with Raney nickel and copper chromite catalysts by Homer Adkins, study of allylic rearrangements by A. C. Cope, the nitration of aliphatic hydrocarbons by H. B. Hass, and the synthesis of quinotoxine by R. B. Woodward, who thus completed the long-awaited synthesis of the famous alkaloid, quinine. Using heavy oxygen, Harold Urey established the course of esterification, showing that the oxygen in the water formed comes from the hydroxyl in the carboxyl group, a mechanism that had been indicated by E. E. Reid long before in his work on mercaptans and thio acids.

W. E. Bachmann synthesized phenanthrene compounds and related substances. Paul D. Bartlett used physicochemical methods in studies of organic reactions, including rearrangements, and the polymerization of allylic compounds. R. C. Fuson studied vinylation. C. D. Hurd pyrolyzed organic compounds and indicated the course of decomposition. John R. Johnson synthesized antibiotics and highly unsaturated compounds. S. M. McElvain made many ketene acetals. A. A. Morton pointed out the relative acidities of hydrocarbons by reactions of their sodium derivatives and discovered a catalytic method of polymerizing diene hydrocarbons to rubberlike products.

Syntheses from carbon monoxide and hydrogen, cracking of hydrocarbons, alkylation and isomerization of hydrocarbons (V. N. Ipatieff), polymerization of several types of organic compounds, and the great synthetic rubber program, sulfa drugs, antimalarials, the use of isotopes in ferreting out the mechanism of organic reactions, hydrogen bonding, resonance, ultraviolet and infrared absorption phenomena and their interpretations—the list of wonderful accomplishments goes on and on. In a way, it brings to mind a statement said to have been made by Gmelin when he was trying to complete his chemical dictionary. He wrote to Liebig in frustration: "For heaven's sake, please stop your work until I get my dictionary published." However, there is no stopping and there is no end.

The writer likes to think of a remark made by P. A. Levene at the close of a lecture on the chemistry of the sphingomyelins: "When we know all about the structure of all the substances in the human body and how they react, then there will still remain the riddle of life itself."

Officers of the Division of Organic Chemistry, 1910–1951

Year	Chairman	Secretary
1910	E. C. Franklin	R. H. McKee
1911	G. B. Frankforter	William J. Hale
1912	Treat B. Johnson	William J. Hale
1913	Treat B. Johnson	William J. Hale
1914	B. F. Allen	C. G. Derick
1915	B. F. Allen	C. G. Derick
1916	C. G. Derick	Harry L. Fisher
1917	J. R. Bailey	Harry L. Fisher
1918	William J. Hale	Harry L. Fisher
1919	L. W. Jones	Harry L. Fisher
1920	E. E. Reid	Roger Adams
1921	Roger Adams	H. T. Clarke
1922	H. T. Clarke	Frank C. Whitmore
1923	Frank C. Whitmore	R. R. Renshaw
1924	R. R. Renshaw	J. A. Nieuwland
1925	J. A. Nieuwland	Frank C. Whitmore
1926	Marston T. Bogert	Frank C. Whitmore
1927	F. B. Dains	Frank C. Whitmore
1928	William Lloyd Evans	Frank C. Whitmore
1929	E. C. Franklin	Frank C. Whitmore
1930	Frank C. Whitmore	Arthur J. Hill
1931	James B. Conant	Arthur J. Hill
1932	Homer Adkins	Arthur J. Hill
1933	C. S. Marvel	Arthur J. Hill
1934	Claude S. Hudson	Arthur J. Hill
1935	Arthur J. Hill	Ralph L. Shriner
1936	Henry Gilman	Ralph L. Shriner
1937	L. C. Raiford	Ralph L. Shriner
1938	Lyndon F. Small	Ralph L. Shriner
1939	Werner E. Bachmann	Ralph L. Shriner
1940	Cliff S. Hamilton	Arthur C. Cope
1941	Nathan L. Drake	Arthur C. Cope
1942	Lee I. Smith	Arthur C. Cope
1943	Louis F. Fieser	Arthur C. Cope
1944	Ralph L. Shriner	Arthur C. Cope
1945	S. M. McElvain	Ralph W. Bost
1946	S. M. McElvain	Ralph W. Bost
1947	Arthur C. Cope	Ralph W. Bost
1948	Paul D. Bartlett	Ralph W. Bost
1949	William G. Young	Ralph W. Bost
1950	Ralph W. Bost	Nelson J. Leonard
1951	William S. Johnson	Nelson J. Leonard

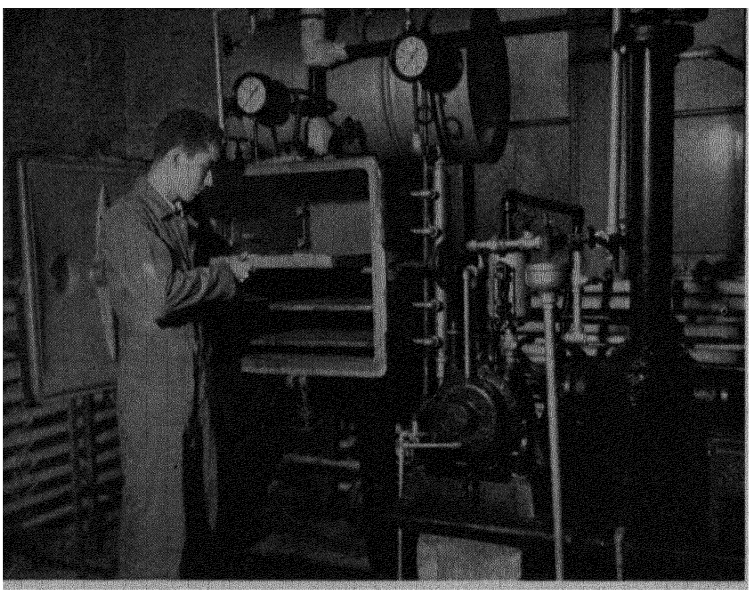
Every vital industry in America owes an enormous debt to the industrial chemist and chemical engineer

Industrial and

W. A. PARDEE
Gulf Research and Development Co., Pittsburgh, Pa.

AMONG all the fields of chemical endeavor the expression of American talent is nowhere more striking than in the industrial application of our store of scientific knowledge. The countless natural riches of our nation have provided fertile soil indeed for the expression of those skills. The past 75 years reveal an astounding growth. Today, that growth has proliferated until virtually every major industry owes an important debt to the industrial chemist and chemical engineer, and the chemical process industries have assumed the lead position on the American industrial scene.

Accounts will be given of developments in many of the chemical process industries elsewhere in this historical series. However, the story is not complete without a description of the advances in basic technology, both engineering and chemical, that are the common denominator for many of the advances in a specific industry. This historical section is devoted to that broad theme. It also includes histories of several important chemical process industries that do not fall within the logical scope of the other sections of the 75-year review.



Research chemical engineer operates experimental vacuum drying equipment

UNIT OPERATIONS

T. H. CHILTON
E. I. du Pont de Nemours & Co., Inc.
Wilmington, Del.

THE concept of unit operations dates back scarcely half way in the 75 years' history of the AMERICAN CHEMICAL SOCIETY. It was in 1915 that the late Arthur D. Little (*11*) introduced this conception, in a report to the Corporation of the Massachusetts Institute of Technology.

Any chemical process, on whatever scale conducted, may be resolved into a coordinated series of what may be termed "unit actions," as pulverizing, mixing, heating, roasting, absorbing, condensing, lixiviating, precipitating, crystallizing, filtering, dissolving, electrolyzing, and so on. The number of these basic unit operations is not very large, and relatively few of them are involved in any particular process. The complexity of chemical engineering results from the variety of conditions as to temperature, pressure, etc., under which the unit actions must be carried out in different processes, and from the limitations as to materials of construction and design of apparatus imposed by the physical and chemical character of the reacting substances. An ability to cope broadly with the demands of his profession can be attained only through the analysis of processes into the unit actions of which they are composed, and the close study of these basic unit actions as they are carried out on the commercial scale under the conditions imposed by practice.

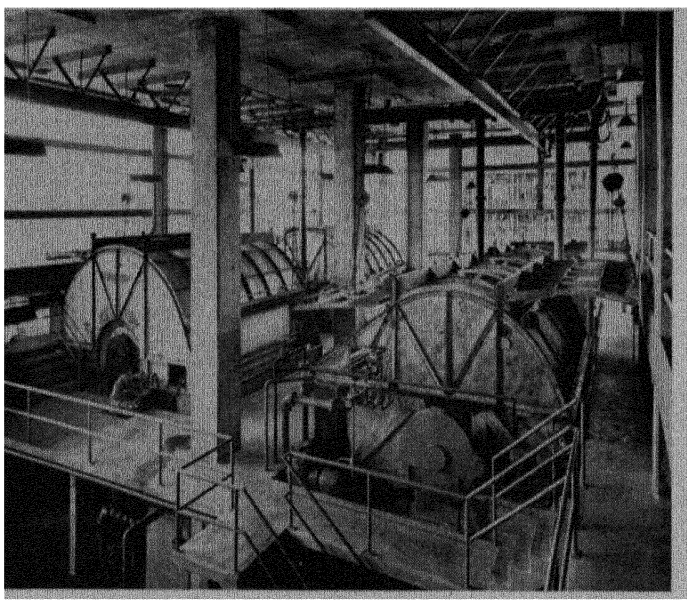
This concept found immediate acceptance at MIT. It became the inspiration of a whole school of teaching and research, there and elsewhere. It formed the basis of the outline of a work on the principles of chemical engineering, developed over the course of several years as mimeographed notes, and finally as the text (*18*) bearing that title, with these historic words in the preface:

Just as the arts of tanning and dyeing were practiced long before the scientific principles upon which they depend were known, so also the practice of chemical engineering preceded any analysis or exposition of the principles upon which such practice is based. The unit operations of chemical engineering have in some instances been developed to such an extent in individual industries that the operation is looked upon as a special one adapted to these conditions alone, and is, therefore, not frequently used by other industries. All important unit operations have much in common, and, if the underlying principles upon which the rational design and operation of basic types of engineering equipment depend are understood, their successful adaptation to manufacturing processes becomes a matter of good management rather than of good fortune.

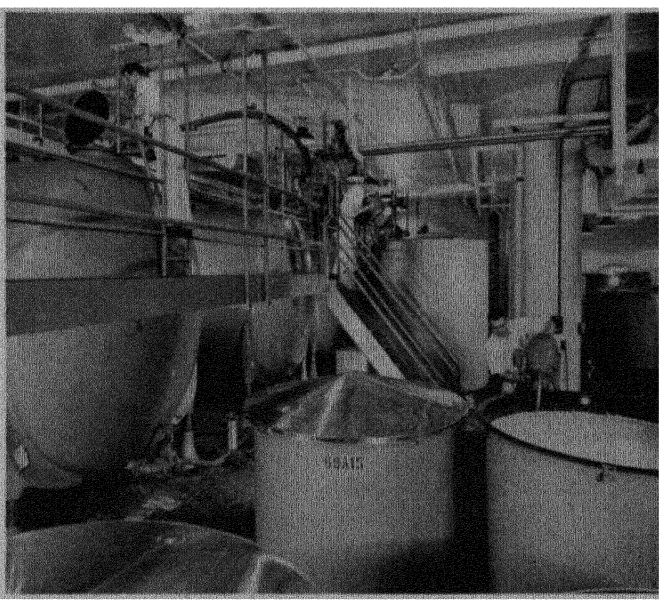
In this book we have attempted to recall to the reader's mind those principles of science upon which chemical engineering operations are based, and then to develop methods for applying these principles to the solution of such problems as present themselves in chemical engineering practice. We have selected for treatment basic operations common to all chemical industries, rather than details of specific processes, and so far as is now possible, the treatment is mathematically quantitative as well as qualitatively descriptive. We venture to hope that the book will stimulate engineers to design apparatus adapted for any particular purpose, rather than just to build it and then to rely on large scale experimentation with expensive changes in construction to effect efficient operation.

Little did not clearly differentiate in his "unit actions" between "unit operations" and "unit processes." Following the adoption of the first by Walker, Lewis, and McAdams, this term,

Engineering Chemistry



Filtration Section at Corn Products Refining plant. The room is only partially enclosed



Fundamental unit operation, mixing, is put into practice in sparkling new industrial plant

"unit operations," has come to represent the primarily physical treatment steps that make up a chemical manufacturing process. Following the adoption of the title "Unit Processes in Organic Synthesis" by Groggins (*4*), this term has come to imply the occurrence of a distinct chemical change, rather than a mere physical treatment.

The unit operations concept formed the inspiration for the researches that were reported in a memorable series of symposia held by the Division of Industrial and Engineering Chemistry in 1921 on drying (*8*); in 1922 on distillation (*9*); in 1924 on heat transfer (*6*); and in 1924, also, on absorption (*14*).

As Stine (*17*) stated in 1928:

> Perhaps the characteristic which most differentiates the chemical engineering of today from the earlier activities of those interested in this field is the quantitative treatment of these various unit operations, and it is this exact and quantitative treatment of these operations which constitutes the province of modern chemical engineering.

There was, of course, chemical engineering before 1915, when the unit operations concept was formulated. There was a chemical manufacturing industry before 1908, when the Division of Industrial and Engineering Chemistry was established (under the original name "Industrial Chemists and Chemical Engineers"), and the American Institute of Chemical Engineers was founded. There was a chemical industry, even in 1876 when the AMERICAN CHEMICAL SOCIETY was founded. But the concept of chemical engineering as a profession and as a body of science emerged slowly during the period. Little (*11*) records one line of this development:

> Although industrial chemistry in its modern sense may be said to have begun as long ago as the French Revolution with the invention by Le Blanc of the soda process, it was nearly one hundred years thereafter before chemical engineering began to be dimly recognised as a distinct profession. In November 1887 the faculty of Massachusetts Institute of Technology appointed a committee "to consider instruction in engineering as relating especially to applied chemistry," and in the faculty meeting of that year it was voted to establish a course in chemical engineering. The course schedule was adopted in February 1888 and went into effect the following autumn, the first class in chemical engineering ever graduated receiving its diplomas from the institute in 1891.

Only one other school had adopted a curriculum in chemical engineering up to the turn of the century—the University of Michigan.

In England in 1880, a movement was instituted to form a "society of chemical engineers." The society defined a chemical engineer as "a person possessing knowledge of chemistry, physics, and mechanics, and who employs that knowledge for the utilisation of chemical reactions on a large scale" (a definition closely paralleling the one adopted in 1948 by the American Institute of Chemical Engineers). But the time was not then ripe, and what emerged was the now venerable Society of Chemical Industry.

G. E. Davis, who took part in the movement referred to, gave a series of lectures on chemical engineering at the Manchester Technical School in 1887. These lectures were later enlarged and published (*3*), first in 1901. The following, referring to the period 1876–1901, has a strangely modern sound:

> There have been many changes in manufacturing chemistry during the last quarter of a century....During the period under review, there has been no change in the chemistry of the situation. Chemists, it is true, have a much greater knowledge of the methods of substitution, of isolation, and of recombining different and various organic radicals, and to their researches we owe much of our present prosperity in the chemical trade; but the greatest progress has been made in the mechanism of plant and in the way in which chemical operations have been carried out on the large scale. Though chemical operations are now much more intricate than they were a quarter of a century ago, they are carried out less expensively, and with greater safety to the workpeople, and at least the moiety of this improvement must be credited to the chemical engineer.

The chapter headings of Davis's two-volume work published in 1904 would not look unfamiliar if they were used in a 1950 text on unit operations:

Moving solids, liquids, and gases
Treating and preparing solids
Application of heat and cold
Separating solubles from insolubles
Absorbing and compressing gases
Evaporation and distillation
Crystallization and dialysis

He even included a section on safety practices.

But most of the treatment was descriptive, and its essentially qualitative character can be inferred from the statement accompanying an illustration of a rectifying column: "The dimensions of the dephlegmating column cannot well be calculated, except from the results of previous experience."

The quantitative treatment that differentiates the unit operations from the earlier rule-of-thumb approach to chemical plant design, strangely enough, was slow in developing. The quantitative basis of rectification calculations was formulated by Sorel (*15*) in 1880, and made available in a book in 1893. But Young's (*20*) book in 1903, even as revised (*19*) in 1922, makes no reference to it, and has a singularly unilluminating treatment of reflux and its relation to number of plates. Lewis (*7*), at the Distillation Symposium of 1922, based his treatment on Sorel, but it was through the classic paper of McCabe and Thiele (*12*) in 1925 that the matter was brought to a point of real usefulness to the chemical engineer.

The groundwork for other unit operations was, of course, being laid. Hausbrand's work (*5*), the first German edition of which appeared in 1899, did give tables of data which could be used for design of heaters, coolers, and condensers, though nothing very fundamental. The fundamental data were beginning to be supplied, however, by various workers—for example, Stanton (*16*) in England.

The period from 1924 to 1934 witnessed the flowering of quantitative researches in chemical engineering, and by 1933 Little (*11*) was able to conclude that the concept of unit operations he had introduced "is now generally accepted."

Oddly enough, the Division of Industrial and Engineering Chemistry gave no formal attention to unit operations in that decade. In 1934, under the chairmanship of W. H. McAdams, a Symposium on Diffusional Processes was held, and during that year, under the leadership of D. B. Keyes, the Chemical Engineering Symposium was organized, and the first symposium held, during the Christmas holidays, on the topic of distillation. Devoted primarily to unit operations, this series of Christmas symposia has done a great deal to foster and strengthen this treatment of the principles of chemical engineering. A listing of the topics covered in successive years is an essential part of the history of unit operations and of the Division of Industrial and Engineering Chemistry. Such a list is given in the divisional history at the end of the section on industrial and engineering chemistry (page 310).

The 1901 "Handbook of Chemical Engineering" (*3*) by Davis, essentially qualitative and descriptive in character, is forgotten, except for historical interest. The 1922 work (*10*) by Liddell was written on a comparable level. But the 1934 "Chemical Engineers' Handbook" (*13*), based on the quantitative approach inherent in the unit operations concept and built on the researches of the preceding 15 or 20 years, has become the indispensable reference work of the profession. The pioneering treatise (*18*) of 1923 and the other of consequence that has followed it (*1*) have uniformly adopted this treatment. The final triumph of Little's concept may now be said to have come in the unabashed adoption for the latest chemical engineering text (*2*) of the simple title: "unit operations."

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UNIT PROCESSES

R. N. SHREVE
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THE great emphasis in the development of chemical engineering came from the origination and expansion of the unit operations concept covering the physical changes that the chemical engineers used. However, chemical changes could not be neglected. When the chemical engineer applied his knowledge of chemical changes or reactions to the plant, there was a very definite separation from the laboratory test tube and beaker stage to that of the factory. In industry, the chemistry itself, yields, and equipment (including instrumentation), all were of paramount significance. Before and after 1932, a number of people working in the field of chemical processes and noting the success of the concept of unit physical operations thought there should be more attention given to these industrial chemical changes. Probably the first man to associate the unit process term with chemical activity was Groggins (*1*).

The Division of Industrial and Engineering Chemistry came

into this picture with a symposium in Denver on August 24, 1932, under the chairmanship of D. B. Keyes. This was titled "The Design, Construction, and Operation of Reaction Equipment" and it included papers descriptive of chemical changes and the equipment needed to commercialize these chemical reactions. Keyes in his introductory comments (*3*) said: "Much has been written in recent years about unit operations but very little about unit processes. It is strange that this particular subject, which means so much to every chemical engineer, should have received scarcely any consideration at all in our modern chemical literature."

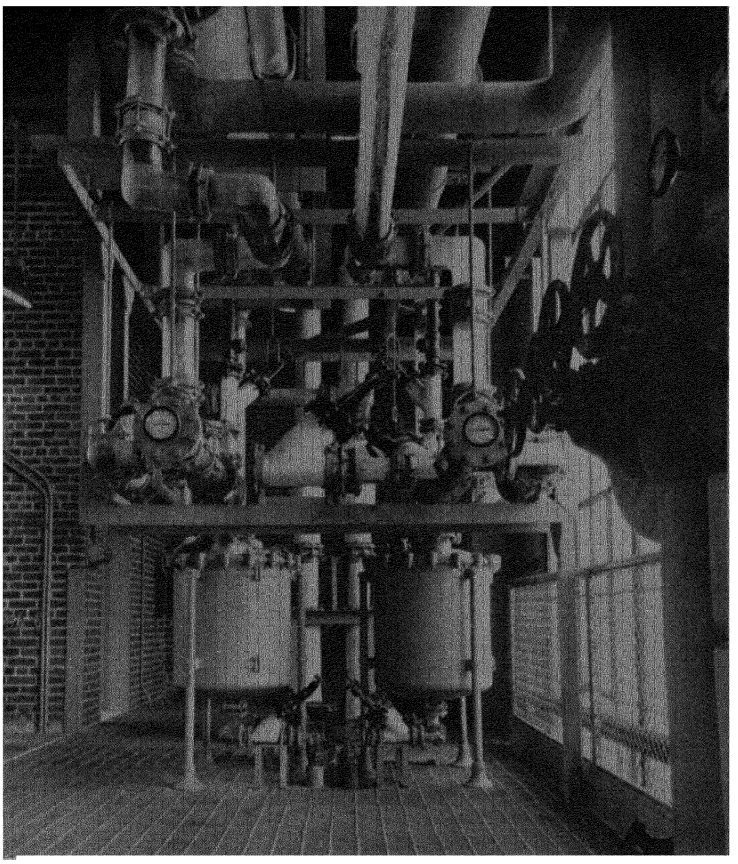
In 1937 the annual series of Unit Process Symposia was inaugurated, under the sponsorship of the division, with R. N. Shreve as chairman. These have been held each year at the fall meeting of the division. The fifteenth symposium was held in Chicago at the fall 1950 meeting.

These symposia have served as a medium for the presentation of papers emphasizing the industrial chemical changes and the necessary equipment. Out of these came the definition of unit processes as chemical changes carried out economically on an industrial scale. A number of suggestions had been made to name or classify these chemical changes in other ways. However, the concept of unit processes is well established in the literature. Fundamentally, the unit processes involve the study of kinetics, equilibria, and any other conditions that affect the chemical change in the direction of an economical process. The equipment to commercialize these chemical changes becomes an integral part of the concept. Such equipment has been presented not only in the annual Unit Process Symposia but in many specialized symposia, all listed in the annual directory of the Division of Industrial and Engineering Chemistry. Among such symposia, very helpful to the chemical process industries, might be mentioned the following, several of which antedate the more formalized Unit Process Symposia:

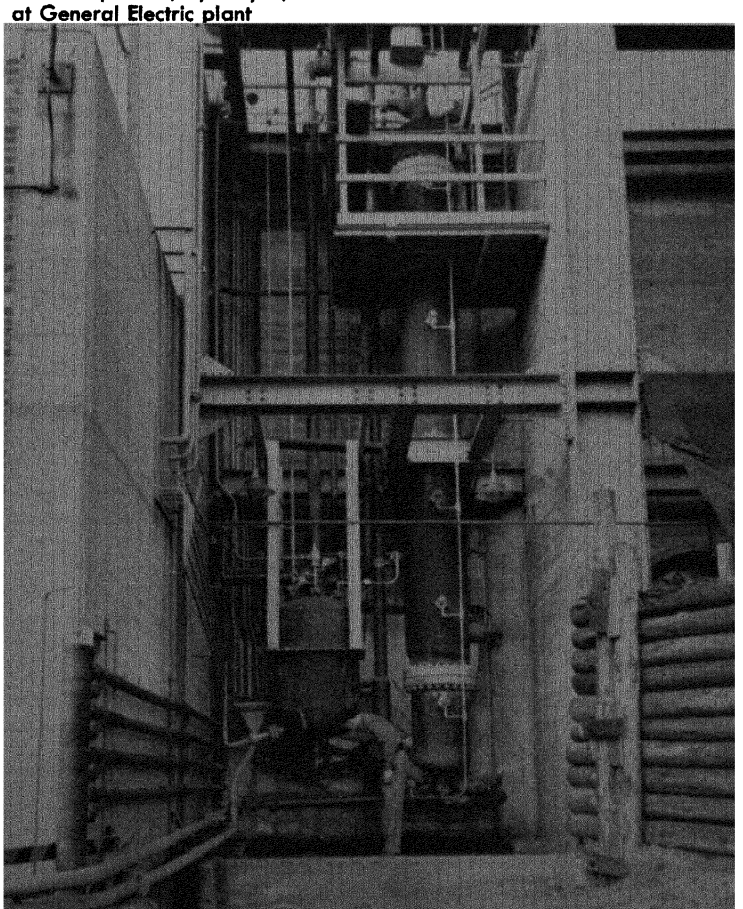
Automatic Process Control (1922)
Combustion (1922)
Materials of Chemical Equipment Construction (1923)
Industrial High-Pressure Reactions (1930)
Chemical Engineering Processes in the Oil Industry (1932)
Automatic Control (1937)
Role of Catalysis in Petroleum Chemistry (1939)
New Engineering Techniques (1941)
High Pressure Technology (1946)
Pilot Plant Design and Construction (1948, 1949, 1950)

Out of the Unit Process Symposia has arisen the annual literature survey entitled Unit Processes Review (*2*), which has appeared in INDUSTRIAL AND ENGINEERING CHEMISTRY for the past three years.

Data pertaining to unit processes are directed toward chemical reactions in factories; hence any facts pertaining to materials with lowered corrosion or increased strength used for the construction of chemical plants are of paramount importance. In the earlier years the Division of Industrial and Engineering Chemistry sponsored many and various symposia on corrosion or on particular aspects of design or of materials of construction. These have been supplemented not only by the annual Unit Process Symposia but in an extraordinarily useful way, by the splendidly classified data contained in the annual Materials of Construction Reviews. These have probably been stimulated by the publicity on unit processes. A chemical engineer who needs carbon or graphite in halogenation will turn to these annual reviews for the newest facts and the most recent references. This would also be true for one who would be handling reactions containing hydrochloric acid which have bothered us so much in decades past and which are now obviated by use of graphite, carbon, tantalum, or rubber-lined equipment. Similarly, these Materials of Construction Reviews bring to the attention of those engaged in commercialising chemical reactions the newer uses of old metals, uses of new alloys, and employment of organic com-



The unit process, hydrolysis, is carried out in these kettles at General Electric plant



Explosion barricade surrounds vinylation tower at General Aniline's Grasselli, N. J., plant

pounds for building plants. Examples are the use of aluminum in oxygen plants and construction of antibiotic reactors. Similarly, attention has been directed to the all-important gasket materials such as elastomers or synthetic rubber (neoprene and others) and fluorinated derivatives (Teflon). When suitable solid materials of construction are not available, linings and protective coatings are becoming important, such as furan resin derivatives, and fluorinated derivatives such as polymonochlorotrifluoroethylene.

The criterion used in admitting papers for the Unit Process Symposia has been whether these pertain to kinetics, equilibria, or other phases of chemical reactions, or the equipment in all its aspects necessary to commercialize these reactions. Those participating in the Unit Process Symposia come both from universities and in the past few years to a growing extent from industry. It probably can be remarked that these Unit Process Symposia have stimulated not only research work but the publication of investigations already made. Some of the interesting topics that have been presented in these symposia over the past decade and a half deserve mention.

In the large majority of the papers presented, the equipment has been described or data necessary for the design of the equipment have appeared. Certain participating authors have limited their presentations strictly to the equipment aspect of the problem—for instance, at the Unit Process Symposia there have been a number of papers pertaining to pilot plants.

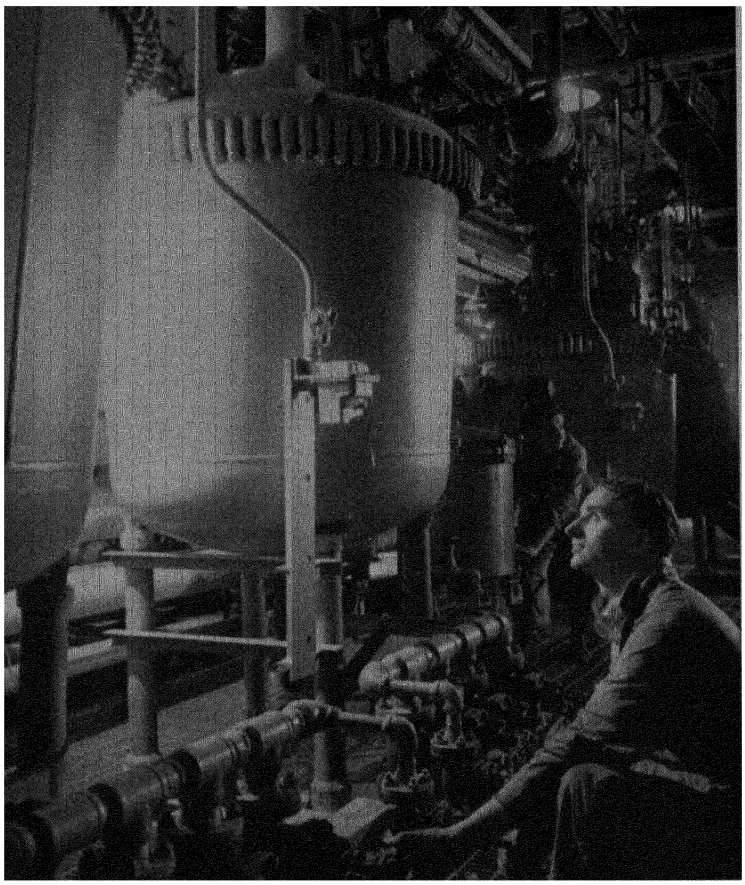
In the fundamental way of looking at the commercialized chemical reactions characteristic of unit processes, there is no need to make a separation between inorganic and organic chemistry. Hence in a number of symposia conducted in the past, inorganic papers have been interspersed with organic. Over the years, there have been many papers pertaining to a number of unit processes such as hydration, nitration, alkylation, base exchange, esterification, chlorination and sulfonation, saponification, and hydration. Often these Unit Process Symposia, by helpfully bringing together papers on an analogous subject, have led to a better understanding of the general principles fundamental to the given reaction.

In the study of organic reactions, there is frequently a generalized relationship between a given reaction carried on in the aliphatic series and the same reaction performed in the aromatic series. The data from one help the other. Hence we find in these Unit Process Symposia no separation into the traditional structural classifications of organic chemicals.

An increase in efficiency results from the discovery and the use of rules that arise by arranging various isolated facts under appropriate classifications. Under the unit process concept isolated facts pertaining to individual nitrations are assembled together under nitration. Here, like aspects stand out and when enough of such data are accumulated, general principles regarding nitration can be deduced. Another example is the correlation of data according to hydrogenations—for instance, we know that hydrogenations are exothermic and require the taking care of this heat. Under the heading of the principal unit chemical process classifications there are being assembled the various data relating to the chemical and equipment components. One cannot yet sit in a quiet corner and fully design new hydrogenations or new nitrations on the basis of known formulas and the known facts. However, that is the aim, and gradually with the accumulation of data pertaining to kinetics, equilibria, catalysis, and equipment, it is expected that chemical engineers will be able more efficiently to design and operate chemical processes.

The influence of this unit process concept is apparent in the advertising pages of the journals, where one sees companies offering to carry out custom hydrogenations. Also many concerns offer equipment for nitrations or hydrogenations or esterifications or another unit process.

Shreve (*4*) states:



At General Electric's Waterford, N. Y., plant, operator controls flow rate to reaction kettle

The fundamental object of these symposia is to gather sufficient data to place a more quantitative foundation under industrial chemical procedures. It would be desirable to have formulas into which, by substitution of the proper data and evaluation thereof, answers would be forthcoming to give an indication of the proper procedures for the manufacturers of chemicals. It is too much to hope for such formulation in the very near future, but it is at least the goal of many working in unit processes.

The unit process conception enables much related knowledge to be classified under its appropriate head of alkylation, oxidation, hydrogenation, and the like. Perhaps when enough data have accumulated, certain formulation can be attempted. At least we can hope for this goal in the kinetics and equilibria of the basic chemistry involved.

The future investigations in the field of unit processes will involve the determination of more data leading to the principles governing the various conditions that enter into the commercialization of chemical reactions and to the final correlation of all these in the hands of the design and construction chemical engineer. This is an exceedingly complicated field, there being so many aspects involved. Because anything that affects the yields or conversions of the chemical change has such an influence on the final cost, probably the most profitable aspects to research are those connected with the largest production out of a given piece of equipment. This may be summarized by saying that we ought to know first what we can about how fast a reaction goes or its kinetics together with catalysis. That should be combined with studies on equilibria or how far the reaction will go. An almost equally important aspect is the continuation of investigations of new materials of construction to eliminate repairs in the process equipment. The initial results from all of these fields should be checked in the pilot plant, so that mistakes can be corrected on a small scale, leading to enlarged profits on a factory scale.

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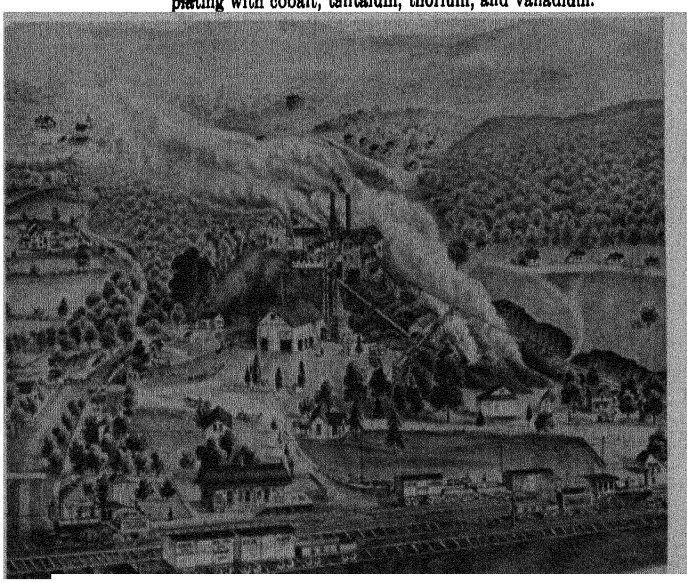
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MATERIALS OF CONSTRUCTION

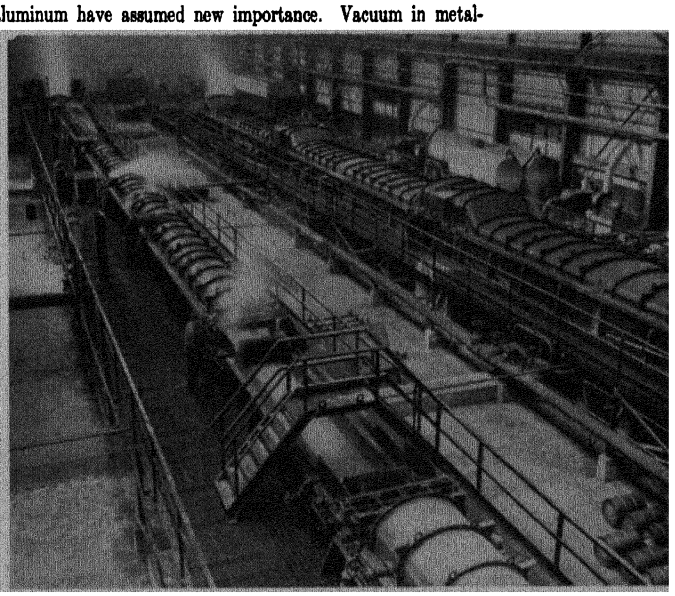
L. T. WORK
New York, N. Y.

AT THE time the Division of Industrial Chemists and Chemical Engineers was formed, chemical industry was small and limited to a few basic materials of construction. Metals included cast iron, steel, a few alloy steels, nickel, copper, bronze, aluminum, tin, lead, zinc, and electroplated metals; nonmetals were wood, stone, concrete, ceramic ware, enamel, rubber, mastics, graphite, and oleoresinous coatings. The intervening period, just short of a half-century, has witnessed tremendous growth, with improvements in the quality and fabrication of many of these materials, and with the introduction of new materials.

Chemical science has had much to offer metallurgy, and the early activities of the division bear evidence of this. Ore sampling, analysis of ores and metals, furnaces, electrochemistry, cyanidation, structure of metals, inclusions, new alloys, corrosion of iron, steel, and other metals, and development of new corrosion-resistant metals were the subjects of papers before the Society. Duriron and Monel were receiving attention. Contributions appeared on aluminum and calcium, cerium, tungsten, radium, plating with cobalt, tantalum, thorium, and vanadium.



Old print of the Greenwood Iron Works, Orange County, New York. The Erie Railroad passes by



Continuous strip picklers in the Irvin Works of the Carnegie Illinois Steel Corp.

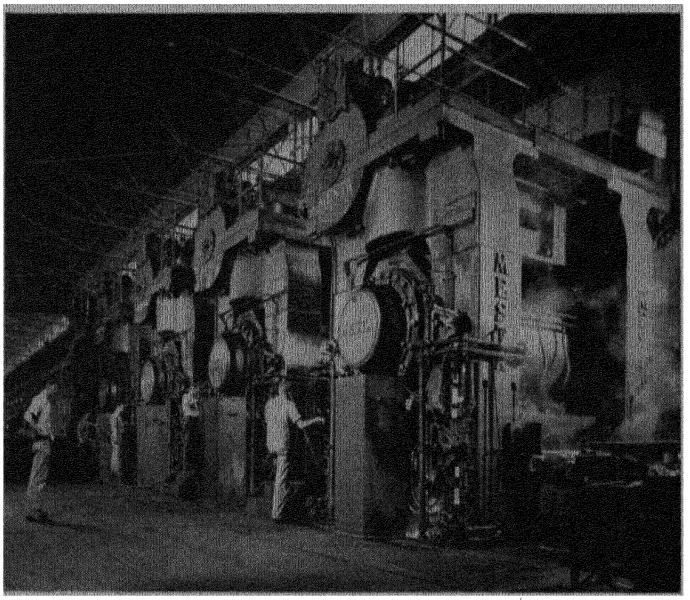
There were two symposia in 1917: on the chemistry and metallurgy of zinc and on the formation of metal. In 1919, there was one on refractories; 1922, 1923, and 1925 were heavily devoted to corrosion, and there were symposia on this subject and on materials of construction. The monographs on "Corrosion Tests and Materials of Construction" (*1*) and the "Chemical Resistance of Engineering Materials" (*2*) appeared in 1923.

Shortly thereafter appeared a second and revised edition of "Chemistry of Engineering Materials" (*4*), which first appeared in 1917. The demands of the war had greatly extended knowledge as America built a chemical industry needing new materials.

This was a period when the physical chemistry approach was replacing classical metallurgy, and when new metals and alloys were being developed by nonclassical methods. The influence of the newer metallurgy began to be felt in metal societies, while electrochemistry under the continuing faithful service of Fink and others created its own field. By the early twenties, these transitions began to be felt, and the interests of the Division of Industrial and Engineering Chemistry became more limited in scope. This had been a period of developing the important scientific factors. In this period, which lasted to World War II, stainless steels, hard surfacing alloys, and some high temperature alloys were among the developments.

The nonmetallic materials were under rapid development from the period between wars. Engineering research under Duff Abrams, and chemical developments under R. H. Bogue improved the manufacture and utilization of cement. Asbestos-cement products began to find their place as sheet and piping. Increasingly larger sizes of borosilicate chemical glass became available, and both it and silica ware were available for special plant requirements. Better enameling made possible larger and more durable enameled units. Improved compositions in refractories and better stoneware became available. Rubber cladding and electrodeposition of latex were developed. Neoprene found a useful place. Better carbon products and the carbon plastics extended the industrial value as inert heat transfer material. Reinforced resin structures, such as Haveg, were developed for strength and to avoid metallic corrosion.

The past decade has again witnessed the impact of war. Welding of metals became perfected as an industrial tool and made possible more tanks and ships; and in peace it has become a new tool for automobile and equipment fabrication. Magnesium and aluminum have assumed new importance. Vacuum in metallurgy has made possible the silicon-reduction reaction for pure magnesium, calcium, and other metals. Hydrides have become useful reactants in making the rarer metals. In the nuclear field, whole new techniques are still to be applied to industry. The development of titanium has progressed rapidly from the early work of Kroll, and the metal gives promise of soon becoming available in tonnage quantities. Zirconium is likewise under development, though it was first offered as a product of thermal halide decomposition. The hard carbides, tantalum, and vanadium are new materials finding specific places in industry. Surface protection has been improved with the newer resins, including the furan and the fluorocarbon types; and anodic and chemical treatments of metallic surfaces have been extensively employed. Hard surfacing, by plating, welding, or metal spraying, has improved wear-resistant parts. Electroplating has been developing on a larger scale, as in tinning. Shortages and equivalents have been problems of our economy in the past decade; and the



Huge sheet-rolling mill at Pennsylvania plant of the Aluminum Co. of America

organic chemicals industry, growing apace, ever increasingly offers products to replace or supplement the metals. Notable among the current developments are the fluorocarbon, polytetrafluoroethylene, and the silicones.

The industry stands today in the position where there are few problems that cannot be solved economically, and the quest still continues for better solutions to the difficult problems of materials for chemical engineering.

Recent symposia by the Division of Industrial and Engineering Chemistry, such as the Titanium Symposium and Packaging Symposium presented at the September 1949 national meeting, the Organic Silicon Compounds Symposium at the April 1947 meeting, and the program on electrical insulating materials at the April 1946 meeting, illustrate that interest in materials of construction as a program subject is still a vital part of the division's activities. The increasing importance of materials of construction is also reflected by the appearance in the October 1947 issue of INDUSTRIAL AND ENGINEERING CHEMISTRY of a series of annual reviews devoted to contemporary developments in the field (*3*).

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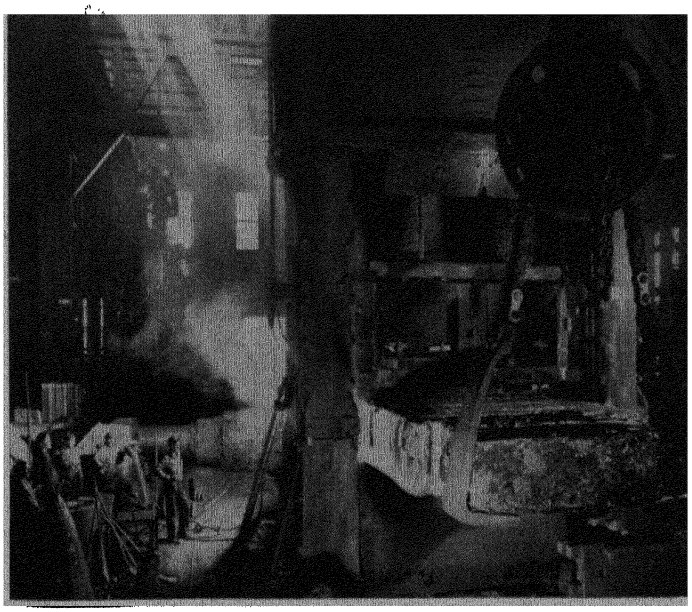
ELECTROCHEMICAL INDUSTRY

R. M. BURNS

Bell Telephone Laboratories, Murray Hill, N. J.

THE electrochemical industry includes the processes and products of the electrolytic cell and the electric furnace and is one of the most important segments of American chemical industry. Its power requirements have increased more rapidly in recent years than those of industry as a whole, and it now consumes nearly 20% of the electrical power generated in this country. Products of this industry, such as chlorine, alkalies, and calcium carbide (the principal source of acetylene and cyanamide), are basic raw materials for a large part of the organic chemical industry. Abrasives and ferroalloys from the electric furnace are essential ingredients in the metallurgical industry.

Industrial electrochemistry has had its tremendous development within the lifetime of the AMERICAN CHEMICAL SOCIETY and mainly during the past 50 or 60 years. It arose from inventions and developed as an experimental art. Many of its early practitioners had little chemical knowledge. Papers before the Society commented upon the scarcity of chemists in industry and the best methods of training industrial chemists. Later during the 1890's, electrolytic or electrothermal products were announced at chemical meetings, and there developed a growing interest in the application of the electric current in chemical processes. Electrochemical methods for the production of white lead, chlorates, paranitro compounds, caustic alkalies, and graphite were described. One interesting reference (*10*) mentions the successful disinfection of sewage by the electrolysis of sea water. With continued expansion of electro processes in the first years of the century, more and more papers of industrial importance appeared. The first volume of the *Journal of Industrial and Engineering Chemistry* refers editorially to electric furnace steel (*22*) and to the manufacture of carbon electrodes (*15*). In subsequent volumes, it is possible to follow the important developments of the electrochemical industry down to the present time. For example, the entire issue for March 1947 is composed of 53 papers on the development, production, handling, and chemistry of fluorine and fluorine compounds. Later issues of this journal contain other papers presented before symposia on fluorine chemistry which have become an annual feature, sponsored by the Fluorine Chemistry Subdivision of the Division of Industrial and Engineering Chemistry.



Forging an armor plate in 14,000-ton press forge at Bethlehem Steel Co.

Electrodeposition of Metals

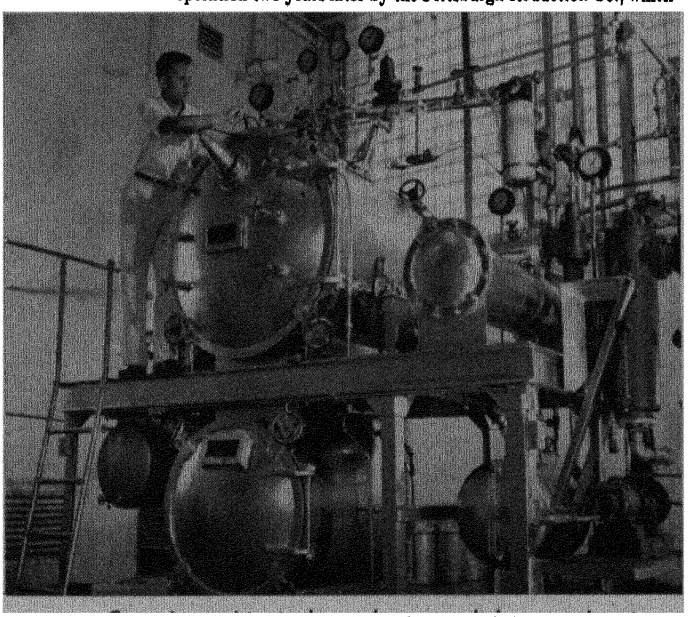
Electroplating is the oldest commercial electrochemical process. Edward Weston constructed the first dynamo for electroplating about 1875. The substitution of this device for batteries as a power source not only increased the attention given to the chemical control of plating baths but led to the firm establishment of the plating industry. From job shop operation, electroplating has developed into large manufacturing units in diversi-

fied industries. This expansion was stimulated by the mass production of automobiles, modern plumbing fixtures, and household appliances. The use of chromium-nickel coatings, beginning about 1925, has proved most suitable in these fields. Among important developments in electroplating in recent years have been "bright" nickel and zinc, very heavy coatings of nickel and of chromium, and high-speed methods of plating steel sheet or strip stock. For example, electrotin, plated at the rate of 1000 feet per minute, was promoted as a conservation measure in the recent war. This process has continued to expand and now accounts for a large fraction of domestic tin plate manufacture.

The depletion of high grade ores makes electro-winning methods of metal extraction attractive. This is particularly true of the complex lead-zinc ores not amenable to pyrometallurgical methods. These methods and electro-refining for attaining high purity have been increasingly extended in recent years to the production of copper, zinc, cadmium, antimony, chromium, cobalt, and manganese.

Electrolytic Processes and Products

The electrolytic reduction of aluminum from a fused salt bath by Charles M. Hall in 1886 initiated the development of the electroprocess industry. Hall's invention was put in commercial operation two years later by the Pittsburgh Reduction Co., which



Corrosion-resistant drum dryer used in experiments on powdered milk is built of stainless steel

in 1907 became the Aluminum Co. of America. From the first plant containing two cells operating at 1800 amperes and producing 50 pounds of aluminum a day, the industry grew until in 1943 there were 16 huge plants with cells operating at 40,000 to 50,000 amperes and a total capacity of over 2 billion pounds a year. Most of this expansion was inspired by military requirements, but postwar demand has been such as to maintain the production level above one billion pounds a year. Active developments toward cost reduction and improved purity are continuing (*3, 9*).

Magnesium has a more recent history. First produced in 1852 by Bunsen by electrolysis of fused magnesium chloride, it attained small scale commercial production in the first decade of the century. This was followed in 1916 by the Dow continuous chloride process utilizing salt brine as the basic raw material. By 1923 production had reached 300 pounds per day. During the period from 1920 to 1939, production of the metal doubled every 2 years. After 1939, the output increased, even more rapidly, reaching a peak of 380,000,000 pounds in the war year 1943. In the latter period, raw material sources were broadened to include sea water, dolomite deposits, and potash by-products, thereby presenting many new chemical engineering and design problems.

The electrolytic alkali-chlorine industry, which has in recent years doubled in size every five or six years, is one of the most striking features of modern industry. Indeed, chlorine production which is 99% electrolytic has come to be the best index of the chemical industry since a wide variety of chlorinated compounds consume nearly 80% of the production. About 75% of the caustic alkali production is electrolytic and finds use mainly in chemicals, textiles, rayon, films, cleaning agents, and petroleum refining(*11*). Experimental work on chlorine-alkali cells resulting in early patents dates from the 1880's. The first commercial installation for electrolytic chlorine was at Rumford Falls, Me., in 1892 (*14*). This was followed in the next few years by other installations in New England and to larger developments at Niagara Falls, Wyandotte and Midland, Mich., and on the Pacific Coast. Of the 350 cell patents since 1883, only 16 have stood the test of time and continue to operate (*20*). From 40 tons of chlorine a day from five plants in 1900, production has grown to 5000 tons a day from 58 plants in 1949 (*6, 13*). Over 1.5 million tons of electrolytic caustic soda were made in this country in 1948.

By-product hydrogen from chlorine-alkali cells finds extensive use in hydrogenation processes and in the production of hydrogen chloride. Both hydrogen and oxygen are also produced on a large scale by the electrolytic decomposition of dilute caustic solutions.

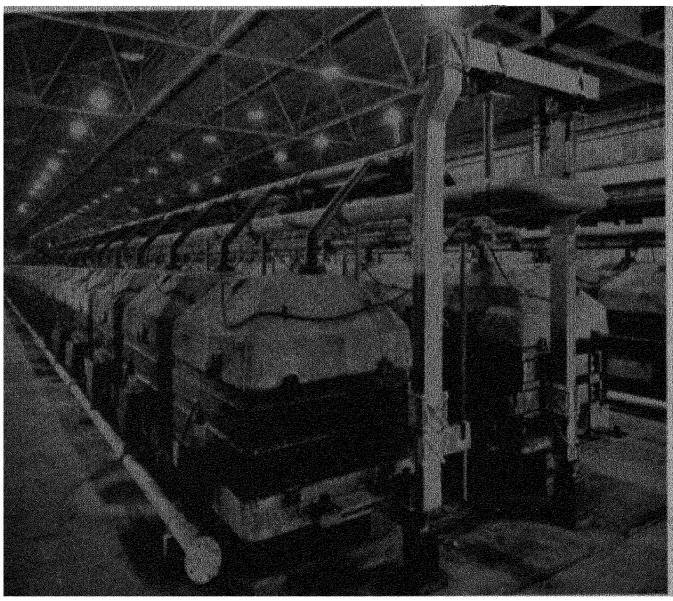
Electrolytic processes are widely employed for the production of hydrogen peroxide and the per salts. Electrolytic chlorate was mentioned in 1889, and as early as 1897 the manufacture of chlorates and perchlorates was begun at Niagara Falls. Since that time, cell design, solutions, and processes have been considerably modified. The demand for these products has never attained high proportions. The present annual production of chlorates is about 25,000 tons, divided about equally between the sodium and potassium salts. The domestic production of perchlorates was increased during the period 1941–45 from an estimated 1000 tons to 20,000 tons to supply demands created by wartime uses (*17, 21*).

The recently increased interest in organic fluorine compounds has led to considerable expansion in the production of elemental fluorine. The direct fluorination of organic compounds (*18*) has become a valuable commercial process.

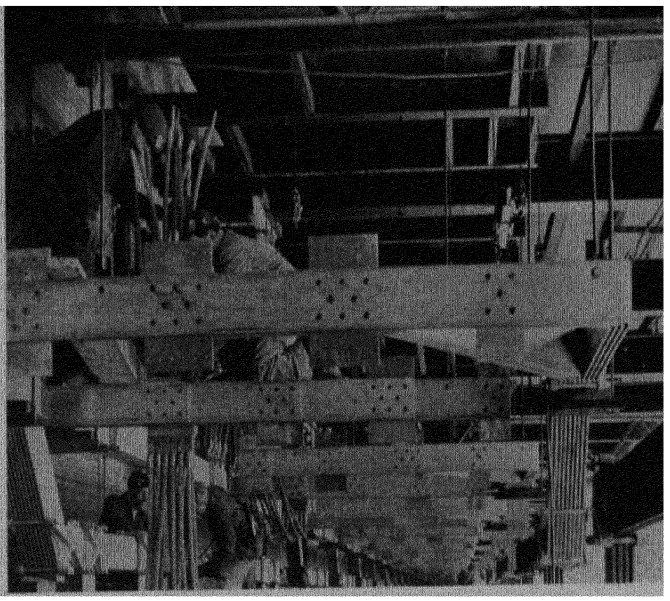
There has been considerable exploration of the use of electro-



These light-weight aircraft landing wheels are made of sand cast magnesium



New electrolytic chlorine-caustic units at the Hooker Electrochemical plant, Tacoma, Wash.



Solid silver bus bars carry electricity to magnesium cells at Dow's plant in Michigan

chemical processes in the production of organic chemicals. Between 1939 and 1945, millions of pounds of mannitol and sorbitol were manufactured by the electrolytic reduction of glucose (*1*).

Electrothermal Products

The higher temperatures, close temperature control, and cleanliness of electrothermal heating have led to the wide use of the electric furnace in chemical and metallurgical manufacture. Graphite, calcium carbide, phosphorus, abrasives, and ferroalloys are among the principal products. The first three of these, and in addition metallic calcium, were prepared in a laboratory electric furnace as early as 1839 by Robert Hare at Philadelphia (*2*).

The first synthetic abrasive, carborundum, was invented by Acheson in 1891. Forty-five years later, the annual electric energy required in its manufacture had attained 87,000,000 kw.-hr., and considerable further expansion occurred during the war. Among more recent abrasive products of the electric furnace are fused alumina, boron carbide, and tungsten carbide.

Acheson observed about 1895 that graphite was produced at furnace temperatures above those suitable for making silicon carbide. The process was commercialized with the founding of the Acheson Graphite Co. in 1900, and the product soon competed successfully with natural graphite in the manufacture of electrodes, crucibles, lubricants, and dry cell components.

Calcium carbide, which can be made commercially only in the electric furnace, received its first industrial development about 1892. Within five years, production of the carbide supplied eight plants engaged in the manufacture of acetylene. Reaction of calcium carbide with nitrogen to form cyanamide was first commercialized in 1905, and this product within 30 years had attained an annual production of 1.5 million tons. Today with acetylene and cyanamide the bases for a large section of the synthetic organic chemical industry, calcium carbide has an annual production of nearly 700,000 tons.

Phosphorus and phosphoric acid are produced electrothermally from a mixture of phosphate rock, coke, and silica. In 1947 the production of phosphorus was 86,000 tons.

The development of the alloy steel industry, which began in the early years of the century, was dependent upon the electric furnace production of ferroalloys. A wide variety of these addition alloys could not be obtained in satisfactorily high purity by blast or open-hearth furnace methods. At the present time the annual production of ferroalloys is of the order of 3 to 4 million tons.

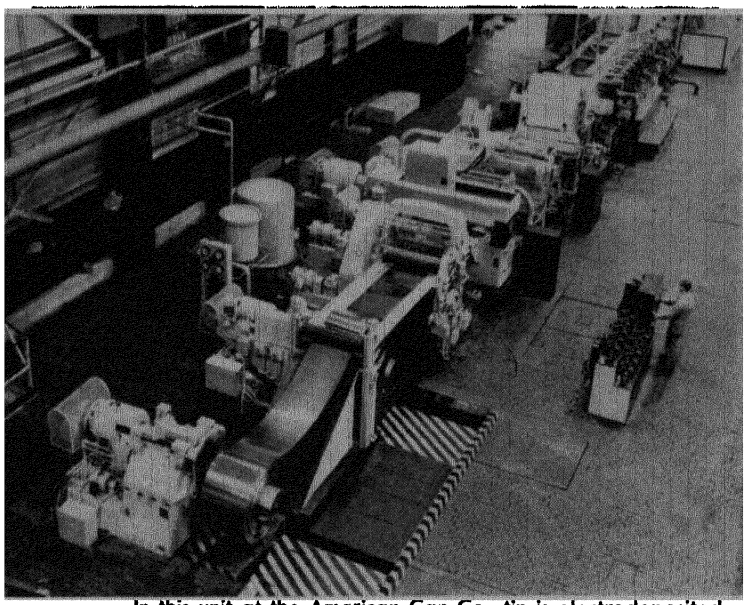
Primary Cells and Storage Batteries

By the time the Society was organized, primary cells had had a 76-year evolutionary history from the pile of Volta to the Leclanché cell, forerunner of the dry battery of today. Sixteen years had elapsed since Planté had invented the storage battery. Until very recently, neither of these devices for obtaining electrical energy from chemical reactions underwent much further development beyond improvement in structural design and chemical purity of ingredients. The development of portable radio equipment, flashlights, and hearing aids gave impetus to new and improved dry cells, and lately cells involving a variety of chemical reactions have been invented. For example, there are the Leclanché-type cells with porous carbon cathodes which are depolarized by air or by chlorine (*7*, *8*); caustic soda cells with zinc anode and either cupric or mercuric oxide cathodes; perchloric acid cells with lead dioxide anodes and lead cathodes (*16*); and finally a magnesium-silver chloride cell utilizing water as electrolyte (*4*, *12*).

The rise of the automobile industry brought about a spectacular increase in the use of storage batteries. This development accounts for the major portion of the half-billion-dollar annual output of these batteries. The standard lead-lead dioxide with sulfuric acid electrolyte of Planté has led the field. The alkaline type of nickel-iron cell developed by Edison and the more modern version employing nickel and cadmium electrodes have never threatened this supremacy. For full-float type of service, such as is employed in the telephone industry, a very marked improvement in performance and life has been obtained by substituting calcium for antimony as hardening agent for grids (*5*, *19*).

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In this unit at the American Can Co., tin is electrodeposited on steel

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DYESTUFF INDUSTRY

L. H. FLETT

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THE dyestuff industry was the earliest of the great synthetic organic chemical industries. It supplied a need which nature had taken care of since the first man daubed his skin and clothes with vegetable dyes. Natural dyestuffs had been a coveted article of international trade. With prices ranging up to several hundred dollars a pound, they were economically important enough to upset the trade balance between nations.

The accidental discovery of mauve, the first synthetic dye, by Perkin in 1856 and the subsequent establishment of a synthetic organic chemical industry have had a most profound effect on mankind. The synthetic organic chemical industry has furnished an unending parade of useful chemicals to enrich our civilization beyond imagination. The ready availability of healing drugs, fine fabrics made with synthetic fibers, easily molded synthetic resins, rubber, flavoring materials, detergents, and all of the other synthetic substitutes of nature's gifts can be traced to the fundamental industrial organic chemistry unfolded in the early development of the synthetic dyes.

At first, advances in the synthetic dye industry were rather slow, but before the turn of the century the dye industry was world-wide. Although the impact of the Perkin discovery was world-wide, the chemistry of dyestuffs and the dyestuff industry developed and flourished in Germany more than in any other country. Possibly this was a result of the educational system which at that time developed and inspired great numbers of young organic chemists, whose fundamental studies unlocked the secrets of color chemistry. During that period, many American chemists found it advisable to complete their studies in Germany. At the outbreak of World War I, the synthetic organic chemical industry, which included the dye industry and the synthetic drug industry, was a monopoly of the Reich, because German technical and scientific advances had far outstripped the rest of the civilized world.

When the hostilities of World War I started, the English government established a blockade of German ports and effectually cut off American imports of the German dyes which had become a necessary part of our economy. Later when we entered World War I, intermediates and dyes became a very necessary part of our military preparation.

In 1914, the combined dyestuff capacity of the United States was only a small fraction of our normal requirements. American dyestuff manufacturers had been successful in the commercial development of a small group of dyestuffs, but they had neither the variety of dyes nor the capacity to supply American needs. Most of the organic chemists available in the United States had been educated in Germany and were on the staffs of academic institutions; industrial organic chemists were practically unknown. However, when urgent necessity demanded expansion of the American dye and drug industry beyond the means of the few dye chemists available the enthusiasm and the adaptability of these American chemists soon made themselves felt, and by the time World War I came to a close in 1918, there was a well established line of organic dyes and synthetic drugs. What was more important, there had been developed a substantial group of experienced industrial organic chemists.

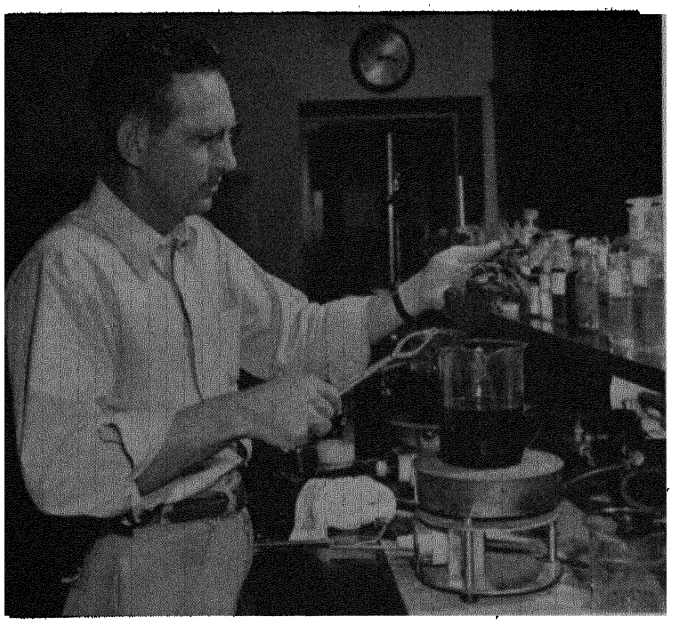
The end of the war found the dye manufacturers in an untenable situation. Because of the necessity of developing a large number of dyestuffs, it had not been possible to develop highly efficient commercial processes. The possibility of competition from German factories with know-how and cheap labor seemed to many people to be an insurmountable handicap to the future. Through the efforts of many individuals, including Francis P. Garvan and the members of the Division of Dye Chemistry of the AMERICAN CHEMICAL SOCIETY, a tariff was established which has permitted the American dye industry to grow and to become the greatest dye industry that the world has ever seen and a strong factor in our national defense.

During the postwar period of uncertainty, many chemists who by that time had become highly skilled in organic research left the industry to enter other new organic chemical ventures. These trained scientists became the nucleus of the vast American organic chemical industry on which our country now depends for the many organic chemicals which have long since become national necessities.

After World War I, the American dye industry, encouraged by tariff protection, undertook the problem of entrenching itself with modern processes and modern equipment; but it was some years before it was in a position to proceed with the development of needed new dyes. However, as World War II approached, the research laboratories of Germany were put to work on problems related to the impending war, and for the first time the American industry assumed scientific leadership. In that critical period, advances in the dyestuff industry were for practical purposes limited to the United States and England.

As part of our well integrated dye industry today, we have in addition to colors for every purpose, many textile aids and finishing agents. One of these, the synthetic detergent, has become the basis of a great new industry producing more than a billion pounds annually.

An interesting new process for printing with resin-bonded pig-



Chemist holds a dyed sample of cotton fiber, which is now ready for rinsing and drying

ment colors was developed in 1937. This process made it possible for the first time to produce brilliant fast pigment prints which will withstand repeated washing and dry cleaning. Because of the ease of application and other advantages of resin-bonded pigment colors, this new process has proved effective for the printing and dyeing of a wide variety of cotton, rayon, and other fabrics.

The AMERICAN CHEMICAL SOCIETY recognized the importance of the dyestuff industry by including a section on dyestuffs when *Chemical Abstracts* was organized in 1907. In 1918, at the instigation of R. Norris Shreve and with the assistance of the Division of Industrial and Engineering Chemistry, the first Symposium on Dyestuffs was held, which was followed in 1919 by the formation of the Dye Section. This became the Dye Division in 1920. Its short but fruitful existence came at a very critical period for the American dyestuff industry.

LEATHERMAKING

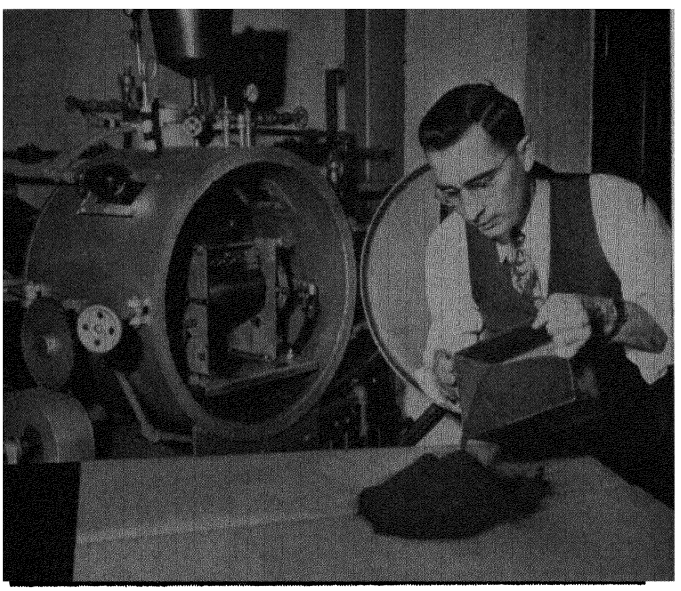
H. G. TURLEY
Rohm & Haas Co., Philadelphia, Pa.

IT CAN be said that the ancient leather industry progressed purely as a craft during the Dark Ages, the Middle Ages, and, indeed, up to the time of the industrial revolution. During the latter period, although there was an awakening of the spirit of inquiry, progress was still, as a craft, taking unto itself new products and adopting crude machinery to replace the former tedious hand work. It will be convenient to discuss the progress of this industry in three periods, each a generation—namely, 1875 to 1900, 1900 to 1925, and 1925 to 1950.

1875–1900

In the first volume of the *Journal of the American Chemical Society* is a report on the progress of analytical chemistry. Details concerning the Lowenthal method for estimating tans are given. This is significant, because for the next 25 years leather chemistry was mostly concerned with the analysis of materials. In this same first volume of the *Journal* is described a German patent for the manufacture of artificial leather. Clearly, the work on leather substitutes goes hand in hand with the continuing study of the chemistry of leather. Today tanners are much concerned about the inroads being made by synthetic materials as substitutes for leather. The replacement of sole leather by rubber and rubberlike products is a sore point fresh in our memory. However, let us remember that substitutes for leather have been produced for centuries. Consider life in the Middle Ages, when leather was used so much for the every day needs now filled by cotton or rubber.

In the last century, very few original papers were contributed on leather. It was still very much a secret craft. In the *Journal* in 1880, a typical process is described for a tanning compound consisting of a weird mixture of divi-divi, oak bark, alum, sour barley flour, and copper sulfate. In the same year, we note in the *Journal* a patent concerning improvements of the Heinzerling rapid tanning process, dealing with chromium salts. This process of chrome tanning, before the turn of the century, was destined to revolutionize the ancient leather industry and was the first direct and significant effect of the chemical industry on leathermaking. Of great importance also is the description of Knapp's patent for preparing iron salts for tanning. Unlike the chrome process, the iron process is not yet successful, but would still be a great contribution to leathermaking if it could be successfully developed.

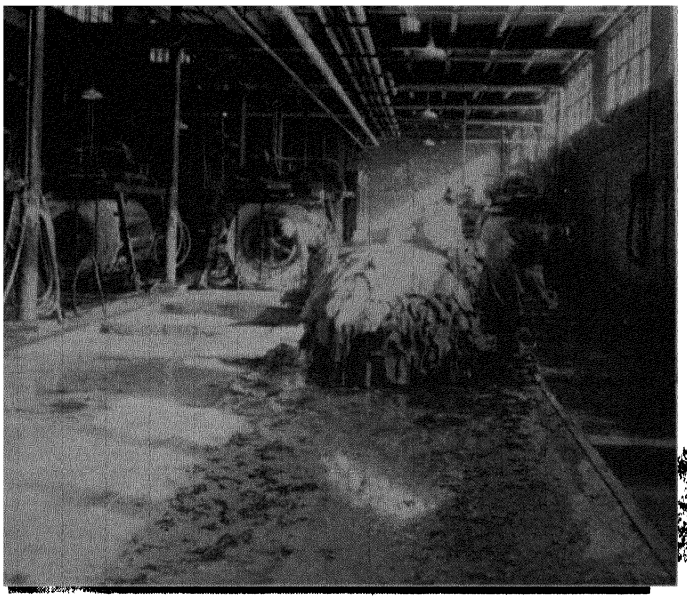


From vacuum drum dryer comes experimental batch of powdered tanning extract obtained from scrub oak bark

The first scientific paper seems to have appeared in 1882 on "The Estimation of Tannic Acid in Tanning Materials" by N. H. Darton. Darton states in his preface that the determination of tannin is a difficult problem and many methods have been proposed to facilitate the analysis, but these give discordant results when compared with the actual weights of leather formed from it. No doubt it was with a very deep sigh that Darton said, "Thus tanners have lost all faith in chemists in general." In some quarters this is the viewpoint of some tanners even today. At the end of this period, progress was made with the difficult analysis of tannins. The strictly chemical processes, such as oxidation with permanganate, were replaced by absorption processes, using the tanners' basic raw material, hide powder. Much credit should be given to the government chemists who, in the Association of Official Agricultural Chemists, brought these techniques to such a satisfactory state that, in essence, these are the methods that are used today. A small group of these chemists founded the American Leather Chemists' Association in 1903—the first trade chemists' association.

1900–1925

This period can be divided into two parts—1900 to the outbreak of World War I, followed by the postwar period. In the



In leathermaking, hides are soaked in solution of lime and other chemicals to remove hair and epidermis

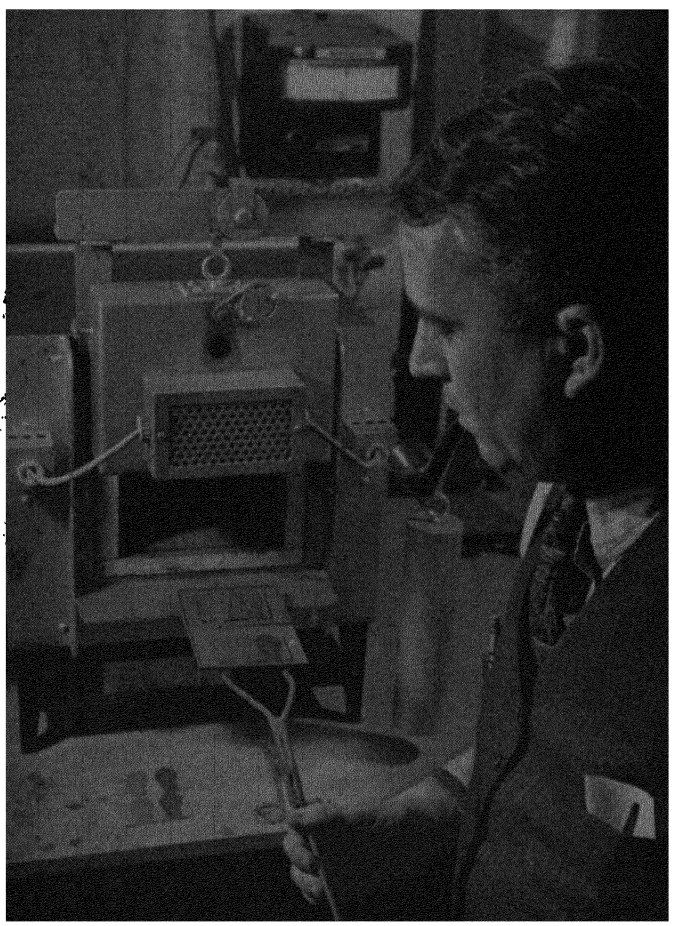
early period, we have an awakening of research, and the Division of Industrial and Engineering Chemistry was founded in 1908. At the fiftieth meeting of the AMERICAN CHEMICAL SOCIETY a paper presented by W. H. Teas entitled "Contributions of the Chemist to the Leather Industry" showed how chemists examined and selected the materials for tanning and leather making and worked out methods for standardizing tanning liquors (*7*). During this period, the oriental method of bating skins with the dung of dogs and birds was replaced by the modern, hygienic mixtures of deliming salts and enzymes. In 1913 there was a reprint of the first announcement of a synthetic tanning agent under the title, "Neradol D—A Synthetic Tan," by Stiasny (*6*). In 1914 appeared the culmination of Emil Fischer's work on the constitution of natural tans. His paper translated in the *Journal* in 1914 is the classic "Synthesis of Depsides, Lichen Substances, and Tannins" (*1*). An item of interest concerning tanning materials in Germany appeared in 1918, saying that the German government was offering prizes of $5000 and $1250 for substitutes for chrome tanning, vegetable tans, and cod oil. It was not until World War II that these goals were realized. In World War II, Germany did use considerable quantities of synthetic tans and synthetic oils. However, there was still no good substitute for chrome tanning.

After World War I, we can see a very definite awakening of research within the leather industry, and our *Journal* contains many articles from the Wilson-Thomas School. Thomas, and his associates of Columbia University, published approximately 23 papers in the period 1920 to 1929. Likewise, J. A. Wilson, from the laboratory of A. Gallun & Sons in Milwaukee, published 22 papers in the same period. This was the era of the application of colloid chemistry to leather manufacture. It was recognized that the making of leather was a fine example of a colloidal phenomenon. We have, on the one hand, the large protein molecule of skin substance, collagen, and the large molecules of the vegetable tans and chrome tans. Wilson, working at Leeds in the laboratory of H. R. Proctor ("the father of leather chemistry"), made the first application of the principles of the Donnan membrane equilibrium and gave a quantitative meaning to the swelling of gelatin in acid and alkali solutions (*5*). The combination of tans, vegetable, and chrome with hide powder under a wide variety of conditions (such as concentration, time, and temperature) was systematically examined by Wilson, Thomas, and coworkers (*9*). Wilson, in this country, was one of the first to recognize the great importance of the microscope in tannery practice and carried out sustained work on the histology of leathermaking. From it he evolved his theories concerning elastin removal and keratose removal, and was one of the first to publish work on the quantitative effects of controlled amounts of enzymes in the bating of leather (*11*). Although much of this work is now seen to be erroneous, it had the great value of stimulating others to further investigations into the obscure process of bating.

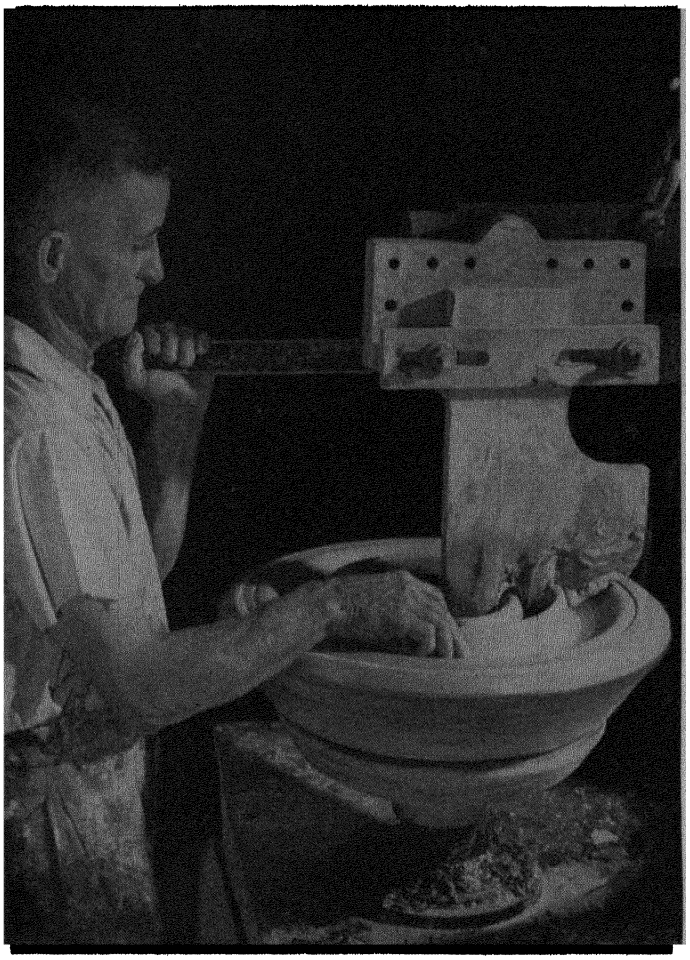
This period also saw the development of the hydrogen ion theory. The leather industry was one of the first to take up this new tool, which has been of such inestimable benefit to the entire industry. Today, in a modern tannery, the determination of the pH of tanning materials and liquors of all types is commonplace. In this early period, chemists worked with the cumbersome hydrogen electrode apparatus, which has since been replaced by the simple manipulations of the glass electrode.

Hand in hand with the investigation of the vegetable tanning process (*15*) went the examination of what was thought at first to be a simple process—chrome tanning—but it has since appeared to be very complicated. Scientific examination of the chrome tanning process is still going on today.

We should also mention the pioneering work of Merrill on the obscure depilating process which the tanner relies on to remove hair from his skins (*4*). The use of sulfides, handed down from the oriental countries in the Middle Ages, was explained by Merrill as a two-step process: a reaction between the hair and sulfide and a reaction between altered hair and hydroxide—i.e., a chemical reduction followed by chemical hydrolysis. Wilson was also one of the first to study the physical properties of leather that cause it to be the unique material it is, and systematically studied



Laboratory furnace is used for a quick check on glass enamels



The shell of a ceramic switch insulator is carefully formed on a "jigger" wheel

such properties as vapor permeability, porosity, and stretch. In 1925 Gustavson applied ion exchange materials to the study of the composition of chrome tanning liquors (*2*).

The Division of Leather and Gelatin Chemistry of the AMERICAN CHEMICAL SOCIETY was established in 1921, and before this division were presented the papers enumerated above.

1925–1950

On the occasion of the fiftieth anniversary of the AMERICAN CHEMICAL SOCIETY, Wilson presented a paper covering "Tanning, 1876–1926" (*12*). The number of papers presented on leather chemistry began to decline. The support for leather research was withdrawn by the chief interested tanner. It seems unfortunate that the industry expected quick returns from its small investment. On reflection, how was it possible, within the short space of 10 years, for an industry to expect a thorough elucidation of its processes which had evolved over a period of thousands of years? The tanning industry continued to support its own research laboratory in Cincinnati, and the *Journal of the American Leather Chemists' Association* continues to publish practically all of the leather research being done in the U.S.A.

In this period, there appeared a few papers by Theis and his coworkers of Lehigh University, principally concerned with the hydration of animal skins and the fat-liquoring process (*14*). During the past few years, there has been an assortment of papers concerning the treatment of tannery wastes. This is becoming an urgent problem in the tanning industry, because of the enlightened legislation introduced for the protection of our streams and rivers.

In 1923 the AMERICAN CHEMICAL SOCIETY sponsored a monograph on "The Chemistry of Leather Manufacture" by John Arthur Wilson (*10*), which met with instant approval and was translated into French and Russian. With the growing volume of leather research, a new edition became necessary, and Volumes I and II appeared in 1928 and 1929, respectively. This book has again been brought up to date by McLaughlin and Theis (*3*).

In the 75 years' history of the AMERICAN CHEMICAL SOCIETY, we have come a long way in our understanding of leather manufacture. The tanner still has his problems, but the chemist has given him, for the first time, methods of examining and controlling his liquors and materials, new tannages, artificial and hygienic bates, new oils, new and improved dyes. He has also evaluated the principal properties of leather, so that today leather is purchased by the Government on a specification basis, a matter unheard of in the past, when only the eye and the fingers of the buyer were the judges of good leather.

It is safe to predict that chemistry will continue to make even greater contributions to the science of leathermaking. In the past three generations, analyses and processes were developed. The next step will be to analyze the fundamental chemistry underlying the individual methods of making various leathers. The problem is becoming too complicated for the modern tanner, and it will take the chemist, physicist, and engineer to arrive at an understanding of not only the "how" but the "why" of leather making. The mathematician will play his part by appraising the value of the finished product by statistical methods.

Better leather is being made today because of the contribution of the chemists and the chemical industry to the advancement of leather making.

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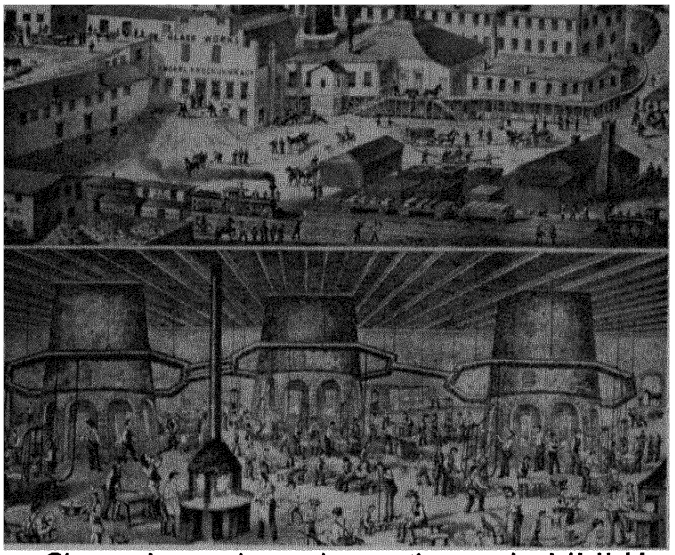
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GLASS AND CERAMICS

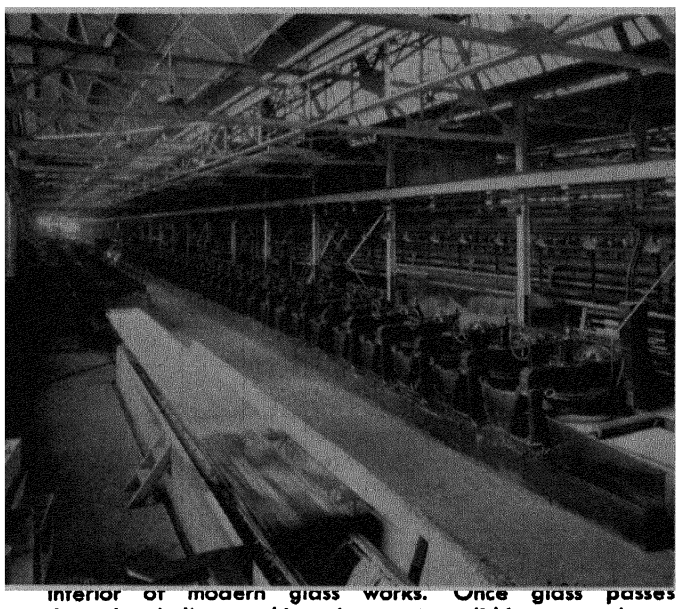
E. W. Tillotson
Mellon Institute, Pittsburgh, Pa.

THE period marked by the founding of the AMERICAN CHEMICAL SOCIETY was one of revolution and evolution in industry and technology, as well as in science. By 1876 the production of Bessemer steel had reached substantial proportions. This plentiful supply of steel at a reasonable cost offered the opportunity for new types of industrial construction and was probably the key to the general mechanisation of industry which is now commonplace.

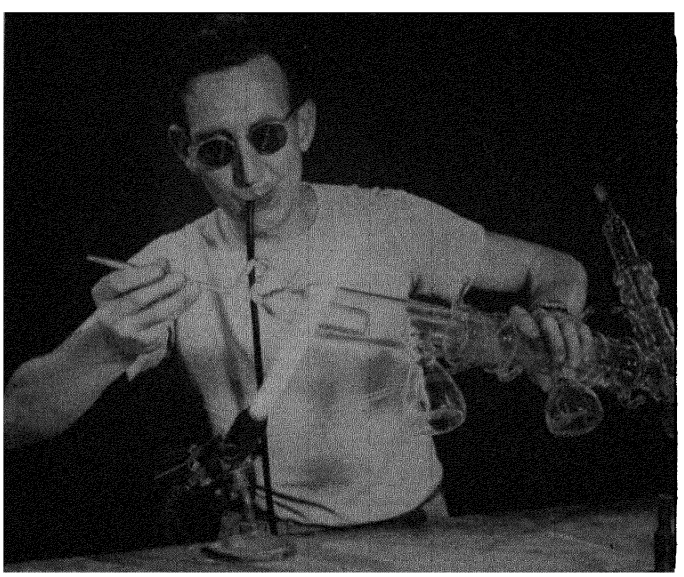
While this was of importance to all industry, it was significantly so in glass and ceramic technology. It made possible, at first, the construction of different types of furnaces and the production of gaseous fuels from coal and eventually led to the intro-



Glass works owned several generations ago by J. H. Hobbs, Brockunier and Co. in Wheeling, W. Va.



Interior of modern glass works. Once glass passes through grinding machines, it goes to polishing operation



Glassblowing is a highly developed art, requiring skillful breath control

duction of automatic forming machines in these several industries. Thus, in the glass industry, a new type of melting furnace, the "tank furnace," for the continuous melting of glass, was introduced in 1879 and this was followed in 1882 by the development of automatic bottle machines, and by mechanically drawn window glass in 1900. In combination with continuous melting and rolling, the continuous grinding and polishing of plate glass came in about 1920.

Mechanical forming had also been introduced for the manufacture of building brick, sewer pipe, and hollow tiles, but the application of science in these manufactures has not yet reached its full development.

The organization of the American Ceramic Society in 1899 signaled a turning point in the technology of the glass and ceramic industries, as the chemist and the physicist became teammates with the practical glassmaker and the ceramist. In glass the names of G. E. Barton, A. V. Bleininger, E. C. Sullivan, W. C. Taylor, A. Silverman, and S. R. Scholes are only a few of the early contributors to the science and technology of glass. A. V. Bleininger and G. E. Barton were the first editors of the "Glass and Pottery" section of *Chemical Abstracts* and Barton continued in that office for many years. In addition to the several earlier papers on this subject sponsored by this division, Symposia on Glass under the chairmanship of F. C. Flint and A. Silverman, respectively, were sponsored by the Division of Industrial and Engineering Chemistry at the April 1933 and the September 1940 ACS meetings.

Glass Industry Moves Ahead

A few notable developments in the glass industry that may be credited almost entirely to the chemist should be mentioned: Pyrex ware (1915), for the laboratory, for the home, and for many industrial uses; Vycor ware, nearly pure silica in composition, manufactured by the usual glassmaking processes with additional chemical treatments, equivalent to fused silica for many purposes, and superior for others; and photosensitive glass, which contains the photosensitive materials as a part of its composition, thus permitting the development of the picture within the body of the glass itself. "Spun" glass and tempered glass had their origin nearly 75 years ago, but only during the past 25 years have become commercially successful. Glass fiber in its various forms and tempered safety glass (with its partner, laminated safety glass) are notable accomplishments of the scientist. Then, too, the chemical resistance of glass for containers, especially for pharmaceutical preparations, has been greatly improved in late years.

Chemists and other scientific men entered the refractories industry only after the turn of the century. In fact, the past 30 years have seen the important developments that have made possible the amazing refractory products now available. Pioneers in these early days were A. V. Bleininger, R. M. Howe, J. S. McDowell, and A. F. Greaves-Walker. A Symposium on Refractories was sponsored in September 1919 by the Division of Industrial and Engineering Chemistry with A. V. Bleininger as chairman.

The manufacture of fireclay refractories was a very early industry in this country, but the introduction of silica refractories (1884), of magnesite and chrome refractories (1896), of silicon carbide (1897), and of high alumina refractories (1906) came within the historical period of these annals.

The importance of refractories in many other industries is obvious. Iron and steel manufacture utilizes about 60% of all the refractories produced, while only about 1% goes to the chemical industries, but this use constitutes a very important factor in the chemical industry.

The service rendered by refractories has been greatly increased during this time, partly by reason of a better selection of raw materials and partly by the introduction of newer materials and the application of technology—for example, considerable use is

now being made of fired tunnel kilns for firing refractories. Besides being cheaper, they permit more accurate control. Another development has made available a variety of refractory shapes cast into molds from compositions melted in the electric furnace.

Enameling of cast iron and sheet iron had its start largely as a means of decoration, as a finishing operation of a foundry product or of a stamped metal product. Each company manufactured its own "frits," a completely empirical affair. With the introduction of science into enamel technology, however, there sprang up a group of independent frit manufacturers, who supply the enamel user and have so improved enamel compositions that the use of enamels has been greatly extended. The chemist began making his contributions to this field about 50 years ago. The pioneers include H. F. Staley, F. H. Riddle, Edward Orton, Jr., R. D. Landrum, E. P. Poste, and R. R. Danielson. The present extensive application of enamels has come about partly by the great improvement of chemical compositions and partly by the cooperative efforts of metallurgists in the control of the metals that are to be enameled.

Other branches of the ceramic industries have had a similar history. Albert V. Bleininger's name appears in each of them, but particularly in the evolution of the technology of whiteware manufacture. The potter's wheel is now being supplanted by ingeniously contrived automatic forming machinery. As a result, the manufacture of porcelain and china tableware is taking its place among the modern mechanized industries. Bleininger and Riddle also were largely responsible for the early development of the modern spark plug, in many ways one of the really remarkable ceramic developments. In addition to those symposia already mentioned, four Symposia on Electrical Insulating Materials were sponsored by the Division of Industrial and Engineering Chemistry in September 1938, April 1940, September 1941, and April 1946. Local sections of the Society have devoted meetings to ceramic subjects—for example, the Pittsburgh Section has sponsored over a dozen such programs since 1918, all of which have been eminently successful.

The story of these silicate industries runs parallel to that of other industries. None is self-sufficient, and each must take advantage of developments elsewhere, make advances in its own technology, and in turn give to other industries products or processes that advance the whole march of technology.

Seventy-five years ago the silicate industries were operated by artisans. Only when the powerful tools of the chemist, the physicist, and workers in other scientific fields were brought into play did these industries pass from the realm of the arts into the domain of science.

DIVISION OF INDUSTRIAL AND ENGINEERING CHEMISTRY

W. A. PARDEE

IN 1907 ACS President Marston T. Bogert appointed a committee to consider the advisability of undertaking the publication of a journal of industrial and engineering chemistry and the formation of an industrial division. At the Christmas 1907 national meeting of the Society in Chicago, this committee recommended and Council approved the publication of the journal and the formation of the Division of Industrial Chemists and Chemical Engineers.

The organizational meeting of this first ACS division was held in North Sheffield Hall, Yale University, on June 30, 1908, at the 38th general meeting of the Society. Presiding over this meeting was William D. Richardson, whose election as first editor-in-chief of the *Journal of Industrial and Engineering Chemistry* was already assured. The first officers of the Division of Industrial Chemists and Chemical Engineers were: Arthur D. Little, chairman; A. H. Low, vice chairman; B. T. Babbit Hyde, secretary; and an executive committee of six.

It was under the leadership of this group of enthusiastic chemists and chemical engineers that the first division of the society began its activities. Over the years, these programs assisted not only in the development of the chemical process industries, but in bringing public awareness and appreciation of the chemist's and the chemical engineer's contributions to our society.

Committee activity was very high in the early days of this division. There were standing committees on:

Definition of Industrial Terms
Trade Customs
Standard Specifications and Methods of Analysis
Research Problems
Descriptive Bibliographies
Publicity

A special committee was appointed in December 1909 to confer with manufacturers for the purpose of determining at what prices various elements and special compounds could be obtained if a large enough market was developed for them. As early as July 1911, a committee was appointed to study the need for a professional code of ethics among chemists. The ground-breaking work of most of these committees was not encouraging. In the early days of the committees on definitions and specifications, manufacturers practically ignored the committees' requests for data concerning their products. Definitions of such materials as bronze, grades of inorganic chemicals, heavy chemicals, pharmaceutical products, iron and steel, portland cement, and various petroleum products were sorely needed, but for some time were not obtainable. Subcommittees attempting to formulate standard specifications on such materials as soda ash, caustic soda, alum, various mineral acids, solder, and turpentine met similar opposition from manufacturers.

The division encouraged and sponsored numerous symposia and general papers covering subjects which later became the fields of specialization of new divisions within the Society. The division's first symposium was held in Boston in December 1909 on the subject of paint. A Symposium on the Chemistry of Dyestuffs was held in September 1918 under the chairmanship of R. N. Shreve. Interest in this program led to the formation of the Dye Section and later the Dye Division. Two symposia on cellulose, held in April and September 1920 under the chairmanship of J. E. Crane and G. J. Esselen, probably played an important part in the formation of the Division of Cellulose Chemistry. A symposium in 1921 on the chemistry of gases and fuels under the chairmanship of C. H. Stone promoted the formation of a section and later a division on this subject. Other symposia which appeared on the programs of the Division of Industrial Chemistry and Chemical Engineers during the early years were:

Smelter Smoke (1910)
Mineral Wastes (1911)
Wood Wastes and Conservation (1915)
Occupational Diseases (1916)
Nitrogen Industry (1916)
Metallurgy (1917)
Potash (1918)
Refractories (1919)

There were also several symposia of somewhat less technical nature:

Contributions of the Chemist to American Industries (1915)
Industrial Chemist in Wartime (1917)
Library Service in Industrial Laboratories (1919)
Future of Certain American-Made Chemicals (1919)
Annual Patent Renewal Fees (1919)

The numerous papers and symposia on subjects relating to education and training of chemists and chemical engineers, fertilizer, petroleum, gas and fuel, sugar, and rubber indicate

clearly enough the active interest of this division in promoting chemistry and chemical engineering in these fields prior to their incorporation as divisions within the Society.

On the early programs of the Division of Industrial Chemists and Chemical Engineers there appear names of technical men synonymous with many important technical developments in American industry. Most of these are covered in the appropriate sections of this paper. However, a few of those not mentioned elsewhere are given here. F. G. Cottrell's early work on electrical precipitation of suspended solids was reported before this division in 1910 at the San Francisco meeting. S. W. Parr reported his work on the Parr calorimeter before the division. C. H. Herty described his studies of pine tree resins. In connection with petroleum technology, D. W. Day presented before the Industrial Section in 1904 a paper entitled "Changes in Crude Petroleum Effected by Diffusion through Clay," and in 1910 Leon La Bond discussed "The Scientific Use of Crude Petroleum as a Source of Power."

In 1919 Council acted on a motion by Harrison E. Howe and changed the name of the Division of Industrial Chemists and Chemical Engineers to Division of Industrial and Engineering Chemistry, the name which the division bears today.

The division has always taken an active interest not only in the welfare of the chemist and the chemical engineer, professionally and socially, but in the transformation of laboratory discoveries into efficient industrial processes. Over the years the concepts of unit processes, based on the chemical reactions, and unit operations, based on physical processing, have emerged as useful structures within which the developing knowledge of the field could be organized. Materials of construction for use in industrial processes must be evaluated; in this phase of technical development the division is also vitally interested.

Numerous individual papers on various unit operations and unit processes appeared in the early programs of the Industrial Section and division. However, the first formal Symposium on Unit Operations appeared on the April 1921 program; the subjects were "Drying" and "Filtration." Other unit operations subjects were covered almost every year until 1934, when the first of a most successful series of special symposia was inaugurated. Since then the Chemical Engineering Symposium has become an institution, while at the same time unit operations has become one of the cornerstones of chemical engineering theory and practice. The list of subjects presented during its existence is given below.

1934 Distillation
1935 Heat Transmission
1936 Absorption and Extraction
1937 Drying and Air Conditioning
1938 Fluid Dynamics
1939 Separation Operations
1940 Diffusion as a Basis of Unit Operations
1941 Applied Thermodynamics
1942 Industrial Reaction Rates
1943 Agitation and Mixing
1944 Adsorption and Ion Exchange
1945 Measurement and Creation of Particle Size
1946 Distillation
1947 Heat Transmission
1948 Fluidized Solids Technique
1949 Absorption and Extraction
1950 Dispersion in Gases

Unit process papers have enjoyed an equally important position in the division's activities. For many years, the division irregularly scheduled individual papers and symposia on more or less specific processes. However, the first symposium bearing the general name, "unit processes," was presented in September 1937. These symposia, under the chairmanship of R. N. Shreve, have been a regular and important feature of the division's fall meeting program each year since 1937.

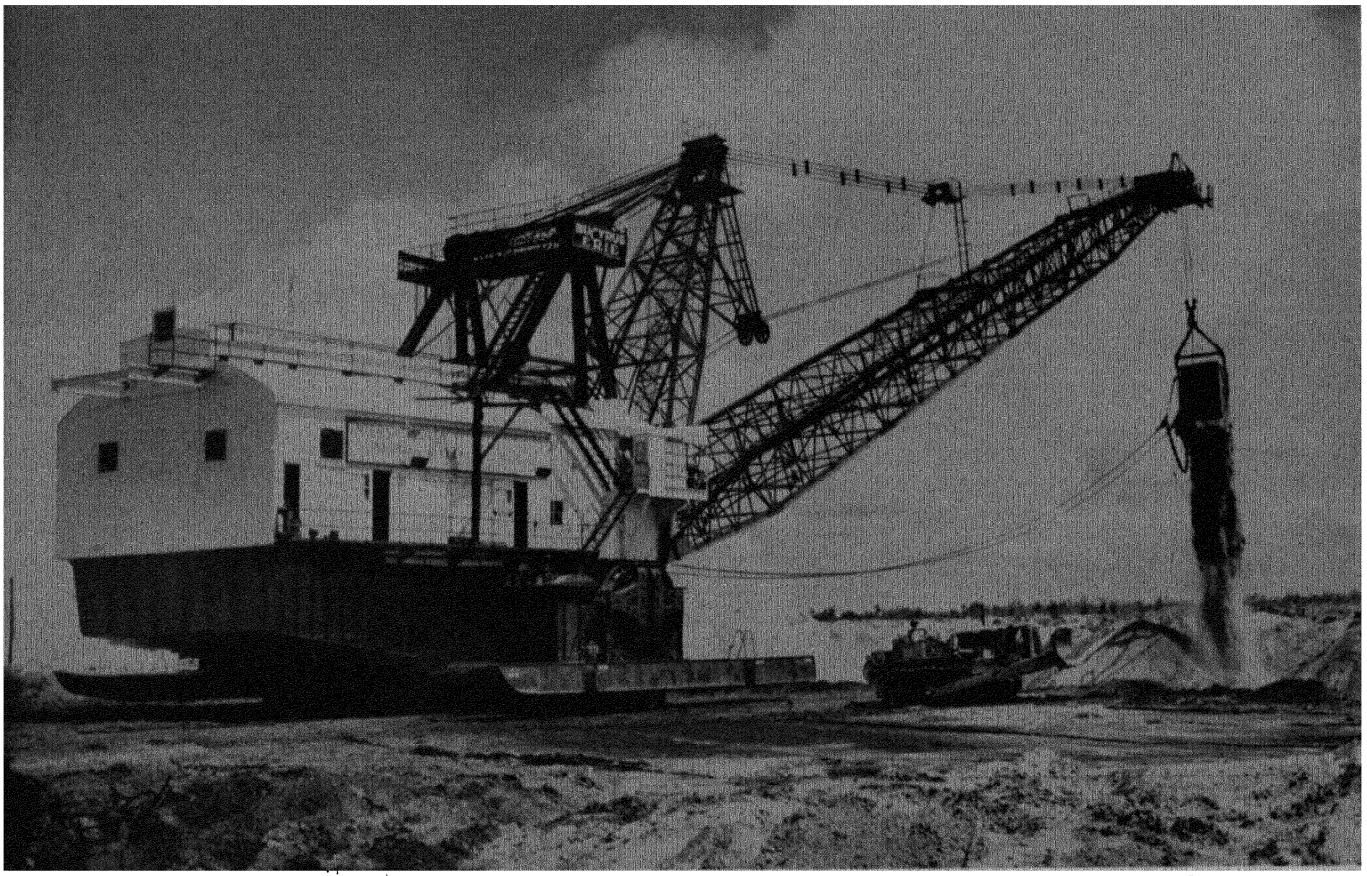
The creation of sections within the divisional organization has aided in the dissemination of technical data on special fields of interest within the scope of the division. While sections have been active and recognized in the past, it is only within the past five years that they have operated on a formal basis and only within the past year that provision for their formal organization within the division was incorporated into this division's bylaws. Sections on Chemical Marketing and on Fluorine Chemistry are active at the present time. A committee was recently appointed to advise the Executive Committee on the formation of several new sections.

Officers of the Division of Industrial and Engineering Chemistry, 1908–1951

Year	Chairman	Secretary-Treasurer
1908–1909	Arthur D. Little	B. T. Babbit Hyde
1910	Arthur D. Little	Francis E. Gallagher
1911	George C. Stone	Francis E. Gallagher
1912	George D. Rosengarten	Francis E. Gallagher
1913	George D. Rosengarten	S. H. Salisbury, Jr.
1914–1915	George P. Adamson	S. H. Salisbury, Jr.
1916–1917	Harrison E. Howe	S. H. Salisbury, Jr.
1918	William H. Walker	S. H. Salisbury, Jr.
1919	H. S. Miner	Harrison E. Howe
1920–1921	H. D. Batchelor	Harrison E. Howe
1922	Warren K. Lewis	Erle M. Billings
1923–1924	D. R. Sperry	Erle M. Billings
1925–1926	W. A. Peters, Jr.	Erle M. Billings
1927	William H. McAdams	Erle M. Billings
1928–1929	Robert J. McKay	Erle M. Billings
1930–1931	Robert E. Wilson	Erle M. Billings
1932–1933	Donald B. Keyes	Erle M. Billings
1934–1936	Walter G. Whitman	Erle M. Billings
1937	Thomas A. Boyd, Jr.	Erle M. Billings
1938–1939	Walter L. Badger	Howard S. Gardner
1940–1941	Barnett F. Dodge	Whitney Weinrich
1942	Lawrence W. Bass	Whitney Weinrich
1943	R. Norris Shreve	Whitney Weinrich
1944	R. Norris Shreve	William A. Pardee
1945–1946	Thomas H. Chilton	William A. Pardee
1947	Francis J. Curtis	William A. Pardee
1948	Henry F. Johnstone	William A. Pardee
1949	Joseph C. Elgin	William A. Pardee
1950	Lincoln T. Work	Charles J. Krister
1951	William A. Pardee	Charles J. Krister

The chairmen and secretary-treasurers, who have so enthusiastically and actively supported the interests of the Division of Industrial and Engineering Chemistry, are listed in the accompanying table. There have been 27 chairmen, nine secretary-treasurers, and 71 executive committee members of this division during its 43 years of activity. Some of the chairmen of the Industrial Section prior to divisional status were: Edward Hart (1904), S. W. Parr (1905), J. D. Pennock (1906), A. D. Little (1907), W. H. Ellis (1907), and William D. Richardson (1908).

The records of the division's activities may be found in the 1905–08 issues of the *Journal of the American Chemical Society*, in the *Journal of Industrial and Engineering Chemistry* (1909–22), and in the *News Edition* (now *Chemical and Engineering News*) from 1923 to the present date.



This 21-cubic-yard dragline excavator used in phosphate mining is appropriately named the Bigger Digger

Fertilizer Chemistry

Chemical science has aided materially in the improvement of existing processes for the manufacture of fertilizers

F. S. LODGE

National Fertilizer Association, Washington, D. C.

THE use of various natural materials to increase crop production has been recorded since the days of early Rome. In the United States such practices were recommended in the diaries of Washington and Jefferson. As early as 1830, Chilean nitrate of soda was imported and two years later commercial importation of guano from Peru was established.

The years 1849 and 1850 mark the actual beginning of chemical fertilizers in this country. The first of these years saw the initial manufacture of superphosphate in the United States in Baltimore, and the issuance to the Chappell brothers of the first chemical fertilizer patent, U. S. Patent 6234. This patent covered the production of a compound or mixed fertilizer in a combined acidulating and mixing process. The components of the mixture included bones, sulfuric acid, "gas or ammoniacal liquor," and a number of "residues" from other chemical operations. These residues contained, among several other things listed, carbonate of potash, calcium sulfate, and magnesium sulfate. From their nature, no doubt, they also contained at least traces of the minor plant-food elements. In this century-old patent are mentioned all the now-known primary and secondary plant foods and probably some of the minor ones. Some processes described in the patent are standard practice today, though in considerably more mechanized form.

In 1850, in Baltimore, mixed fertilizers were produced for the first time in this country. By 1856 it is believed that production reached 20,000 tons. Even so, three times that much Peruvian guano was imported the same year. From then until the late sixties, production seems to have increased slowly and steadily as more plants were built and demand increased, but by-product materials were the main source of the ingredients used in the mixtures. The phosphoric acid came mostly from bones, packing house tankage, and fish scrap. These materials, along with imports of Peruvian guano and Chilean nitrate of soda, furnished the nitrogen. Potash was just being exploited as a plant food by Liebig. Imports of potash from Germany started in 1869.

Shortly after the end of the Civil War, the value of the phosphate rock deposits near Charleston, S. C., was recognized and their development undertaken. Treatment of this rock with sulfuric acid produced superphosphate, which soon became the principal source of phosphoric acid in fertilizers. The development of fertilizer manufacture from a scavenger industry into a chemical industry began in this era.

By 1875, about the time the AMERICAN CHEMICAL SOCIETY was founded, annual consumption of fertilizers and fertilizer materials had increased to nearly a million tons, and the chemical problems involved in fertilizer manufacture became important. It had

been realized almost from the first that the agricultural value of a fertilizer was in direct proportion to its content of certain chemical compounds, notably those carrying nitrogen and phosphates. The first record of a fertilizer analysis by a state official appears in 1851. Little was then known of satisfactory chemical methods for quantitative measurement.

As early as 1856, a state fertilizer control law was enacted in Massachusetts, but its requirements were so rigid and exacting that it could not be enforced. A revised law more in keeping with then-known analytical methods was enacted in 1872. Today all 48 states have such laws. The literature shows that much of the guano imported during the early years was heavily leached, with practically no plant-food content remaining. To establish fraud in such cases and prevent further importations of worthless material, it was necessary to develop analytical methods sufficiently accurate to stand up in court and assist in protecting the consumers.

The formation of the Association of Official Agricultural Chemists in the early 1880's and their subsequent research in developing accurate methods of chemical analysis have been of incalculable value to agricultural chemistry in all of its branches.

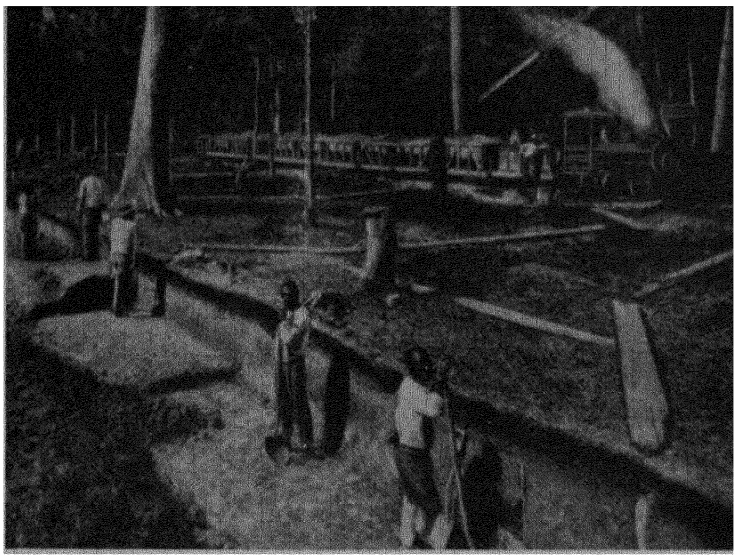
Chemical Processes Used in Production of Fertilizers

Discovery of the phosphate rock deposits of Florida and Tennessee in 1881 and 1893, respectively, and their development contributed additional impetus to the expansion of the chemical side of the fertilizer industry. In the early 1890's the first concentrated superphosphate was produced in this country and by-product sulfate of ammonia was first recovered from the coking of coal.

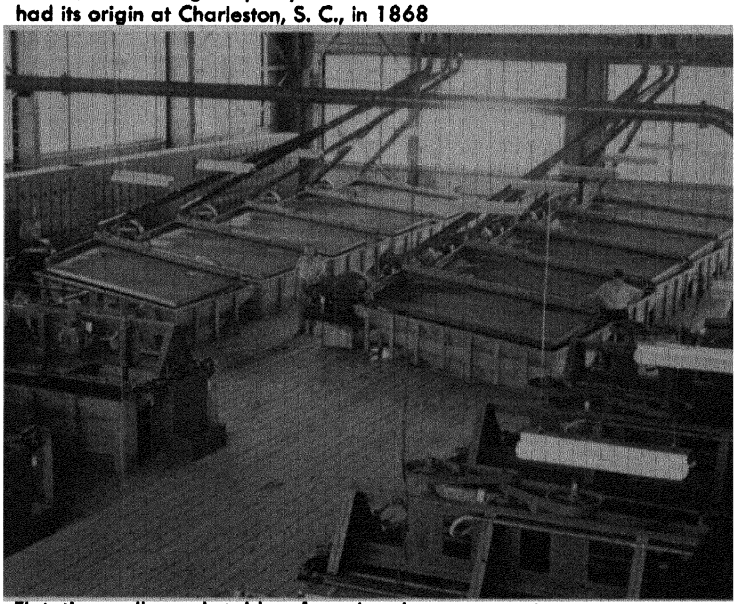
During the first 50 years of the industry's progress, the nitrogen used came almost entirely from the organic wastes of other industries. The principal sources were the oilseed meals, packing house by-products (such as tankage, blood, and bone), fish scrap, garbage tankage, and peat. In 1900, over 91% of the nitrogen was in the natural organic form and only 9% came from chemical salts. Increased production of by-product sulfate of ammonia and additional imports of nitrate of soda, together with better knowledge of formulation possibilities, rapidly increased the use of the chemical forms until by 1920 about equal percentages of organic and chemical forms were used. In 1949, less than 5% of the nitrogen consumed as fertilizer was in the organic form. Practically all these previously used organic by-products were diverted to use as animal feeds. About 1926 the processes of using aqua and anhydrous ammonia directly in fertilizers were introduced and the later use of ammonia solutions containing ammonium nitrate or urea contributed greatly to this development. Production of cyanamide at Niagara Falls, Ont., in 1909, followed by the production of synthetic anhydrous ammonia in 1921, added to our nitrogen resources. The synthetic ammonia plants built by the Government in the World War II program and later released to private ownership and management ensured an adequate supply for all peacetime needs.

One of the greatest chemical achievements of the fertilizer industry was the establishment of a nationally self-sufficient potash industry. The chemical process problems and chemical engineering details worked out in connection with the production, through fractional crystallization, of potash from the brines of Searles Lake, Calif., and the salt flats near Wendover, Utah, and the recovery and concentration of potash from the solid deposits of low grade salts beneath the New Mexico desert near Carlsbad, N. M., have been outstanding contributions to industrial chemistry.

Although the chemistry of superphosphate manufacture has been changed little in the last 100 years, there has been much refinement in the technique of its application. The techniques have advanced from hand-stirring in mortar boxes with hoes to almost automatic mechanical installations for weighing and mixing the ingredients, and from hand-digging of dens of super-



Commercial mining of phosphate rock in the United States had its origin at Charleston, S. C., in 1868



Flotation cells and tables for phosphate processing at International Minerals and Chemical Corp., Mulberry, Fla.



The size of modern plants is typified by this view of American Potash and Chemical Co., Trona, Calif.

phosphate to mechanical dens that excavate themselves and deliver the crumbled and aerated superphosphate to storage.

The manufacture of a higher grade superphosphate or concentrated superphosphate began in 1872 (*4*). This process was essentially an acidulation of phosphate rock with somewhat weaker sulfuric acid than was used to make normal superphosphate. The sulfuric acid converted the phosphorus content to phosphoric acid. The product was leached to obtain the phosphoric acid in dilute solution, which was then concentrated and used to acidulate more ground phosphate rock. The resulting product, known as concentrated superphosphate (also called double superphosphate, triple superphosphate, and treble superphosphate), contains 40 to 48% available phosphoric acid. The phosphoric acid for the acidulation may also be obtained by smelting phosphate rock in an electric furnace, recovering the volatilized phosphorus, which is then burned and collected in the form of concentrated phosphoric acid. Officially, superphosphates containing up to 25% available phosphoric acid (P_2O_5 basis) are known as normal superphosphate and those containing above 25% as concentrated superphosphate.

The processes for converting the comparatively insoluble and unavailable phosphorus content of phosphate rock into compounds which carry the phosphorus in forms which can be utilized readily by plants have perhaps undergone more research effort than have all the other fertilizer chemical problems. Thousands of dollars have been spent on this research problem. It is still perhaps the most vital chemical problem facing the industry because of the impending shortage of sulfur required by the superphosphate manufacturers for their production of sulfuric acid. Among the many processes that have been investigated in this research which have reached at least the pilot plant stage, if not even the production stage, are:

1. Calcination of phosphate rock in rotary cement kilns with and without such reagents as soda ash, silica, or water vapor.
2. Production of calcium metaphosphate by burning elemental phosphorus in the presence of phosphate rock.
3. Fusion of phosphate rock with serpentine or olivine.
4. Acidulation of phosphate rock with hydrochloric or nitric acid.
5. Direct defluorination of rock by heat processes.

The Future of the Fertilizer Industry

These various advances in chemical technology in the fertilizer industry have placed our nation in an independent position as to its necessary requirements of plant food. Sufficient capacity is available in the form of synthetic ammonia plants to produce all our conceivable agricultural needs of nitrogen from the haustible supply in the air. There are deposits of phosphate rock already surveyed which will last an estimated 3000 years, together with sufficient mining and processing capacity to satisfy our needs of available phosphoric acid. We have enough capacity already installed to produce and refine our needed potash, with reserve deposits mapped out to last at least 200 years.

Consumption of fertilizers had increased to 2.2 million tons by 1900, with an average plant-nutrient content in mixed goods of 13.9%. By 1930, it had reached 8.2 millon tons, with an average nutrient content in mixed goods of 17.90%. The approximately 50% drop in consumption reached in the depression of 1932 was all recovered by 1940, and steady increases continued until 1949 registered a consumption of 16.5 million tons with an average nutrient content of over 22%.

As these many improvements and advances in fertilizer chemistry came to pass, the attention of the industry was brought more and more to the supreme importance of chemical science to its welfare. The functions and significance of chemical control in the industry became recognized, and the fertilizer chemist became a man of importance and value rather than a necessary evil. Fertilizer chemistry became recognized as a separate branch of the profession.

Fertilizer Chemistry and the American Chemical Society

The Division of Fertilizer Chemistry of the AMERICAN CHEMICAL SOCIETY was authorized in 1908, shortly after the Society inaugurated the divisional system, being one of the four divisions authorized that first year.

The organization of the Division of Fertilizer Chemistry was perfected in 1909 with F. B. Carpenter, chairman, and J. E. Breckenridge, secretary.

An executive committee, selected from chemists in state and government service and from the fertilizer industry, has functioned throughout the years, particularly in program arrangements and in deciding matters of policy.

Although the division held meetings between 1909 and 1916, no record of the attendance or programs seems to have been published; in fact, the attendance was usually small and the papers presented were few. In 1916, for instance, at the spring meeting held at the University of Illinois, Urbana, Ill., only three members were present—J. E. Breckenridge, then chairman, F. B. Carpenter, and the author of this history. At that meeting, free, informal discussion of the chemical problems of the fertilizer industry resulted in a definite outline for future meetings of the division.

Inasmuch as the spring meetings of the Society generally take place at the height of the fertilizer shipping season when it is very inconvenient, if not impossible, for industry chemists to be absent from their laboratories, it was proposed that meetings of the division should be held only during the fall meetings of the Society and this policy has been maintained.

In order to stimulate interest in the meetings of the division and ensure larger attendance, it seemed desirable, as far as possible, to have one topic predominate at each meeting. Believing that the question of obtaining representative samples of fertilizer shipments for the purpose of analysis by state officials administering fertilizer laws was of the first importance, this subject was decided upon as the major topic for discussion at the 1916 fall meeting. The availability of the nitrogen in organic fertilizer materials was to be a secondary topic for discussion.

At the 1916 fall meeting, a report (*3*) was made on the sampling devices and methods used by the control officials of practically all of the fertilizer-consuming states. In many cases, the methods and implements used were so crude and so inadequate that representative samples could not be obtained by their use. Approximately 100 people were present at the 1916 meeting, including many state control officials. As a result of this meeting, a committee composed of control officials and industry chemists was appointed to carry out collaborative work on sampling for the purpose of developing standard methods of sampling fertilizers that might be designated as "official" by the Association of Official Agricultural Chemists. A similar committee was appointed by the Association of Official Agricultural Chemists to cooperate with the AMERICAN CHEMICAL SOCIETY committee. Such methods were reported and approved at the 1917 meeting of the Division of Fertilizer Chemistry and were later, in 1920, adopted in substance by the Association of Official Agricultural Chemists. Many states adopted these methods and sampling ceased to be a major problem.

Attendance was light at the division meetings during the World War I period, and papers and discussions generally centered around analytical methods and technique. Since 1920 the meetings of the division have been uniformly well attended when held in the eastern half of the country. No meeting of the division was scheduled in 1925, when the fall meeting of the Society was held in Los Angeles. Meetings of the division, attended as they are by scores of industry chemists and official state and government chemists, provide a forum where problems of fertilizer chemistry may be discussed. The results growing out of such discussions have been of incalculable benefit to agricultural and fertilizer chemistry and hence to agriculture itself. In addition, such meetings of official chemical workers and re-

Officers of the Division of Fertilizer Chemistry, 1909–1951

Year	Chairman	Secretary	Year	Chairman	Secretary
1909–1910	F. B. Carpenter	J. E. Breckenridge	1930–1931	E. W. Magruder	H. C. Moore
1911–1912	Paul Rudnick	J. P. Street	1932–1933	E. W. Magruder	H. C. Moore
1913	Paul Rudnick	J. E. Breckenridge	1934–1935	E. W. Magruder	H. C. Moore
1914–1915	J. E. Breckenridge	E. L. Baker	1936–1937	E. W. Magruder	H. C. Moore
1916	J. E. Breckenridge	F. B. Carpenter	1938–1939	E. W. Magruder	H. B. Siems
1917	J. E. Breckenridge	L. L. Van Slyke	1940–1941	H. B. Siems	C. A. Butt
1918	J. E. Breckenridge	F. B. Carpenter	1942–1943	H. B. Siems	C. A. Butt
1919–1920	F. B. Carpenter	H. C. Moore	1944–1945	H. B. Siems	C. A. Butt
1921–1922	F. B. Carpenter	H. C. Moore	1946	H. B. Siems	C. A. Butt
1923–1924	F. B. Carpenter	H. C. Moore	1947	C. A. Butt	J. B. Hester
1925–1926	F. B. Carpenter	H. C. Moore	1948–1949	J. B. Hester	Vincent Sauchelli
1927	F. B. Carpenter	H. C. Moore	1950–1951	Vincent Sauchelli	S. F. Thornton
1928–1929	E. W. Magruder	H. C. Moore			

searchers on common ground with chemists from industry faced with practical problems have established friendly relations and have broadened the viewpoints of each with advantage to all.

Meetings of the division, coming as they do usually a few weeks prior to the annual meeting of the Association of Official Agricultural Chemists and the annual meeting of the American Association of Fertilizer Control Officials, afford an opportunity to present and discuss pressing problems for consideration by those organizations. Technical workers in fertilizer manufacturing processes and scientists engaged in agronomic and chemical research on plant foods find in the meetings of the Division of Fertilizer Chemistry interested and sympathetic audiences to whom they are welcome to present their problems and research findings and with whom such matters may be discussed with mutual understanding and advantage.

In addition to sampling, many other subjects originally presented and discussed before the division have later received consideration and final action by the Association of Official Agricultural Chemists. They include:

1. Chemical methods for evaluating the activity of organic nitrogen in fertilizer materials. Adopted 1927 (*1*).
2. A change in the size of sample used in the determination of available phosphoric acid, so as to measure more accurately the phosphoric acid content available to plants as food. Official 1931 (*1, 2*).
3. Method for the determination of the amount of potash in fertilizers that is available as plant food, in place of the amount that is water-soluble potash (*1*).
4. Recognition of the role of the so-called minor plant food elements in plant nutrition and their determination in fertilizer materials and mixtures. Adopted 1938 (*1*).
5. Discussions resulting in the establishment by the Association of Official Agricultural Chemists of its Committee on Definition of Terms and Interpretation of Results on Fertilizers and Liming Materials. Appointed 1920 (*1*).
6. Study of the problems involved in producing fertilizers of predetermined residual reaction in the soil, not spoken of as "acid-forming" and "nonacid-forming" mixtures. Adopted 1936 (*1, 5*).

Following the idea of having one subject predominate at each meeting of the division, beginning about 1940 a symposium on some prominent phase of fertilizer chemistry has been held each year. In addition, at least one session at each meeting is devoted to papers pertaining to the broad field of fertilizer technology but not appropriate for the symposium. Some of these symposia have been held jointly with one or more other divisions of the Society. Symposia on the following subjects have been conducted over the past 10 years:

1940 Joint Symposium on Liebig and His Contributions to Agricultural Chemistry
1941 Joint Symposium on Phosphates
1942 Potash
1943 Boron in Agriculture
1944 Nitrogen in Agriculture
1945 No meeting of the Society
1946 Magnesium in Agriculture
1947 Calcium in Agriculture
1948 Processing of Phosphates
1949 Sulfur in Agriculture

Attendance at the divisional meetings during the past 10 years has been very good, from 100 to 250 being present. Through the years, the organization of the division has been somewhat informal in character. No divisional dues have been assessed and no formal membership requirements have been adopted. The close relationship between fertilizer chemistry, soil chemistry, and agronomy in general has made it desirable for many papers to be placed on the division programs that at first thought might seem inappropriate for presentation before the AMERICAN CHEMICAL SOCIETY. However, fertilizer chemistry in its broad aspects goes far beyond the reactions within fertilizer mixtures. The chemistry of the soil, the chemical content and physical characteristics of food, feed, and fiber are all vitally concerned with and affected by the utilization of fertilizers. As a result, fertilizer chemistry and agronomy go hand-in-hand, and many official and commercial agronomists and soil scientists attend the division meetings. Some 600 members of the AMERICAN CHEMICAL SOCIETY are now listed as members of the Division of Fertilizer Chemistry.

Members who have held positions in state or federal laboratories or other official organizations have generally preferred not to accept election as a division officer but have at all times served on the Division Executive Committee. Chemists and agronomists representing commercial organizations have consequently accepted such officer assignments and have attempted to manage the division meetings and programs so that they would be useful and interesting to all segments of the membership. The continually increasing interest and attendance noted at the annual meetings reflect the divisional officers' success along these lines.

Many factory and field problems in fertilizer chemistry remain unsolved and many presently used processes are open to improvement and refinement. It is hoped that the divisional meetings of the future, by revealing the latest in research findings, will be as helpful as those of the past.

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(2) Jacob, K. D., *et al.*, *Ind. Eng. Chem.*, 22, 1385 (1930).
(3) Lodge, F. S., *Am. Fertilizer*, 45, 26 (Oct. 14, 1916).
(4) Mehring, A. L., U. S. Dept. Agr., *Circ.* 718 (December 1944).
(5) Pierre, W. H., *Am. Fertilizer*, 75, 18 (Sept. 12, 1931).



Research worker studies how chemical nutrients affect young apple trees grown in pots of sand



Scientist investigates the action of boron, copper, manganese, and zinc on growth of tung trees



Extraction is employed in analyzing milk from cows that were fed specially treated forage crops

Agricultural and Food Chemistry

Agriculture, food, nutrition, pesticides, and fermentation are all included within its broad ken

F. C. BLANCK

Mellon Institute of Industrial Research, Pittsburgh, Pa.

CHEMISTRY has always been interested in the problems of agriculture and food. Man's food, clothing, and shelter all come from the soil. Many new branches of science have developed to study special phases of the over-all problem. Nevertheless, the contributions of the chemist to the elucidation of these questions have been outstanding and will continue to be so. Chemistry can no longer be considered a science which stands by itself, but rather as an essential tool in man's effort to develop those resources so necessary to his welfare, happiness, and health.

The extreme breadth of the field of agriculture and food makes it necessary to confine our review of the past 75 years of progress to those areas which will not conflict with the reports of more specialized divisions.

AGRICULTURE AND FOOD

F. C. BLANCK

IN 1926, the late C. A. Browne published a scholarly and comprehensive report on the progress of agricultural chemistry from its earliest American period to 1926, the date of the 50th anniversary of the founding of the AMERICAN CHEMICAL SOCIETY. In this paper, the pioneering work of numerous investigators was inspiringly discussed. In addition, attention was given to the advances in the chemistry of fertilizers, animal nutrition, dairy products, crops, insecticides, fungicides, food technology, and food control.

In the section that immediately follows, attention has been focused on newer fields and applications. The earlier interest in individual agricultural commodities has not lessened. In fact, there has been a steady increase in our store of knowledge, particularly since the development of new research tools and procedures.

Plant Hormones. The word "hormone" was first used by the animal physiologist, Starling, in 1905. The original concept that hormones are chemical substances made in one part of an organism and transported to other parts where they produce their effects (Starling) has been broadened to include the fact that they are effective in very minute amounts.

In plant biology, the term hormone was extended still further in 1935, when Zimmerman and Wilcoxon discovered that several synthetic compounds, when applied to plants, bring about effects that are qualitatively indistinguishable from those of naturally occurring hormones. Indoleacetic, indolebutyric, naphthaleneacetic, dichlorophenoxyacetic, naphthoxyacetic, phenylacetic, and indolepropionic acids are some of the compounds now useful in this field. Uses of plant hormones include the rooting of cuttings, thinning of fruit blossoms, controlling of preharvest drop of fruits, as aids to fruit set and seedless fruit production, treating seeds, breaking or inducing of dormancy, and chemical modification of existing plant varieties.

Plant Breeding Studies. Tremendous research activity has characterized this field. The utilitarian value of increased yield, resistance to disease, higher content of certain valuable constituents, and better quality has stimulated the cooperative approach by the plant breeder, the geneticist, and the chemist, who evaluate the progress that has been made in improving the composition or nutritive value of new plant varieties.

Vegetable Composition. In recent years, much attention has been given to the vitamin and mineral content of vegetables, with special reference to the influence of variety, climate, and fertilizer practices on their constituents. Because vitamin C is readily determinable, most of the studies have followed the development of this vitamin. They have shown that variety and climate (light) exert a significant effect on the ascorbic acid content of vegetables, but that differences in fertilizers and soil conditions have little practical significance. With other vitamins, the studies have also shown that the location and/or season greatly influence the amounts of carotene, riboflavin, and thiamine in plant materials.

Maturity Standards. It has long been known that the maximum nutritional value and palatability of many raw foods, notably fruits, were reached at the point of maximum maturity. For many years, a concerted attack has been made on this problem, particularly by the application of chemical methods to determine the changes taking place in growing products from an early stage to the point of recognized optimum maturity. This has resulted in the development of a number of maturity standards which have been valuable in providing food items of maximum acceptability.

Hydrogen Ion Concentration. The development of the pH scale is based on the theory of electrolytic dissociation (Arrhenius, 1887), and the scale now in use was devised by Sorensen (1909). The application of this new technique to foods and their processing has received great attention in the past 25 to 30 years. Milk, flour, dough, bread, crackers, fruit jellies, canned foods, sea food, discoloration of food in metal containers, and corrosion of metal containers are segments of the food field in which the measurement of pH has been important. In fact, this determination is now a routine operation in modern food processing plants.

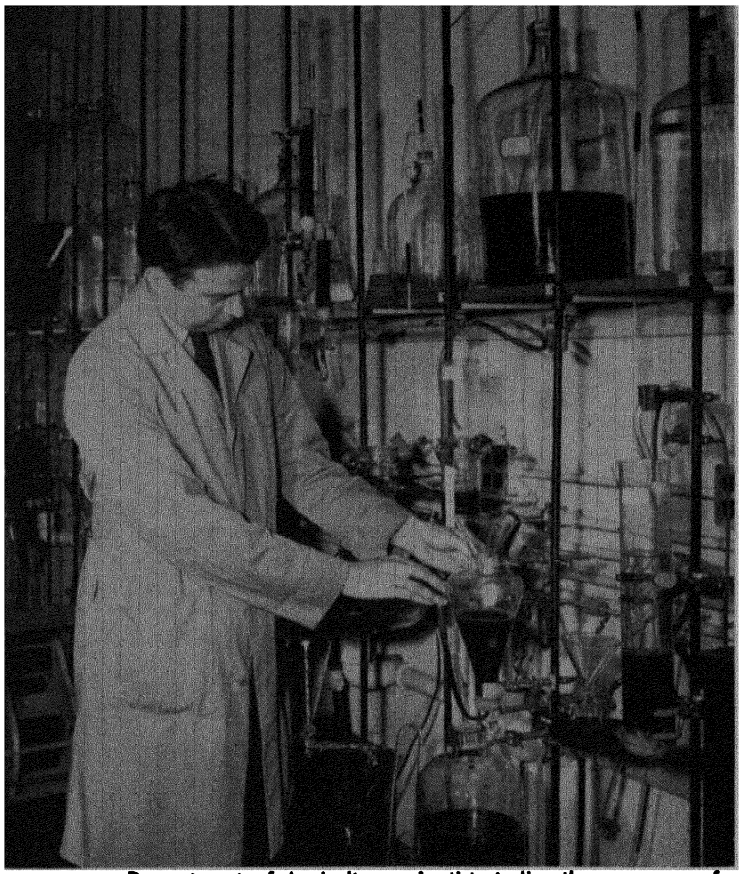
Ion Exchange. Ion exchange, defined by Walton (1941) "as a reversible interchange of ions between a liquid phase and a solid body which does not involve any radical change in the solid structure," was observed by Way (1850) in the passage of potassium chloride solution through soil. The cation exchangers are of three types: (1) aluminosilicates, (2) sulfonated coals, and (3) resinous cation exchangers. The anion exchangers are all organic amines.

Ion exchangers are particularly suitable for the concentration of valuable ions present in such small amounts in solution that they cannot be recovered economically by precipitation or evaporation. In many laboratory applications as well as in the food field, they are valuable. Ion exchange has been used in the preparation of apple sirup, recovery of tartaric acid from grape wastes, recovery of citric acid and sugar sirups from pineapple wastes and of pectin from grapefruit peel, readjustment of salts in milk, removal of nonsugar solids in sucrose production, and removal of organic impurities which contribute to color formation in starch conversion products during storage. Removal of ash from corn sugar liquor by ion exchange methods has made possible the recovery of more dextrose.

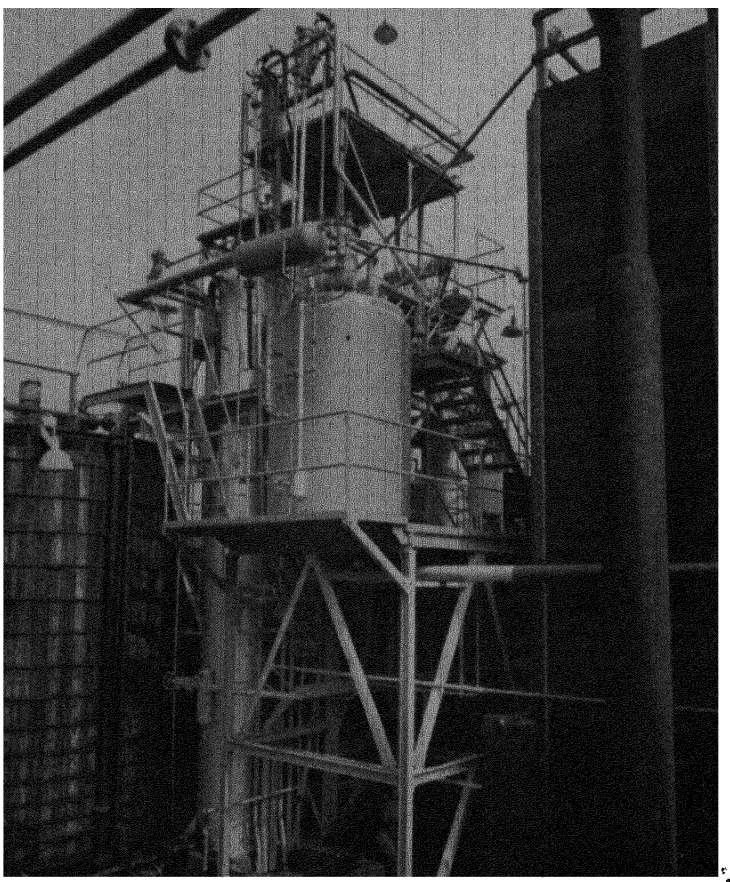
Antioxidants. The development of rancidity in edible fats and oils and food products containing them has long been a problem of commercial and economic importance. Within the past 10 years, this situation has been attacked with renewed vigor. As a result, there are now available a number of compounds of proved value, especially when employed with certain fats. (Nordihydroguaiaretic acid (NDGA), Tenox II (butylated hydroxyanisol plus propyl gallate plus citric acid), lauryl gallate, fat-soluble esters of ascorbic acid, α-tocopherol, gum guaiac, and oat flours have been employed either singly or in combination to delay the development of rancidity in fatty foods. More detailed discussion of this subject will be found in the historical treatment of advances in fats and oils.

Canning. A major method of food preservation is canning. Introduced into this country in 1819–20, it did not become widespread until the use of tin containers in 1840. The closed, steam-pressure retort or autoclave was patented in 1874. By 1918–20 the use of the sanitary style of can for fruits and vegetables became practically universal. The period 1923–28 marked the development of a method for the mathematical calculation of adequate heat processes for canned foods from physical and bacteriological data. In 1937, electrolytic tinning was introduced, followed by the first commercial production of electrolytic tin plate. In recent years, the development of the high-temperature, short-time method of sterilization gives promise of even higher quality of the finished product.

Dehydration. The preservation of foods by drying is one of the oldest food processes known. It was not until World War I that commercial dehydration other than sun drying reached any magnitude in this country. Because of the compactness of dehydrated foods and their savings of space and containers, considerable effort was expended during that period in developing commercial dehydration. These efforts were unsuccessful because certain fundamental procedures were not understood. The products deteriorated rapidly, were difficult to reconstitute, and were not particularly acceptable as prepared food items. In World War II, dehydration again came to the forefront. It was recognized that the blanching or adequate heat treatment of vegetables was necessary to inactivate enzymes before proceeding with the dehydration technique. It was further learned that the



Department of Agriculture scientist studies the recovery of tartaric acid from grape waste



Mojonnier evaporator is used in production of frozen orange juice concentrate at California plant

packaging of a number of dehydrated items in hermetically sealed containers in the presence of an inert gas such as nitrogen or carbon dioxide not only increased the life of the dehydrated product but also permitted better retention of nutrients. A further advance was made by limiting the moisture content to the lowest possible amount consistent with large scale commercial operations. During World War II and in the present feeding program for our armed forces, dehydrated soups occupy an important position. These soups are usually precooked before dehydration to a powder. Such soups reconstitute readily and yield an acceptable food item.

Freezing Concentration of Juices. This new development of the past three years is the most spectacular and important contribution to food technology in the past 10 to 15 years. This has been made possible by the development of new types of equipment which utilize very high vacua without additional application of heat. In practice, the fruit juices, notably orange juice, are concentrated to approximately one quarter of their volume and then sufficient fresh juice is added to impart additional flavor. The finished product represents a final concentration of 4 to 1 and is packed in tin containers which must at all times be kept in a frozen state during storage. The spectacular increase in production and consumption of this new type of product is well illustrated by the fact that in 1950 the total production amounted to 25 million gallons.

Quality Evaluation of Foods. Today, more than ever, the consuming public is alive to the importance of food quality. Consequently within the past 10 to 15 years, increased attention has been given to this phase of food technology. Wherever possible, suitable chemical, physical, and organoleptic tests are utilized to determine the acceptability of the many different types of food now available to the American public.

Nutritive Value of Foods. With the development of our knowledge of nutrition and more particularly the development of quantitative methods for the determination of food nutrients, including vitamins and amino acids, increasing attention is being paid by food processors to the retention of these values in processed foods. The raw materials must be followed through every step in the manufacturing operation in order to determine points at which nutrient losses may occur, and take appropriate steps to eliminate or at least substantially reduce such losses.

Food Deterioration and Spoilage. Since man's first effort to preserve foods, he has been plagued with problems incidental to food deterioration and spoilage. While such changes, particularly spoilage, are primarily microbiological in character, such deterioration and spoilage are frequently accompanied by the development of specific chemical compounds, the isolation and identification of which are accepted as *prima facie* evidence of spoilage or decomposition. As chemical methods become more refined and are suitable for microdetermination, further progress will be made in applying microanalysis to the problems of food spoilage and decomposition.

Regulatory Control of Foods. The passage of the Food and Drug Act of 1906 marked a milestone in the better protection of the consuming public against the adulteration and misbranding of foods. However, experience showed many weaknesses in the old law which reduced its value as a protective measure. Consequently, in 1938 Congress enacted the Food, Drug and Cosmetic Act, which represents a most important advance in the legal control of the purity and labeling of our foods. Perhaps its most outstanding feature is the provision whereby definitions and standards for foods, having the full force of law, can be promulgated. In all definitions and standards so far announced, full advantage is taken of the use of chemical methods in determining the minimum content of the essential ingredients in such defined food products.

We have learned much about the composition of food and agricultural raw materials, the factors influencing their growth

and chemical make-up, their transformations to new uses, the development of new chemicals to meet the needs of agriculture, and the improvement of the purity and quality of our foods. There is still much more to learn.

Browne stated 25 years ago: "Chemistry in its relationship to agriculture has changed from an independent to a cooperative science, and it is in the borderland where [agricultural chemistry] and the other sciences meet that the agricultural scientists of the future will find the greatest opportunities for service and accomplishment."

NUTRITION

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PROGRESS in the investigation of mammalian nutrition before 1875 is mainly associated with the names of Lavoisier, Gay-Lussac, Liebig, Boussingault, Mulder, Schmidt, Bidder, Regnault, Reiset, Bachl, Moleschott, Voit, Stohman, Magendie, Henneberg, Rubner, and others who worked under the guidance of these pioneers. The principal facts which were established by their work were:

Metabolism of food involves oxidation. There are relationships between food, work, and heat production.

The nitrogen content of the urine can be used as a measure of protein metabolism in the body, as proteins contain nitrogen and no significant amounts of nitrogen are excreted in respiration and the shedding of epidermal structures.

Analyses had been made of a number of foods and feeding stuffs which revealed their content of carbon, hydrogen, nitrogen, and oxygen. Henneberg and Stohmann had developed their method by which the moisture, ash, nitrogen (protein), nitrogen-free extract, and crude fiber were determined. This formed the basis of food analyses for many years.

Energy for muscular work can be derived from carbohydrate and fat as well as protein, and the latter is taken from muscle substance only after nonnitrogenous reserves are exhausted. Muscular work does not lead to increased nitrogen excretion in the urine.

Results of respiration studies revealed the significance of the respiratory quotient as a means for determining the kind of nutrient being burned for energy and the kind of reserve material being stored from ingested foods.

Stohmann had determined the calorific values of fats, fatty acids, certain proteins, several sugars, urea, and other metabolic products.

It had been shown that animals cannot be maintained in health when restricted to a single nutrient such as sugar, albumin, gelatin, or olive oil.

Some attention had been given to determining the physiological significance of inorganic salts, acidity, and the maintenance of neutrality in the body.

Progress in Research Since 1875. During the last quarter of the nineteenth century, W. A. Atwater analyzed all of the more important human foods of the United States, using the "Weende method" devised by Henneberg and Stohmann. Atwater determined the caloric values of foods and, in many cases, their digestibility. With a respiration calorimeter, he determined the energy requirements of human subjects doing several kinds of work. He was the leader in making dietary surveys designed to discover the consumption of protein and calories of people of many different occupations and many different economic circumstances. He recommended the purchase of foods on the basis of the cost of the protein and energy which these foods provided.

Contributions of Agricultural Experiment Stations. The first agricultural experiment station was established at Weende, near Göttingen, Germany, in 1857. There Henneberg, von Wolff, and Stohmann set the pattern for experiments in animal nutrition, with the objective of achieving economic animal production. The scientific questions which these experimentors asked themselves were: What are the specific nutrients in different feeding stuffs, in what proportions do they occur in each, and in what proportions must the nutritive ingredients be fed in order to produce from the minimum of feed the maximum of flesh (lean), fat, or both? Their investigations covered methods of analysis, digestibility, and the nutritive effects as shown by experience in feeding.

Henneberg soon reached the conclusion that without the aid of respiration experiments the laws underlying the formation of flesh and fat could not be worked out conclusively. He constructed a respiration apparatus similar to the one which had been built a short time before by Pettenkofer and Voit at Munich for the study of the metabolism of carnivorous animals. Atwater and Rosa in America built the first such apparatus for the study of human nutrition, and Armsby built one for the study of the metabolism of cattle.

In 1884 Boussingault published his "Economie Rurale," in which he described his studies on the relation between the content of albuminous matter and food consumed and the growth of farm animals. In 1847 Laws and Gilbert began their studies of animal production at Rothamsted. These studies were imitated by animal husbandrymen and agricultural chemists everywhere until about 1920.

The fact early emerged that there were marked discrepancies between the chemical composition of feeds and their animal weight production values as tested by feeding. By 1889 this fact was so glaringly apparent that a committee of the Association of Official Agricultural Chemists in that year issued a report on the shortcomings of the standard methods for food and feed analysis. The members agreed that efforts should be directed toward devising methods which would reveal the natures and amounts of individual chemical substances in natural products. Little progress was made in this direction until after 1900, although many new chemical substances were isolated from plant and animal materials. As the nutritive significance of none of these was known, the discoveries disclosed nothing new in nutrition.

What was needed was a new approach to the study of the nutritive constituents of foods. The objective of learning the nature of every constituent of plant and animal tissues was admirable, but it was still more important to discover those substances, well characterized chemically, which a diet must provide in order to support the normal physiological needs of the animal. It was also necessary to determine the proportions in which these substances should be supplied to secure best results. Chemical studies could never provide such information. It was necessary to combine chemical studies with animal feeding tests in which basal diets, simplified as far as possible, were used. So far as could be realized, the chemical compositions of these diets had to be known in terms of final digestion products. Between 1898 and 1906, no less than 20 studies were published, describing attempts to nourish animals on mixtures of purified proteins, carbohydrates, fats, and mixtures of inorganic salts. Those of Pekelharing (1905) and of Wilcock and Hopkins (1906) were especially noteworthy. Although these "synthetic" diets provided everything which food chemists thought significant, their animals failed. These investigators found that failing animals could be improved greatly by the inclusion in the experimental diet of a small amount of whole milk solids. These studies made it apparent that there existed nutrients of which chemists knew nothing at all and that these were not furnished by diets composed exclusively of the recognized classes of nutrients.

Studies on Beriberi. Eijkman produced polyneuritis in birds by restricting them to a diet of polished rice and then cured the disease with extracts of rice polishings. These experiments were soon followed by the work of Vordermann on the substitution of whole rice for polished rice in the diets of prisoners and inmates of asylums. Together, these studies ushered in a new era in nutritional investigations.

The notable studies of Kossel on the basic amino acids and the

equally important studies of E. Fischer (1900 to 1910) on the composition of protein hydrolysates (work which was greatly extended by T. B. Osborne, E. Abderhalden, and others) brought to light the great differences in the amino acid make-up of proteins from different sources and extended the list of known amino acids which result from protein hydrolysis. These results led to the important conclusion that in animal nutrition it is not permissible to speak of the "protein moiety" of any diet as comparable to that of another diet derived from different plant and animal sources. Instead, the amino acid composition was recognized as the important property. W. C. Rose demonstrated that only 10 of the amino acids resulting from protein digestion are indispensable to the nutrition of the rat when all other factors of a normal diet are provided. This finding concluded a long series of studies by Osborne, Mendel, Abderhalden, and many others who sought to determine the amino acid needs of animals.

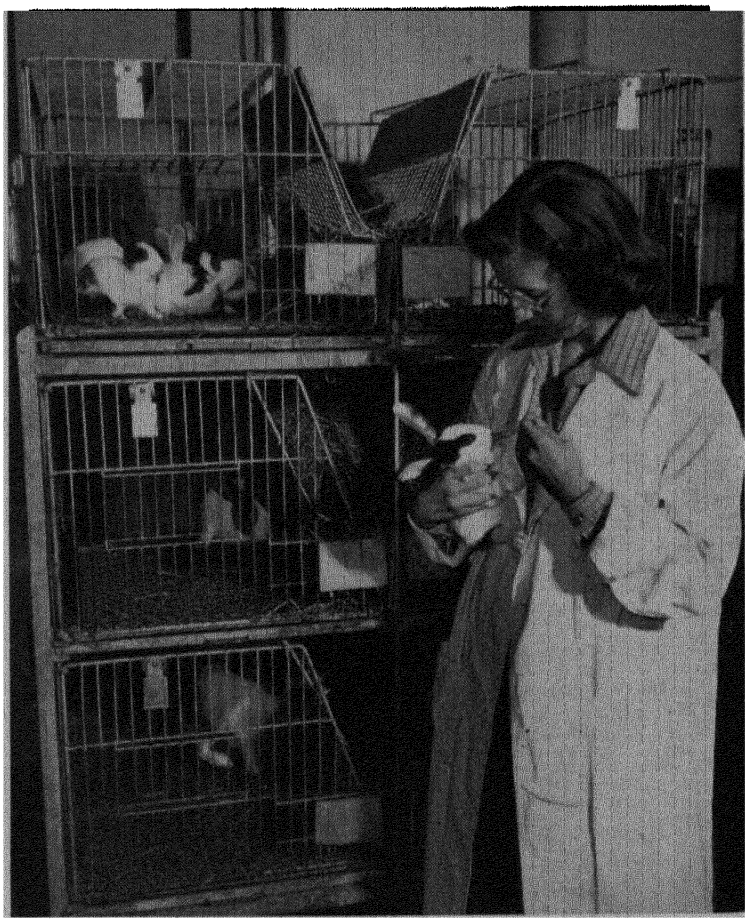
The Era of Vitamins. In 1906 F. G. Hopkins expressed the belief that not only beriberi but also such disorders as scurvy and rickets were caused by a deficiency of hitherto unsuspected nutrients. Pekalharing had come to the same conclusion the preceding year on the basis of his observations of the pathological effects of restricting animals to a diet of purified food substances. In 1913 McCollum and Davis demonstrated that certain fats contain an essential nutrient not contained in other fats. This was the first demonstration of a fat-soluble unknown important in mammalian nutrition. Funk, whose speculations on the nutritional origin of several pathological states extended those of Pekalharing and Hopkins, coined the term "vitamin" in 1911 to include all such unknown nutrients.

Organic *vs.* Inorganic Phosphorus in Nutrition. Between 1895 and 1910 there was a widespread belief that organic compounds containing phosphorus might be important in nutrition, because the ability of the body to synthesize complex substances of this type was questioned. The problem was solved by the experiments of Hart, McCollum, and Fuller (1909), who showed that inorganic salts of orthophosphoric acid could serve all the purposes of mammalian nutrition, including the synthesis of phospholipins, phosphoproteins, and nucleic acids. This conclusion was supported by the studies of Plimmer (1909, 1913), who demonstrated that for each of these types of organic phosphorus compounds, all of which are prominent in animal and plant materials, there are enzymes in the digestive fluids and tissues which bring about their hydrolysis. Therefore, even when they are taken with food, they are resolved before absorption into orthophosphoric acid and the respective organic components.

Development of Biological Method for Analysis of a Foodstuff. For more than a century, medical literature had contained proof that scurvy could be prevented and cured by the consumption of fresh vegetables or infusions (Kramer, 1720) and that beriberi could be eradicated by alteration of the diet (Takaki, 1882). The studies on animals made by Eijkman, Pekelharing, and Hopkins extended the proof that pathological conditions could be induced by deficient diets. Nevertheless, the idea was only slowly accepted that food constituents other than those routinely estimated by analytical chemists were of physiological significance. From 1909 to 1913, Osborne and Mendel, using a diet composed of purified food substances together with 28.3% of dried, deproteinated whey, secured results with growing rats which revealed astonishing differences in the nutritive values of proteins from different sources and emphasized the practical significance of a deficiency of lysine and tryptophan in the proteins of cereals. Not until they had confirmed the observation of McCollum and Davis respecting the presence in butter fat and egg yolk fat of some substance indispensable to nutrition but not found in lard or olive oil, did they accept the view that there were undiscovered nutrients of the class now known as vitamins. There was a sharp turn in the thinking of experimenters in animal nutrition upon the publication of McCollum and Davis' procedure for revealing the nature of the dietary deficiencies of individual foodstuffs. This biological method of inquiry into the reasons for observed nutritive failure of animals on an experimental diet may be illustrated by their study of the feeding of wheat kernel to young rats.

When wheat was the sole food: no growth, short life. Wheat plus a purified protein (source of amino acids): no growth, short life. Wheat plus a salt mixture which gave it a mineral content similar to that of milk: very little growth. Wheat plus a growth-promoting fat (butter fat): no growth.

From these results, it was apparent that more than one nutritive factor was involved in determining the inadequacy of wheat as a food. Supplementing wheat with two kinds of nutrients gave the following results: Wheat plus a protein, plus the salt mixture: good growth for a time, few or no young, short life. Wheat plus protein, plus a growth-promoting fat: no growth, short life. Wheat plus the salt mixture, plus the growth-promoting fat: fair growth for a time, few or no young, short life. When young rats were fed wheat plus all three kinds of supplements, the results were good growth, normal number of young, success in rearing young, life approximately the normal span.



Rabbits are fed manganese dietary supplement to determine its effect on animal growth

In 1915 McCollum and Davis carried out a series of experiments with polished rice supplemented with a purified protein, a salt mixture, and a growth-promoting fat. The three types of supplements were not effective in sustaining growth or maintaining life beyond a few weeks. But when the three supplements were given along with polished rice and a small addition of wheat germ or an alcoholic or water extract of germ, growth and reproduction of the rat were normal. Thus it was shown that for normal growth and reproduction two nutrients of unidentified

nature—one soluble in fats and associated with fats in foods, the other insoluble in fats but soluble in water and in alcohol—are indispensable. This water-soluble factor was in later years shown to contain several components. These studies at once turned nutrition studies in a new direction. During the next decade Morgan published a score of papers on the biological analysis of various foods. Osborne and Mendel abandoned their former techniques and studied the shortcomings of a considerable variety of natural foods by the new procedure, the biological method, which supplemented the chemical methods of food analysis.

Prevention of Infantile Scurvy. By 1890 there was a growing appreciation of the role of raw milk in transmitting typhoid fever, scarlet fever, septic sore throat, and bovine tuberculosis. Pasteurization, which rendered milk safe that had been infected previously by dangerous human contact, was strongly recommended by the medical profession. Accordingly, pasteurization ordinances were adopted in progressive cities. These proved a blessing to the adult population, but brought tragedy to bottle-fed infants who were fed a boiled milk formula or pasteurized milk and generally barley water. The danger of restricting infants to a cooked formula was not understood. In 1912 Holst and Froelich in Oslo showed that a diet consisting exclusively of cooked or dried foods would induce scurvy in guinea pigs and that fresh uncooked vegetable food would cure the disease. A. F. Hess (1915) applied the new knowledge to infant feeding. He was very active in teaching the medical profession and mothers the necessity of giving the bottle-fed infant some fresh fruit juice daily to protect it against scurvy. This has now become universal practice.



Inadequate diet has resulted in the below-average growth of laboratory rat at the right

Prevention of Rickets in Children. Cod liver oil had been employed as a remedy for rickets for many years. Beginning in 1918 Mellanby showed its effectiveness in the treatment of experimental rickets in pups. Sherman and Pappenheimer noted that a change in the phosphate content of a diet largely composed of white flour might cause healing of rickets in rats. McCollum, Park, and associates showed what characteristics of a diet would cause acute and severe rickets in young rats. With the experimentally induced disease they were able in 1922 to demonstrate that a second fat-soluble vitamin (vitamin D) is present in cod liver oil.

In 1925 Steenbock and A. F. Hess independently discovered that exposure of a rickets-producing diet to ultraviolet rays generated vitamin D. They showed that the precursor of vitamin D which was activated by light is a sterol.

Discovery of Etiology of Pellagra. Between 1913 and 1926, J. Goldberger conducted numerous studies which revealed that pellegra is caused by a dietary deficiency, and described the effectiveness of various foods in preventing the disease. In 1938 Elvehjem and associates discovered that nicotinic acid or its amide would cure black tongue in dogs. Spies and associates confirmed its curative value in human pellagra.

Discovery and Synthesis of Other Vitamins. R. R. Williams isolated from rice polishings a large sample of the antineuritic vitamin, now called B_1 or thiamine. Study of this material resulted in its synthesis (1937). R. J. Williams (1933) discovered pantothenic acid. Pyridoxine (vitamin B_6) was discovered by György (1934). Among many other important vitamin discoveries were riboflavin, biotin, vitamin E, vitamin K, ascorbic acid, and vitamin B_{12}.

Essential Fatty Acids. In 1932 Burr and Burr demonstrated that linoleic or linolenic acid must be supplied in the diet of rats to prevent the symptoms of the "fat-deficiency syndrome."

Lipotrophic Factors. In 1932 Best and others demonstrated the lipotrophic property of choline. In 1935 Best and Huntsman showed that casein possesses lipotrophic properties, which were traced by Tucker and Eckstein (1937) to the amino acid methionine.

Trace Elements. In 1925 Hart demonstrated the nutritional significance of copper. Later investigators have discovered that manganese, zinc, and cobalt are indispensable nutrients.

From the standpoint of human welfare, the discoveries that have been made during the past decades in the field of food and nutrition have been at least as significant as those in the field of preventive and clinical medicine.

INSECTICIDES AND FUNGICIDES

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ALTHOUGH some of the pesticides of today were known to have value centuries ago, extensive use of effective insecticides and fungicides had its beginning only a few years before the founding of the AMERICAN CHEMICAL SOCIETY. About 1860 several developments made agriculturists in the United States more conscious of the need of insect control.

Probably the most important of these was the sudden appearance of the Colorado potato beetle as an economic problem. This insect, native to the eastern slopes of the Rocky Mountains, where it had previously fed on wild solanaceous plants, found the potato a particularly acceptable food when the westward spread of potato culture brought that important crop plant within its reach. Paris green was found to be highly effective against this beetle, and by 1870 was used widely as an agricultural insecticide. Within a few years, London purple became available, and from 1880 to 1900 these two chemicals were the most commonly used insecticides. However, the composition of London purple was

variable; some lots might be satisfactory, whereas others contained sufficient water-soluble arsenic to cause foliage injury. Paris green also burned foliage. Moreover, it is a heavy powder, it settles rapidly from suspensions, and has poor adhesive properties.

Thus the need for insecticides having better physical and chemical properties was evident. Emphasis then was on arsenic-containing insecticides, and in 1892 lead arsenate was prepared for the first time. The superiority of lead arsenate over other insecticides was soon demonstrated, and by 1910 it had largely replaced Paris green and London purple. Until displaced by DDT and Parathion shortly after the end of World War II, lead arsenate was more extensively used against orchard pests than any other insecticide. In 1920 about 30 million pounds were used. The annual usage increased to about 80 million pounds in 1945.

Inorganic fluorine compounds have also been [illegible] insecticides for a long time, sodium fluoride probably [illegible] first. In 1896 a British patent covering several fluor[illegible]-silicates, and borofluosilicates was issued. Sodium alu[illegible]um fluosilicate is widely sold today as a mothproofing agent, while sodium fluoaluminate (cryolite) serves as an agricultural insecticide.

Oils have been used as insecticides for hundreds of years, but not until the latter half of the 19th century were systematic studies undertaken to determine their value in insect control. On horticultural crops, oils serve as dormant sprays against scale insects, mites, insect eggs, and certain hibernating caterpillars; as additives to increase the effectiveness of other insecticides; and as carriers for many insecticidal chemicals. In 1865 kerosene was recommended for the control of scale insects on orange trees. Because undiluted kerosene severely injured foliage and fruit, emulsions of oil in water, produced at first merely by violent mechanical agitation and later with the aid of soap as an emulsifying agent, were substituted. Kerosene was gradually replaced by crude oils and eventually by lubricating oils. The development of oil sprays was temporarily retarded by the introduction, in about 1900, of lime-sulfur solution as a more effective spray for the control of scale insects. However, interest was renewed about 1923 when the superiority of light lubricating oil emulsion over lime-sulfur for control of the San José scale was demonstrated.

Some of the progress that has been made in the use of oils as insecticides was reviewed at the Symposium on Agricultural Applications of Petroleum Products held at the September 1950 meeting of the AMERICAN CHEMICAL SOCIETY in Chicago.

Fumigants Among First Insecticides

Another important class of pesticides is fumigants, which were also among the first insecticides used by man. Burning sulfur was probably the oldest fumigant. Today many volatile insecticides are in general use. Until the early 1920's, hydrogen cyanide and carbon disulfide were the most important commercial fumigants. Hydrogen cyanide was originally developed for the control of scale insects on citrus. Carbon disulfide found wide use as a grain fumigant. Although efficacious, it is flammable and its vapor when mixed with air is highly explosive. After representatives of leading railway systems had recommended that the United States Department of Agriculture find a substitute for carbon disulfide, many volatile compounds were tested. A number of highly effective products were developed, among which are methyl bromide, ethylene dichloride, ethylene dibromide, ethylene oxide, and dichloropropane-dichloropropene.

Progress in the development of fungicides has paralleled that of insecticides. Copper and sulfur, the oldest and still the most widely used fungicides, have felt the inroads of organic compounds. Combinations of copper sulfate and lime have been used since 1870, but it was not until about 1885 that Millardet exploited the use of Bordeaux mixture. As a result of recent investigations, fixed copper fungicides are standard products for the control of a number of plant diseases.

The early 1930's saw the development of derivatives of thiuram disulfide and dithiocarbamates as fungicides, both of which are used commercially. Extensive explorations have also been made among organic compounds to find products suitable as seed protectants of cereal, field, and vegetable crops. Organic mercury-containing compounds have been found very effective, as has chloranil.

The passage in 1887 of the Hatch Agricultural Experiment Station Act establishing state experiment stations made possible more intensive studies of insecticides, fungicides, and other pesticides. In 1896 the U. S. Department of Agriculture assigned J. K. Haywood, a chemist, to work on insecticides. He and E. D. Sanderson, chairman of a standing commitee on proprietary insecticides of the American Association of Economic Entomologists, were largely responsible for the writing and passage of the Insecticide Act of 1910. This act was designed to prevent the manufacture, sale, or transportation in interstate commerce of adulterated or misbranded insecticides and fungicides, and to prevent the importation of such articles into the United States. In 1947 the Federal Insecticide, Fungicide, and Rodenticide Act was passed. This act, which repeals the Insecticide Act of 1910, regulates the marketing of economic poisons and devices. In addition to the federal act, 38 states have laws regulating the sale of pesticides.

New Compounds

By 1910 agricultural practices had become more intensified, and insect populations increased, as did the losses they caused to many important crops. People began to realize that an adequate supply of food and feed was impossible without the use of insecticides and fungicides. The war against insects and fungi became world-wide. Studies by state and federal workers were supplemented by those carried out in the laboratories of our large chemical and oil companies and nonprofit institutions. Soon after World War I, many synthetic organic chemicals became available, for which a use was being sought. Their availability, together with the growing concern about the health hazards from toxic residues on sprayed fruits and vegetables, shifted the trend in the development of new insecticides from inorganic to organic compounds. In the early 1920's numerous compounds related to nicotine were tested.

In 1924 six comprehensive articles were published on the structure of the active principles of pyrethrum flowers. They exert a rapid paralytical, or knockdown, effect upon many insects, a characteristic not shown by any of the newer insecticides. Rapid removal or destruction of disease-carrying insects is especially desirable, and pyrethrum is most effective against such insects, as well as household pests.

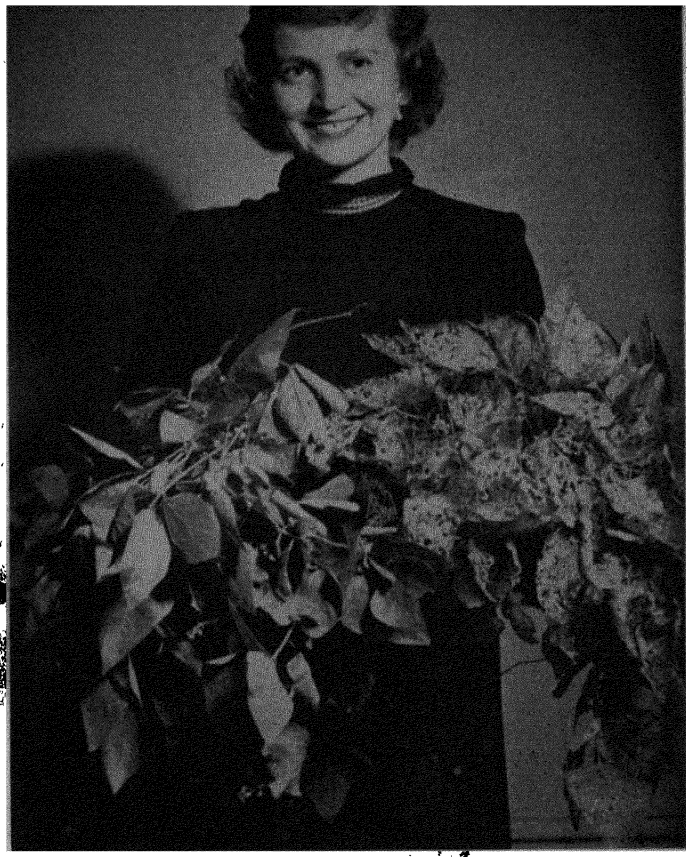
Those six articles published in 1924 provided fundamental information on the structures of the pyrethrins. It was not until 1947, however, that the detailed structures of these complex compounds were determined with certainty. Originally it was believed that pyrethrum contained two active principles, pyrethrin I and pyrethrin II. Intensive studies by F. B. LaForge and his associates of the Bureau of Entomology and Plant Quarantine over about 15 years revealed the presence of two other active principles closely related to the pyrethrins. They have been designated as cinerin I and cinerin II. Following the determination of the exact structures of the pyrethrins and the cinerins, their syntheses, as well as that of closely related compounds, were undertaken by these workers. Early in 1949 the stereoisomer of cinerolone was synthesized. When esterified with chrysanthemum monocarboxylic acid, this stereoisomer furnished an isomer of cinerin I, which was as insecticidal as the natural ester to houseflies and other insects. The synthesis of

homologs of cinerin I followed. One of them showed outstanding toxicity to insects. It was first called the allyl homolog of cinerin I, but recently has been given the coined name, allethrin. Within a year after the synthesis of the pyrethrinlike esters was announced, allethrin was in commercial production. This is an outstanding accomplishment, especially when it is considered that its preparation requires at least twelve chemical steps, each step necessitating careful chemical control to ensure a good product and maximum yield. Industry is to be congratulated for having done a fine job in so short a time.

Several years before Pearl Harbor it was apparent that in the event of a war there would be a shortage of pyrethrum. Efforts were therefore directed toward finding products that would replace part of the pyrethrins without decreasing their insecticidal value. In about 1940 the discovery was made that sesame oil increased the toxicity of the pyrethrins. The effectiveness of sesamin, the active ingredient, was shown to be due to the presence of the methylene dioxyphenyl grouping. Numerous compounds containing this grouping were prepared. Among the commercial products that have been developed are piperonyl cyclonene, piperonyl butoxide, and *n*-propyl isome.

An intensive study of the structure of rotenone, initiated about 1928 independently and almost simultaneously in Germany, Japan, and this country, culminated in the determination of its structure late in 1931.

The discovery of DDT revolutionized work on insecticides. Within a short time, several chemically unrelated chlorinated hydrocarbons—benzene hexachloride, chlordan and toxaphene—were also found to have outstanding insecticidal properties. More recently several organic phosphorus-containing compounds have merited attention as insecticides; among the more important are Parathion, hexaethyl tetraphosphate, and tetraethyl pyrophosphate.



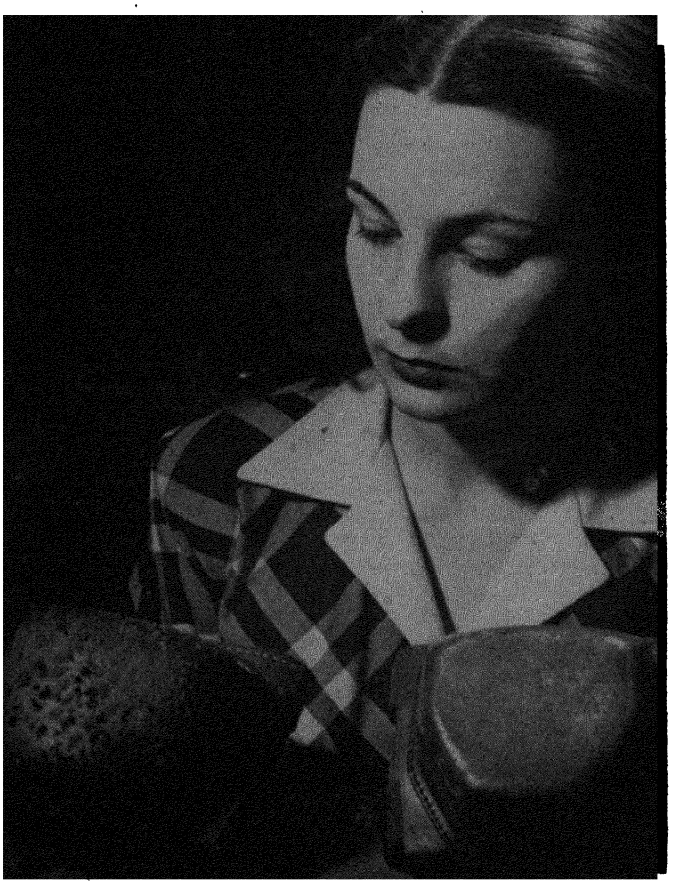
Healthy snap beans (left) were treated with insecticide. Untreated plants (right) were badly damaged by beetles

Product Analysis

The knowledge that an organic compound is highly toxic to several species of insects does not alone justify its immediate wide scale use. Information must be obtained as to the effect of the chemical on public health, farm animals, soils, vegetation, beneficial insects including bees, and wildlife wherever these interests are involved. It must also be determined whether the compound can best be applied as a dust, a spray, or an aerosol. For such determinations, a knowledge of the physical and chemical characteristics of the product is needed, including its composition, its solubility in various solvents, and its compatibility with other insecticides, fungicides, and dust diluents. Methods for analysis of the product itself, as well as in dusts, in sprays, and in combination with other insecticides, must be developed. In these and many other studies, considerable progress has been made, and today they are receiving greater attention than ever before.

Recently much progress has also been made in equipment and methods of applying insecticides. The so-called aerosol method of insecticide dispersion merits at least brief discussion. Three general types of aerosols are recognized—those produced by mechanical means, those generated thermally, and those that employ a liquefied gas. The last type played a prominent role during the war in controlling flying insects, such as disease-carrying mosquitoes and flies. Approximately 35 million 1-pound aerosol bombs containing pyrethrum extract and sesame oil dissolved in dichlorodifluoromethane were manufactured for the armed forces during the war.

Although much progress in the development and use of pesticides has been made during the past 75 years, many problems remain to be solved. The recent hearing of the Food and Drug Administration relative to the need for pesticides has injected a note of uncertainty as to the future of some pesticides. However, pesticides are required for the production and protection



Untreated leather camera case (left) was severely attacked by fungi. Treated case (right) was undamaged

of our food, feed, and fiber crops, and there is little question that the challenge can be met.

RODENTICIDES

J. C. WARD
U. S. Dept. of Agriculture, Washington, D. C.

THE control of pest animals by poison is not a new procedure in this country, for there are records of the use of arsenicals, phosphorus, barium carbonate, and strychnine since about the middle of the nineteenth century.

Many improvements in methods and materials, however, have taken place within the past 30 years. Prior to 1920 the importance of the pest mammal problem had been emphasized by outbreaks of rat-borne bubonic plague in San Francisco and other coastal cities. There was extensive loss of livestock on the western plains from rabies transmitted by coyotes. The need for organized control of mammals which were able to transmit disease and to do widespread economic damage was well recognized by 1920, even though the chemical agents available were limited to those mentioned above, with the addition of the cyanides. Research in control methods was aimed largely at developing and testing traps of various kinds, in devising poisonous mixtures, and in finding more effective ways to use them.

Shortly after 1920, research workers in this country learned of three products which had previously been known elsewhere in the world. These were imported for test. The first was a rat-control material known to the ancient Egyptians, red squill, an onionlike plant native to the Mediterranean Sea region. The effective portion of the plant is the bulb, which is prepared by slicing, drying, and grinding to a fine powder. As a crude drug, the product was found to possess variable killing power. It did not become popular as a rat poison in this country until research in methods of preparation had disclosed that carefully controlled temperatures in the oven-drying process produced a powder that had more uniform killing power. When oven-dried red squill became generally available, this poison came into widespread use for domestic rat control.

The second poison was thallium sulfate, originally employed in Germany. It was adopted rapidly in this country for use in carefully supervised field rodent-control programs where the pest animals had learned to avoid the strychnine-treated baits in common use. Almost concurrently, it was found to be valuable in domestic rat and mouse poisoning.

The final material in this series of new stomach poisons was zinc phosphide. Its immediate popularity was low, because it was less effective than thallium and more dangerous than red squill. As a consequence, for some time zinc phosphide attracted little attention even among research workers. A new fumigant, chloropicrin, was found to have value in rat and field rodent control between 1920 and 1925. It was not until the outbreak of World War II that an aggressive search for new mammal poisons was undertaken. In a wartime project, sponsored by the Office of Scientific Research and Development and carried out by the U. S. Fish and Wildlife Service in cooperation with various governmental research laboratories and the chemical industry, literally thousands of chemicals and plant extracts were tested to determine whether they could be used to destroy or repel rodents. Since the end of the war, this program has been continued with the support of the Quartermaster Corps, United States Army. So far, it has evaluated three new poisons which have gained commercial status—α-naphthylthiourea (ANTU), sodium fluoroacetate (Compound 1080), and 3-(α-acetonylbenzyl)-4-hydroxycoumarin (warfarin).

ANTU and 1080 proved effective for certain uses in time to be substituted for other poisons which were in short supply during the war. ANTU was found to be a rather specific poison, as it is very toxic to the Norway rat, is of little value in black rat or house mouse control, and is useless against field rodents. Compound 1080, on the other hand, proved to be the most generally effective poison yet known for the destruction of pest mammals. It is too dangerous, however, for use by the general public. In the hands of experts who follow sound methods of bait preparation and distribution, this chemical will control rats and mice, ground squirrels, prairie dogs, marmots, and coyotes. Compound 1080, besides causing trouble through direct accidental poisoning, creates a rather unique secondary poisoning hazard for animals that eat rodents killed by it. As a consequence, it should be entrusted only to experts who will use it with utmost care.

The latest in the list of newer agents is warfarin. So far, it has shown promise in the control of commensal rats and mice. Its possible value against other species of noxious mammals is being studied. Its value in rat control was discovered by Karl Paul Link of the University of Wisconsin, during laboratory study on a series of synthetic organic chemicals investigated as possible substitutes for the drug, dicoumarol. Warfarin is unique among poisons now in use, because, under most conditions, death will occur only after an animal has repeatedly eaten bait containing low percentages of the poison. Warfarin acts by decreasing the clotting ability of the blood. The animals which continue to eat bait containing traces of this chemical suffer internal hemorrhages and die with symptoms similar to severe anemia. When properly placed and maintained, however, this product seems to have promise, as it is suitable for careful use by the general public.

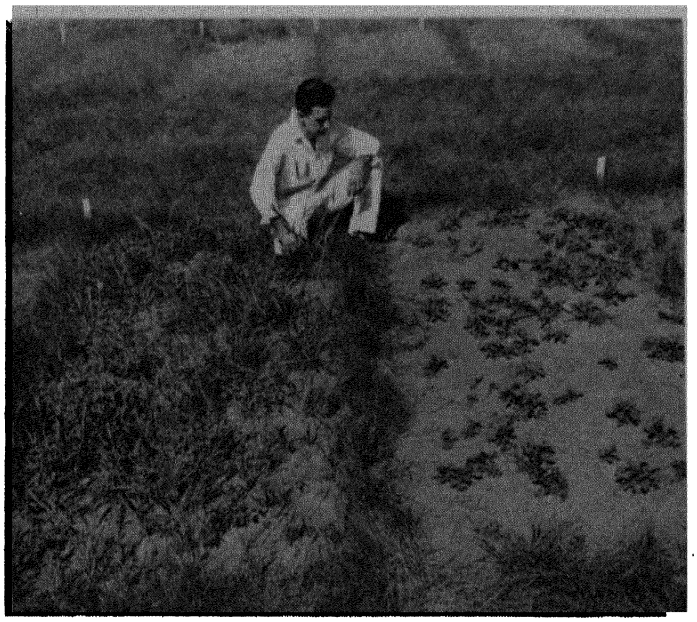
Among fumigants, methyl bromide appeared during this period of rodenticide history. It has taken its place alongside carbon disulfide, calcium cyanide, chloropicrin, and gas-generating cartridges as a useful agent for the gassing of rodent burrows. What new, safer, or more effective poisons will be discovered in the future cannot be forecast. However, scientists responsible for safeguarding public health and conserving the food supplies of the world are looking with confidence toward controlling plague, endemic typhus, and many other diseases carried by rodents, and toward reducing the staggering drain on food resources from pest mammals through increasing use of the more effective agents now available.

HERBICIDES

P. W. ZIMMERMAN AND A. E. HITCHCOCK
Boyce Thompson Institute for Plant Research, Inc., Yonkers, N. Y.

THE history of chemical weed control can be roughly divided into two parts—before and after the advent of 2,4-dichlorophenoxyacetic acid (2,4-D) as a plant growth regulator. Substituted phenoxy and benzoic acids were brought out in 1942 as a new group of highly physiologically active compounds.

Though chemicals have been used for many years to control weeds, no large-scale applications were made until after 1930. Up to 1942 the chemicals in use were contact (nonhormonelike) herbicides and soil sterilants, such as arsenicals, chlorinated benzenes, chlorates, sulfuric acid, sulfates, substituted phenols, cyanamides, and oils. These were often referred to as selective, nonselective, temporary, and permanent soil sterilants. Sodium arsenite for weed control along railroad tracks and Diesel oils for fire-control strips along highways are widely employed.



Previously, plot at the right had been sprayed with herbicide, sodium TCA 70%, to destroy weeds

Within two years after the high activity of 2,4-D became known, it was shown to be a potent selective herbicide. About the same time, 2-methyl-4-chlorophenoxyacetic acid was utilized as a herbicide in England. Many of the substituted phenoxy acids have herbicidal value, although 2,4-D appears to be the most active and has been most generally used. Its special value is associated with a selective activity when applied to various species of plants.

The fact that the majority of common broad-leaved weeds are susceptible to 2,4-D, whereas most members of the grass family are relatively resistant, has led to the large scale use of 2,4-D for controlling weeds in cereal crops and corn, and on lawns and pastures. The capacity of 2,4-D to be translocated throughout the plant, even into the roots, is a unique characteristic which is one of the reasons why it is referred to as a hormone type of herbicide. This is in contrast to contact herbicides, which kill tissue locally where applied without being translocated throughout the plant to any appreciable extent. Thus deep-rooted perennial weeds are controlled more effectively by 2,4-D than by contact herbicides.

Relatively small amounts of 2,4-D are required to control herbaceous weeds in crops belonging to the grass family, the quantity being less than 1 pound per acre for cereals, flax, and corn and from 1 to 3 pounds per acre for lawns and pastures. Considerably higher doses of 2,4-D (2 to 8 pounds per acre) are required to control woody plants (brush) as compared with the doses used for controlling herbaceous weeds. Control of woody plants involves many problems not encountered in the control of herbaceous weeds, one of the most difficult being adequate coverage even with spray equipment designed especially for spraying the dense canopy of foliage on large plants. 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T) appears to be more effective than 2,4-D on some species of woody plants, but it has not been determined whether the difference in effectiveness is sufficient to offset its much higher cost.

Pre-Emergence Treatment

In view of the susceptibility of most vegetable crops to injury by herbicidal sprays, attention in recent years has been centered on the use of pre-emergence treatments, whereby the herbicide is applied before the crop emerges through the soil. Pre-emergence treatment with 2,4-D and contact herbicides, including oils, dinitro compounds, cyanamides, cyanates, chlorinated phenols, and several new ones which are being tested, has given effective weed control for periods of 3 to 6 weeks. The period of weed control has been extended in the case of row crops such as corn, beans, onions, carrots, and cabbage by the use of a post-emergence herbicidal treatment consisting of a controlled directional spray applied between the rows and toward the base of the crop plants, so as to avoid direct contact with the more sensitive developing foliage. If post-emergence treatment proves successful, it will mean a tremendous increase in the quantity of herbicides used on crop plants. A close relative of 2,4-D, sodium 2,4-dichlorophenoxyethyl sulfate, has the unique property of being relatively nontoxic to the foliage of many crop plants, but after coming in contact with soil this compound changes in form, presumably by biological action, and thereafter functions much the same as 2,4-D in killing and controlling the growth of weeds.

In contrast to the phenomenal advances made in the control of land weeds, relatively little progress has been made in the control of aquatic weeds in rivers, streams, ditches, lakes, ponds, pools, and marshes. This is due primarily to the fact that many of the chemicals which kill water weeds are also toxic to fish and other animal life. Although 2,4-D has proved effective for controlling water hyacinth and alligator weed in the Gulf Coast waterways without injury to fish and other wild life, many other species of aquatic plants have not been controlled effectively by this herbicide. The control of water weeds appears to be one of the most important problems facing herbicidal research workers at the present time.

Some idea of the amazing increase in the use of herbicides during the past five years may be judged by the sales of 2,4-D alone, which amounted to approximately 6 million pounds in 1947, with the prediction that in a few years the sales would reach 100 million pounds. Thus 2,4-D has become a close competitor or has surpassed the sale of DDT, which has amounted to 25 million to 50 million pounds annually. In view of the large acreage under cultivation in the United States (about 1 billion acres) and the vast extent of noncrop areas, including inland waters, a marked increase in the use of herbicides is anticipated for the future. Many laboratories and agencies are searching for new herbicides with the prospect of finding some which are even more effective than those now in use.

FERMENTATION

C. S. BORUFF AND J. M. VAN LANEN
Hiram Walker & Sons, Inc., Peoria, Ill.

APPLIED microbiology during the formative years of the AMERICAN CHEMICAL SOCIETY was confined to the manufacture of fermented foods and beverages by "arts" which for centuries had remained practically unchanged. Even fermentation itself went unrecognized as a biological process, although it had long been the topic of profuse speculation. In 1857, the early investigations of Pasteur on various aspects of this subject began to appear in print, and for the first time specific microorganisms were related to fermentation products, both normal and abnormal. Pasteur's descriptions of the alcoholic, lactic, acetic, and butyric fermentations were so lucid that they are now commonly accepted as marking the beginning of both pure and applied microbiology. The new concepts established by Pasteur were rapidly disseminated throughout both Europe and the United States and attracted widespread scientific interest. Marked refinements in methods of studying microorganisms followed within the next two decades, and numerous pathogenic and nonpathogenic species were isolated and cataloged.

Only one other period of early development might be con-

sidered of comparable importance to the so-called descriptive era of microbiology associated with Pasteur. This occurred some years later when the biochemistry of growth, fermentation, and respiration was unfolded largely through the monumental investigations of Harden and Young, Neuberg, Meyerhof, Warburg, Wieland, and others. These explorations disclosed the basic similarity of all cellular processes, a principle which Kluyver and Donker brought forth more precisely in "Die Einheit in der Biochemie." This is an area of biochemistry which has been greatly amplified and extended in the recent past. The foundations laid during these two periods exerted a profound and lasting influence upon the fermentation industry and upon its subsequent progress.

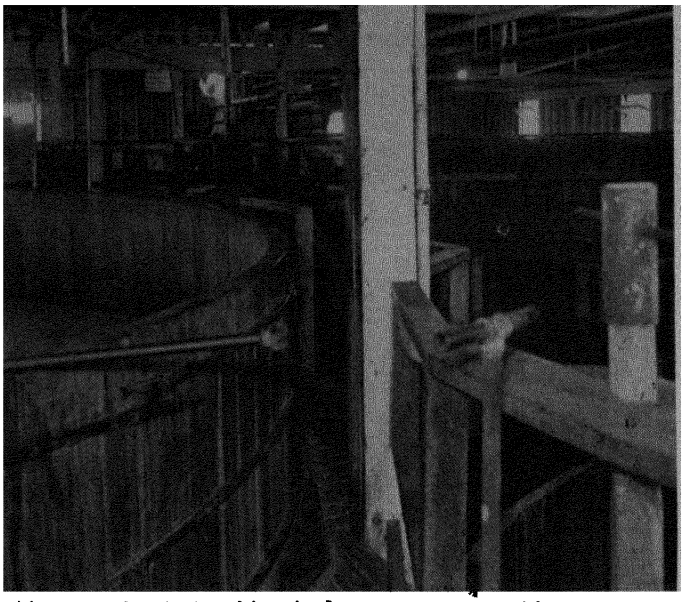
Before the turn of the century, a number of compounds were reported as products of fermentation—lactic acid from bacteria (1857), glycerol from yeasts (1858), gallic acid through the action of molds on tannin (1867), butyl alcohol from certain anaerobic bacteria (1876), and citric and oxalic acids from the so-called Citromyces (1893). In the United States, some lactic acid was produced commercially as early as 1881; however, the first major item was industrial alcohol. This development was made possible largely through the passage by Congress of the "Free Industrial and Denatured Alcohol Act" in 1906. Previously, all alcohol, regardless of end use, carried a heavy and restrictive tax. By 1907 there were eight denaturing plants operating with a total output of about 1,750,000 gallons.

Another large scale fermentation process involved the production of acetone and butanol. This fermentation had been investigated in England prior to 1910, the butanol obtained being of interest, primarily as a source of butadiene for synthetic rubber. However, this fermentation process did not receive its real impetus until the dire need for acetone arose in World War I in connection with the manufacture of cordite. The Weismann organism, which gave high yields of acetone from starchy substrates, was selected and developed first in England, then at the Gooderham & Worts Distillery in Toronto, and finally on a much larger scale in this country at Terre Haute and Peoria, where grain was readily available. The successful operation of the acetone-butanol fermentation was an important milestone in the field of industrial fermentation. First, it required the development of process equipment capable of maintaining absolutely pure culture conditions. Secondly, it produced the first United States company to be based wholly on the manufacture of fermentation chemicals—i.e., Commercial Solvents Corp., which was formed in 1919.

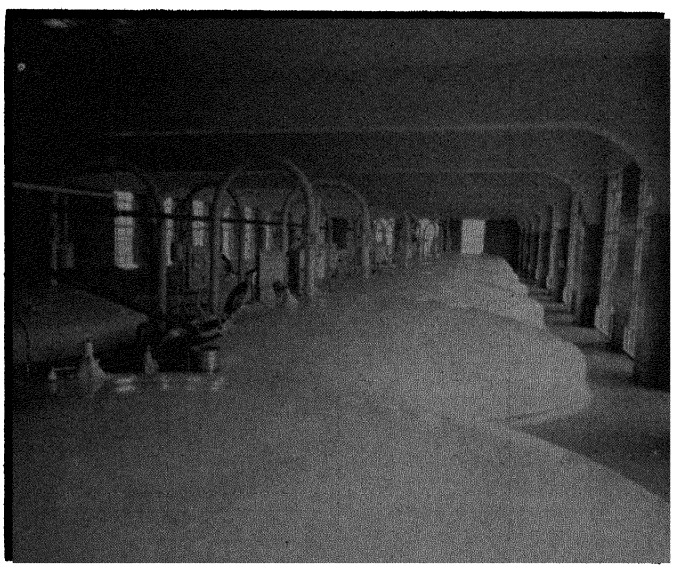
Another notable advance which followed a few years later was the commercial production of chemicals by molds, the first product being citric acid. Begun in New York about 1923, this process soon gained sufficient proportions to meet full domestic requirements and, until foreign duties became prohibitive, provided substantial quantities for export. Other mold processes were introduced, such as those for gluconic, fumaric, itaconic, and kojic acids. The techniques developed and experience obtained contributed invaluably to the production of antibiotics which became so vital during World War II.

During the twenties and thirties, industrial microbiology in general kept pace with technical progress in the chemical and physical sciences, and consequently the use of microorganisms became more widespread. In addition, collaboration between industry, government, and academic institutions with the object of furthering fermentation theory and practice became apparent. Courses in a number of universities were devoted to training industrial microbiologists.

During the late thirties microorganisms were rather widely employed in biochemical studies, especially in the measurement and biosynthesis of various factors of nutritional importance. Molds and bacteria were found to be unusually rich in various vitamins. With yeasts they provided products of both biochemical and commercial interest. Fermentation residues were discovered to be practical vitamin supplements for animal feeds, and the recovery of feed by-products became an important factor in the economics of the larger volume fermentations. This biosynthetic property of microorganisms has been increasingly exploited, an outstanding example being the recent production of both feed and pharmaceutical forms of vitamin B_{12} by fermentative means.



None too hygienic, old-style fermenters were wide open to contamination from the atmosphere



These enclosed alcohol fermentation vessels at modern distillery are kept spotlessly clean

Today, as a consequence of these varied developments, industrial microbiology is a highly evolved technology, and the dollar volume of its products has risen sharply. It functions prominently in every research organization encountering biological problems and requires for maximum productivity the talents and training of not only bacteriologists but also such other specialists as geneticists, biochemists, physicists, chemists, and engineers. Biological variables inherent in microbial growth and metabolism can now be controlled with sufficient precision to justify treating fermentation as a unit process. The full potentialities of this so-called modern approach to industrial fermentation are perhaps best reflected by the industry's exceptional productivity during World War II when the need for chemicals and biologicals was at its highest. Penicillin produc-

tion, for example, was begun with crude surface culture equipment, converted to submerged processes by strain and media selection, and finally improved further by the use of high-yielding mutants and penicillin precursors. Within four years, yields were increased several hundredfold. Meanwhile other fermentations underwent similar, although less spectacular, increases in efficiency. These accomplishments have created among the chemical and process industries a very definite attitude of optimism concerning the future of industrial fermentations.

DIVISION OF AGRICULTURAL AND FOOD CHEMISTRY

AFTER several years' existence as a section under various names the Division of Agricultural and Food Chemistry was authorized by the AMERICAN CHEMICAL SOCIETY Council on December 30, 1908. Organization was promptly effected with the election of W. D. Bigelow as chairman for 1909. Since then, 30 members have been honored by election to the divisional chairmanship.

The first formal meeting called for the purpose of organizing a fermentation group in the AMERICAN CHEMICAL SOCIETY was held during the Pittsburgh convention in 1936. Only a few persons, mostly representing academic institutions, attended this meeting and little interest was displayed. It was evident that a large segment of the fermentation industry was reluctant to disclose its trade secrets. During World War II, however, the demand for fermentation chemicals and pharmaceuticals, in addition to the sizable problems involved in handling unfamiliar raw materials, made it mandatory for government, industrial, and university personnel to work out their fermentation problems together. That this experience in cooperation had a favorable effect is implied by the fact that the next organizational meeting, which was held in Chicago in 1946, attracted about 75 people and resulted in immediate approval of the formation of a Fermentation Section. A steering committee was appointed and was composed of A. F. Langlykke, R. D. Coghill, C. N. Frey, W. H. Peterson, C. S. Boruff (temporary chairman), and J. M. Van Lanen (secretary).

To make the committee representative of each of the major fields of fermentation, the steering group was increased in the spring of 1947 to seven members by the addition of W. V. Cruess and P. P. Gray, and in the fall of 1949 to eight members. Two committee representatives are elected by the membership each year and serve four-year terms. The current committee and the fields represented are:

P. P. Gray	Brewing
C. S. Boruff	Beverage and industrial alcohol
R. D. Coghill	Pharmaceuticals
A. F. Langlykke	Pharmaceuticals
L. A. Underkofler	Universities
F. J. Rudert	Yeast and foods
M. J. Johnson	Universities
M. A. Joslyn	Wines and foods

Because the scope of industrial microbiology is so broad, the Fermentation Section could have been appropriately sponsored by any one of a number of existing ACS divisions. However, historically, technologically, and economically, fermentation has many interests in common with agriculture, notably with regard to the raw materials used. Fermentation chemists were gratified, therefore, to receive an invitation to organize under the Division of Agricultural and Food Chemistry. This association, which is now in its fourth year, has given every evidence of being mutually beneficial. Apart from the programs of general interest, held at each of the national ACS meetings beginning in the spring of 1947, symposia have been or will be presented on the subjects of wines, antibiotics, vitamin B_{12}, and microbial metabolism.

The formation of the ACS Fermentation Subdivision, with its accompanying membership activity and its open discussion and publication of fermentation research, has contributed much and should continue to add materially not only to the over-all utility of this field but to the further refinement of its technology.

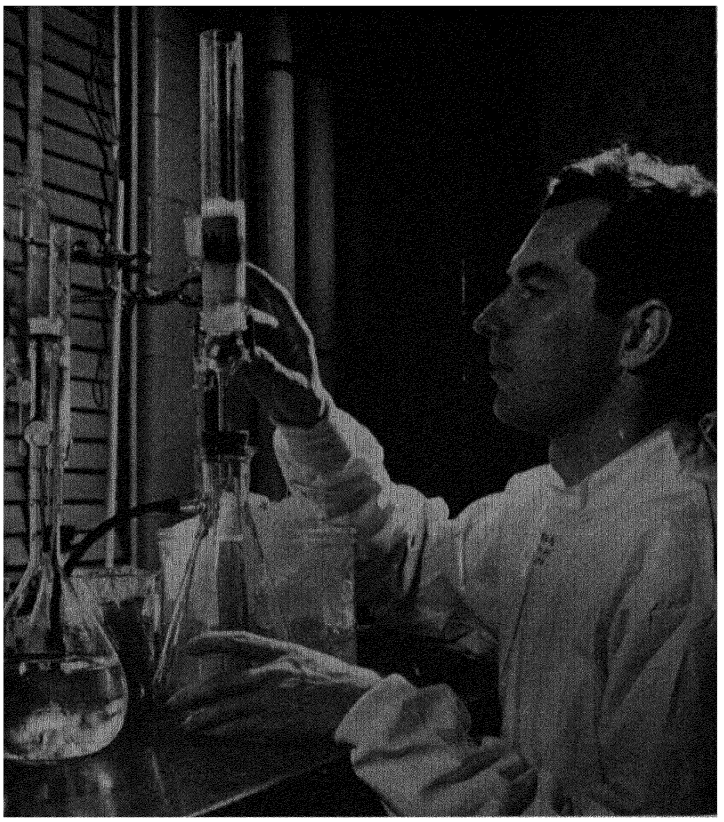
The Fermentation Subdivision was approved at the Chicago meeting in 1946. The following have been officers: 1946–1950, C. S. Boruff, chairman, and J. M. Van Lanen, secretary; 1951, W. H. Peterson, chairman, and J. M. Van Lanen, secretary.

The Pesticide Subdivision was approved in September 1950 with J. L. St. John, chairman, and L. G. Cox, secretary.

Since its organization, the Division of Agricultural and Food Chemistry has held 83 symposia, either alone or jointly with a total of 10 other divisions. Throughout its long history, the division has been alert to new advances in its field and has promptly developed symposia and special programs to bring these new advances to the attention of the scientific public. The division has not only contributed to the professional knowledge of its members but has furnished a major incentive for further study. Most assuredly, the next 75 years will exceed even the past 75 years in the productivity and application of new scientific concepts to agriculture and food technology.

Officers of the Division of Agricultural and Food Chemistry, 1909–1951

Year	Chairman	Secretary
1909	W. D. Bigelow	W. B. D. Penniman
1910	C. D. Woods	C. E. Curry
1911	H. E. Barnard	C. E. Curry
1912–1913	H. E. Barnard	Glen F. Mason
1914–1915	F. W. Robinson	Glen F. Mason
1916	L. M. Tolman	Glen F. Mason
1917	T. J. Bryan	Glen F. Mason
1918	T. J. Bryan	F. T. Flanders
1919	W. D. Richardson	T. J. Bryan
1920–1921	C. E. Coates	T. J. Bryan
1922	T. J. Bryan	C. S. Brinton
1923	H. A. Noyes	C. S. Brinton
1924–1925	C. H. Bailey	C. S. Brinton
1926–1927	E. F. Kohman	C. S. Brinton
1928–1929	F. C. Blanck	H. A. Schuette
1930	R. C. Roark	H. A. Schuette
1931	J. S. McHargue	J. H. Nair
1932–1933	H. A. Schuette	J. H. Nair
1934	D. K. Tressler	J. H. Nair
1935	D. K. Tressler	H. R. Kraybill
1936	J. H. Nair	H. R. Kraybill
1937–1938	H. R. Kraybill	G. A. Fitzgerald
1939	R. C. Newton	G. A. Fitzgerald
1940	C. N. Frey	E. H. Harvey
1941	G. A. Fitzgerald	C. R. Fellers
1942–1943	E. H. Harvey	R. H. Lueck
1944–1946	N. B. Guerrant	P. Logue
1947	B. L. Oser	L. E. Clifcorn
1948	P. M. Logue	L. E. Clifcorn
1949	C. R. Fellers	A. N. Prater
1950	L. E. Clifcorn	A. N. Prater
1951	B. E. Proctor	A. N. Prater



Scientist employs a chromatographic column in his study of the nature of cancer

Medicinal Chemistry

Hand in hand with pharmacologists and clinicians, chemists are waging unrelenting battle against the devastations of disease

M. L. MOORE
Smith, Kline and French Laboratories
Philadelphia, Pa.

THE year 1876 was a monumental one for the American people. Not only had they demonstrated their ability to survive 100 years as a political union, but they had every reason to look forward to a bright economic, cultural, and scientific future. The medical and pharmaceutical professions caught this spirit of enthusiasm and, in numerous addresses and papers, proudly reviewed a century of progress in American medicine and pharmacy. Edward H. Clarke, professor of materia medica at Harvard University, in surveying the developments in practical medicine, said (*1*):

When Boerhaave, the most accomplished and celebrated physician of the 18th century, died, he left behind him an elegant volume, the title page of which declared that it contained all the secrets of medicine. On opening the volume, every page, except one, was blank, on that one was written, "Keep the head cool, the feet warm, and the bowels open." This legacy of Boerhaave to suffering humanity typified, not inaptly or unjustly, the acquirements, not of medical science, but of medical art at the close of the 18th century.... To quiet the nervous system, to equalize the circulation, to provide for the normal action of the intestinal canal, and to leave all the rest to the *vis medicatrix naturae* was sound medical treatment; and it was as far as sound therapeutics had gone 100 years ago....

The blank pages of the book, containing all the secrets of medicine, which Boerhaave bequeathed to the future, were prophetic of the work which medical science was destined to accomplish. The science of his age could inscribe only a single sentence upon a single page. The present century, whose closing hours the nation celebrates, has filled two or three additional pages with the secrets it has discovered, calling them vaccination, anesthesia, and preventive medicine. It now transmits the volume to the coming ages, confident that each succeeding century will make new discoveries, till all of Nature's secrets are discovered, and then the title of the book shall be the just index of its contents.

The outstanding contribution of the previous century, and in all probability of all time to the medical art, was the demonstration in the Massachusetts General Hospital by William Thomas Green Morton in October 1846 that ethyl ether could be used with safety and certainty to produce surgical anesthesia. The use of ether was followed within one year by nitrous oxide and by chloroform, and by 1876 the techniques and hazards of administration had been well defined.

In 1876, chemists were actively searching for antiseptic agents which would prove superior to the phenol introduced nine years earlier by the English surgeon, Joseph Lister. The physician of the day used bromide for the sedation of epileptics. He had a choice of central nervous system depressants: opium or morphine, alcohol, cannabis indica, and the recently introduced chloral hydrate. Sodium salicylate, previously recognized as an excellent antiseptic agent, was introduced as an antipyretic in 1875 and for the treatment of rheumatic fever one year later. Amyl nitrite was available for the treatment of angina pectoris; the oxytocic properties of ergot were well known; colchicum autumnale was used not only in cases of gout but also as a general diuretic. The cardiac action of digitalis was known. Syphilis was treated with mercury or with iodides or both. Podophyllin was a popular cathartic.

There was an intense and sustained interest in the isolation of physiologically active substances from plants. It is perhaps coincidental, however, that the first paper in the 1876 number of the *American Journal of Pharmacy* by Wormley (*5*) was entitled, "The Alkaloids of Veratrum Veride and Album—History, Preparation, and Recovery from Complex Mixtures and the Blood," a subject that has received frequent attention from chemists and pharmacologists. During the past year, this work has led to the brilliant isolation of the active hypotensive principles by Wintersteiner and Fried.

In 1876, there was no American pharmaceutical industry as we know it today, although many of today's largest pharmaceutical companies had their beginnings in this era. The 1876 number of the *Proceedings of the American Pharmaceutical Association* devotes considerable space to the exhibits of pharmaceutical interest at the International Exposition held that year in Philadelphia (*3*).

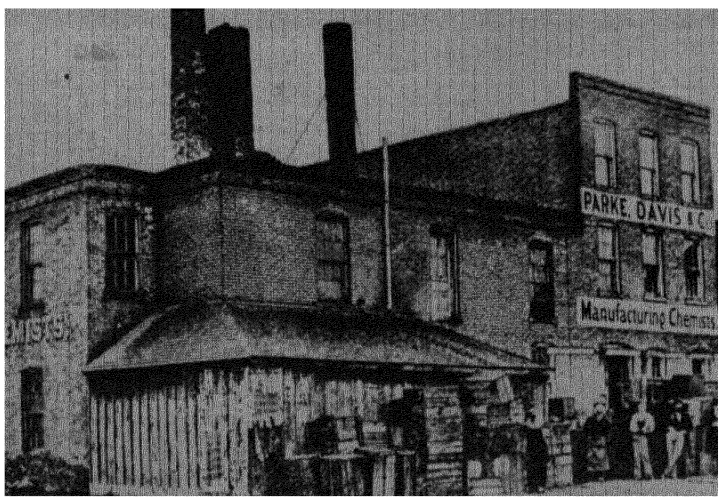
McKesson & Robbins (established 1833) had a display of indigenous crude drugs, pills, sirups, elixirs, and perfume extracts....

Charles Pfizer & Co. (established 1849) displayed thirty-four specimens, contained in glass shades with round tops—corrosive sublimates, resublimated iodine, senment, iodoform, Rochelle salt... refined camphor, iodide and bromide of potassium being most prominent....

Frederick Stearns (established 1855) had the greatest variety of pharmaceutical preparations in the whole exhibition....



A corner of an apothecary shop in 1750, as reconstructed by the Smithsonian Institution



In 1874, a few employees posed in front of the original Parke, Davis & Co. laboratory



Construction of new research building of Parke, Davis & Co. proceeded without interruption through winter of 1901

William R. Warner & Co. (established 1856) exhibited the largest collection of sugar-coated pills. . . .

John Wyeth & Brother (established 1860) had a very extensive collection of pharmaceutical preparations, suppositories, compressed pills, and elixirs occupying a prominent position.

Edward Robinson Squibb, who had begun the production of pure medicinal agents in 1857, was not only a vice president and member of the Board of the AMERICAN CHEMICAL SOCIETY in 1876, but was also a delegate from the Medical Society of New York to the National Convention for reissuing the Pharmacopeia. Parke, Davis & Co. was 10 years old in 1876, and Eli Lilly and Co. was founded in that year. The research laboratory of Parke, Davis & Co., which was completed in 1902, was the first building constructed specifically for research purposes by any industry in the United States.

Early Dependence Upon Germany

The foundation upon which modern medicinal chemistry began to develop consisted to a considerable extent of discoveries made in Germany from about 1870 until the termination of World War I in 1918. It was during that period that a large number of synthetic organic chemicals were found to be excellent palliative drugs—antipyretics, analgesics, hypnotics, and local anesthetics. Effective general antiseptics and antisyphilitics were discovered. The hormones, epinephrine, and thyroxine were isolated. The use of plant products began to decrease and biologicals became more and more important. The compressed tablet gained ascendancy over the fluid extract. The complexity of pharmaceutical preparations began to decrease, and the use of a single, therapeutically active substance instead of a mixture was becoming more common.

In 1891, Ehrlich began his investigational work in chemotherapy after he had found that methylene blue stained malaria parasites very effectively. In time, he was able to cure some cases of tertian malaria. These results were not particularly impressive but they did stimulate him to start on the experimental chemotherapy of trypanosome infections. Ehrlich's work culminated in the discovery that trypan red was both curative and prophylactic for trypanosome infections in mice. This was the first cure of an experimentally produced disease by administration of a synthetic organic substance of known chemical composition.

Many compounds which later became important medicaments were prepared initially because of their chemical interest and with no thought of possible therapeutic application. The following table contains a partial list of synthetic medicaments which were introduced between 1875 and 1918. Some of these drugs are important because they represent the first synthetic substitutes for plant products. Although many of the drugs introduced during this time have since been replaced by safer and more effective substances, a number of them still find a foremost place in a present-day list of the best therapeutic agents.

Compounds	Medicinal Activity	Discovery of Therapeutic Properties	Synthesis Described
Salicylic acid	Antipyretic, antirheumatic	1875	1860[a]
Homatropine (tropine mandelate)	Mydriatic	1880	1880
Paraldehyde	Hypnotic	1882	1835
Antipyrine (1,5-dimethyl-2-phenyl-3-pyrazolone)	Antipyretic, analgesic	1884	1884
Urethan (ethyl carbamate)	Hypnotic	1885	1834
Acetanilide	Antipyretic, analgesic	1886	1853
Salol (phenyl salicylate)	Intestinal antiseptic	1886	1885
Chloretone (1,1,1-trichloro-2-methyl-2-propanol)	Local anesthetic, hypnotic, antiseptic	1893 (1899)	1881
Phenacetin (p-acetophenetidin)	Antipyretic, analgesic	1887	1887[b]
Methenamine (hexamethylenetetramine)	Urinary antiseptic	1894	1859, 1860[c]
α- and β-eucaine	Local anesthetics	1896	1896
Aminopyrine (4-dimethylamino-1,5-dimethyl-2-phenyl-3-pyrazolone)	Antipyretic, analgesic	1896	1896
Holocaine (*N,N'*-di-*p*-phenetylacetamidine)	Local anesthetic	1897	1895
Aspirin (acetylsalicylic acid)	Antipyretic, analgesic	1899	1853, 1859[c]

Vioform (5-chloro-7-iodo-8-hydroxyquinioline)	Iodoform substitute, amebicide	1900 1931-1933	1899
Adrenaline [3,4-dihydroxy-α-(methylaminomethyl)-bensyl alcohol]	Vasoconstrictor	1901 (isolated)	1904
Phenolphthalein	Laxative	1901	1871
Benzocaine (ethyl *p*-aminobenzoate)	Local anesthetic	1902	1808
Barbital (5,5-diethylbarbituric acid)	Hypnotic	1903	1882
Novocain (Procaine) (2-diethylaminoethyl *p*-aminobenzoate)	Local anesthetic	1905	1906
Phenolsulfonephthalein	Renal function test	1909	1898
Arsphenamine (3,3'-diamino-4,4'-dihydroxyarsenobensene)	Antisyphilitic	1910	1910
Neoarsphenamine (3,3'-diamino-4,4'-dihydroxyarsenobensene methanesulfoxylate)	Antisyphilitic	1912	1912
Phenobarbital (5-ethyl-5-phenylbarbituric acid)	Hypnotic, anticonvulsant in epilepsy	1912	1912
Thyroxine (*S*-[4-(3',5'-diiodo-4'-hydroxyphenoxy)-3,5-diiodophenyl]-alanine)	Thyroid therapy	1914 (isolated)	1926
Chloramine-T (sodium *N*-chloro-*p*-toluenesulfonchloramide)	Germicide	1916	1905
Dichloramine-T (*N,N*-dichloro-*p*-toluenesulfonamide)	Germicide	1916	1905

[a] First practical process.
[b] It seems probable that *p*-acetophenetidin (phenacetin) may have been obtained first by the American chemist E. J. Hallock (*2*).
[c] Composition or structure determined.

DIVISION OF MEDICINAL CHEMISTRY

The Division of Medicinal Chemistry was among the first to be organized when divisions were first authorized by the AMERICAN CHEMICAL SOCIETY. It was officially accepted as the Division of Pharmaceutical Chemistry by resolution at the meeting of the AMERICAN CHEMICAL SOCIETY in Detroit, June 29 to July 2, 1909. In the first year, A. B. Stevens was elected chairman and B. L. Murphy, secretary.

The contributions to the early programs of the division dealt almost exclusively with pharmaceutical assays, improvements of pharmaceutical products, and discussions of drug standards which were made necessary by the passage of the Food and Drug Law of 1906. Papers on these problems predominated until well into the twenties. However, a few papers began to appear on the programs of the division which indicated the development of an interest in new drugs, especially those obtained synthetically. Not only pharmacologists but chemists also were inquiring into the mechanisms of drug action. For example, one feels that part of the program at the 59th meeting in St. Louis, April 12 to 16, 1920, namely,

Researches on Hypnotics. E. H. VOLWILER
Researches on Anesthetics. ROGER ADAMS
Drug Absorption in the Intestinal Tract. G. H. A. CLOWES AND A. L. WATERS

foreshadowed the program of the First National Symposium on Medicinal Chemistry at Ann Arbor in 1948.

With the recognition of a growing interest in synthetic medicinal products, a change in name to the Division of Chemistry of Medicinal Products was approved by the Council of the Society at the 60th meeting in Chicago, September 6, 1920. This name was used from 1921 until the 76th meeting of the Society at Swampscott, Mass., September 1928, when the present name, Division of Medicinal Chemistry, was first used. Incidentally, the minutes of neither the Council nor the Board of Directors make any mention of the approval of this last change. In fact, no mention of the change has been found in the divisional secretary's report to the Society.

Drugs in World War I

The British blockade, established soon after the beginning of World War I, stopped the importation of indispensable synthetic drugs from Germany. Furthermore, the intermediates necessary for the manufacture of these drugs were not available in this country, and we lacked the knowledge and experience necessary for their successful large scale production. The only solution of this problem was the rapid establishment of an organic chemical industry which could manufacture the necessary intermediates. Moreover, it was necessary for pharmaceutical houses to develop satisfactory commercial processes for the production of the required drugs. The sale of enemy-owned patents by the Alien Property Custodian to the Chemical Foundation, the granting by the latter organization of nonexclusive licenses to all proper applicants, and the establishment of an effective tariff embargo, and other means of protection enabled the chemical and pharmaceutical companies to establish a synthetic medicinal industry.

The three drugs for which there was the most demand at that time were: Salvarsan (arsphenamine), Veronal (barbital), and Novocain (procaine). The production of these was begun by several manufacturers, who also prepared Atophan (cinchophen; 2-phenylcinchoninic acid) and Luminal (phenobarbital).



Wolcott's Instant Pain Annihilator was claimed to be highly effective in warding off the demons of neuralgia, toothache, headache, weak nerves, consumption, burns, scalds, catarrh, and other bodily ills

In order to meet the critical need for a potent local anesthetic, at a time when American-made procaine had not yet become available, gamma-diethylaminopropyl cinnamate hydrochloride, which was first synthesized in this country and described in a

U. S. patent in 1916, was placed on the market in 1918 under the name of Apothesine hydrochloride.

An ACS Symposium on the Development of American Synthetic Medicinals was held at the Pittsburgh meeting, September 4 to 8, 1922. Of this program, E. H. Volwiler, secretary of the division, wrote (*4*):

> The papers and discussions in the course of this symposium indicated the rapid strides being made to establish a truly American medicinal chemical industry, not only by developing the manufacture of substances already known, but by producing new, superior products as well.

Such programs, along with the wide distribution to the chemical profession of a number of books dealing with chemistry and medicine by the Chemical Foundation under the direction of Francis P. Garvan, did much to stimulate the interest of chemists in medicinal chemical research.

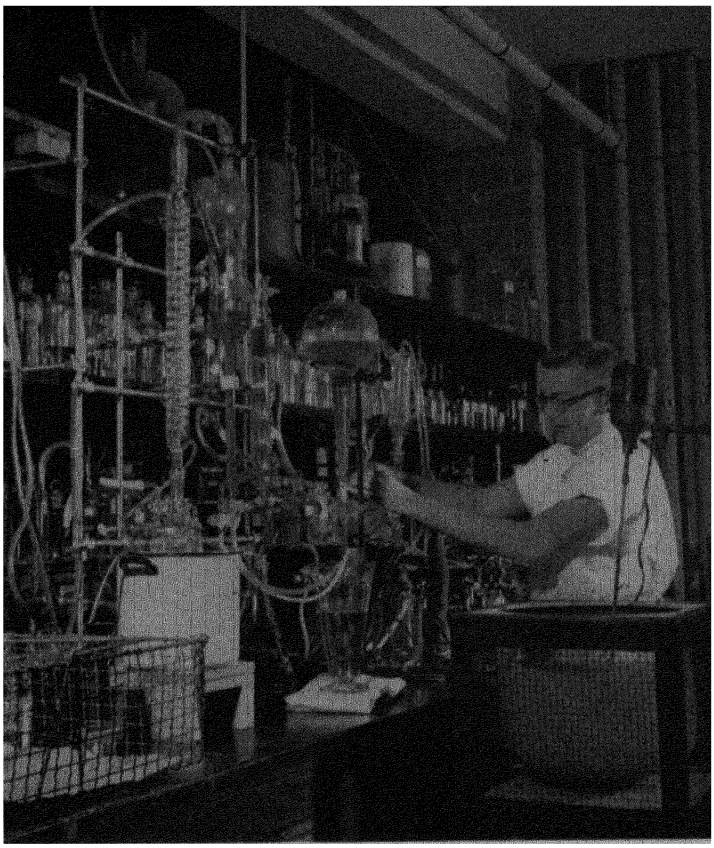
During the war years, a number of compounds which had been known prior to that time came into use for the treatment of wounds. Some of these substances, such as chloramine-T, dichloramine-T, gentian violet, crystal violet, methyl violet, brilliant green, and acriflavine, continued to be employed after the war. The azo dye, scarlet red, had already been recommended in 1909 as an agent to promote the healing of wounds.

Organometallic Compounds

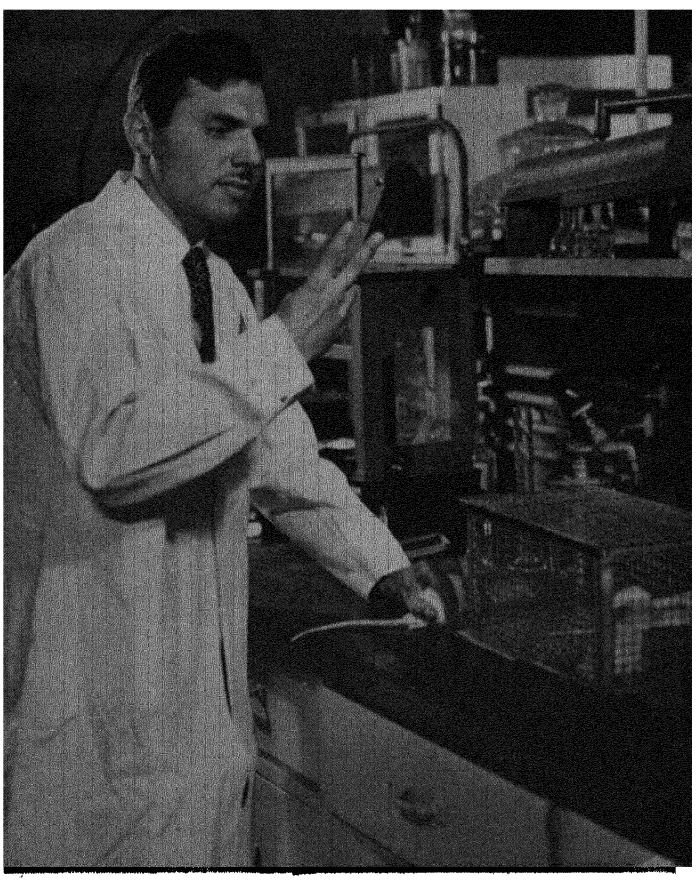
A systematic investigation of a large number of organic arsenical compounds was begun in this county in 1919 and led to the discovery of tryparsamide, the first reasonably satisfactory drug for the treatment of human sleeping sickness. Two isomers of sodium hydroxyacetylaminophenylarsonate, orsanine (for the treatment of sleeping sickness) and Stovarsol (the first orally active drug against spirochetal infections), were introduced somewhat later. 3-Amino-4-hydroxyphenylarsenoxide was originally investigated by Ehrlich but was pronounced too toxic for clinical use. It remained of considerable interest, however, because biochemical evidence indicated that it might be the oxidation product through which the arsphenamines exerted their spirochetal action in the body. After several years of careful laboratory and clinical research, the high therapeutic efficiency of the drug was appreciated, and it became established under the name of Mapharsen as one of the most useful arsenicals.

Inorganic mercury compounds were used as local antiseptics soon after the introduction of phenol. The toxicity and obvious disadvantages of these preparations and the promising chemotherapeutic activity of the organic arsenicals led to the synthesis of complex mercury-containing organic compounds more suited for therapeutic application. The antiseptic activity of organic mercurials was discussed at the 62nd meeting of the Society, in New York, September 6 to 10, 1921, at which time the introduction of Mercurochrome was announced. Many valuable organic mercurial antiseptics have been obtained including Metaphen (anhydride of 4-nitro-3-hydroxymercuri-*o*-cresol), Merthiolate (sodium ethylmercurithiosalicylate), Mercresin (mixture of *sec*-amyltricresol and *o*-hydroxyphenyl mercuric chloride), and more recently the simple compound, phenylmercuric nitrate.

A Symposium on Chemistry in the Field of Microbiology was held at the 69th meeting in Baltimore, Md., on April 20, 1925, at which the high germicidal potency of the alkylated phenols was reported. This work led to the introduction of hexylresorcinol as both a general and urinary antiseptic, and as an efficient anthelmintic agent. Other alkyl substituted and halogenated phenols such as cresol, amylphenol, chloro-hexol (2-chloro-4-*n*-hexylphenol), amyltricresols, thymol, hexyl-*m*-cresols, and the more recently introduced G-11 [hexachlorophene; 2,2′-methylene-bis-(3,4,6-trichlorophenol)] have found wide use as antiseptic and disinfectant agents. A group of cationic surface acting agents represented by the quaternary ammonium compounds, such as benzalkonium chloride, benzethonium chloride, and cetyl



At the National Institutes of Health, researcher investigates the synthesis of a new drug



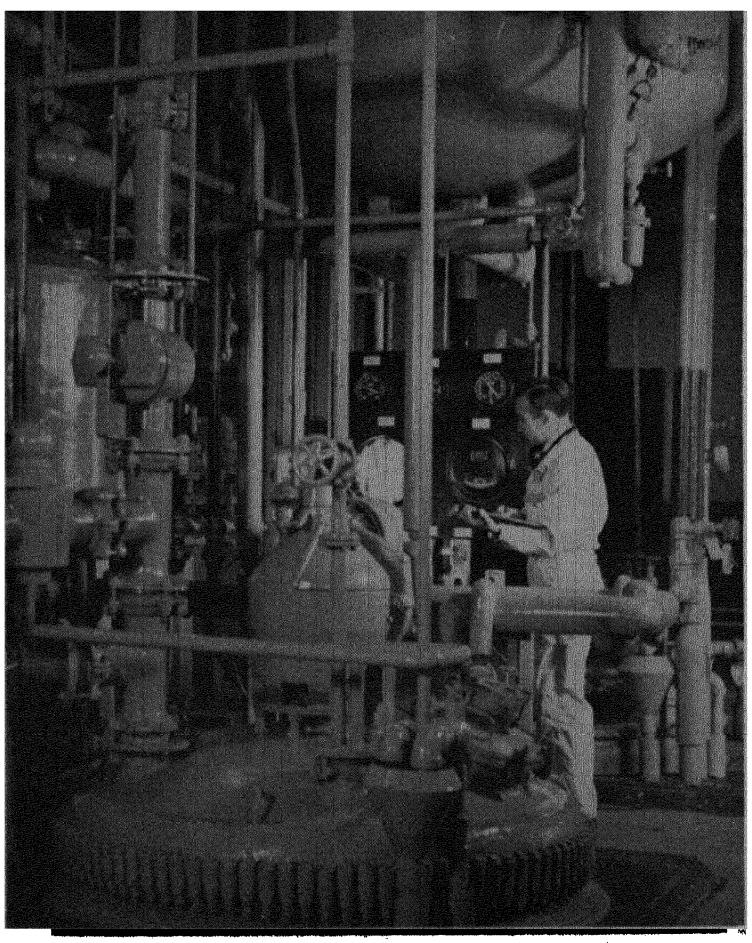
Injection of cysteine protects most rats from death by exposure to radioactivity

pyridinium chloride, were found to have marked bactericidal activity and have been used for several years as effective local antiseptics and disinfectant agents.

While Ehrlich had initiated synthetic chemotherapy with his investigation of various dyes, more effective results had been achieved with organometallic trypanocidal and antispirochetal drugs. However, in 1920, an important departure was made when the Bayer Co. introduced Germanin (Bayer 205, Suramin) a colorless, nonmetallic, organic compound which proved to be an extraordinarily useful trypanocidal agent.

Antimalarial Agents

Other successful investigations originating from the work of Ehrlich were in the antimalarial field. Experience gained in altering the structure of methylene blue was applied to other ring systems, with the result that Plasmochin [pamaquine, 8-(diethylaminoisopentylamino)-6-methoxyquinoline], a derivative of 6-methoxy-8-aminoquinoline, was produced in 1924. Similar substitutions and modifications were made in other heterocyclic nuclei. These transformations led eventually to the synthesis of the acridine derivative, Atabrine [quinacrine, 6-chloro-9-(4-diethylamino-1-methybutylamino)-2-methoxy-acridine]. The real value of this drug was to remain unrecognized until World War II, when it was shown by field trials to be not only superior to quinine as a suppressive against benign and malignant tertiary malarias but also a cure for the malignant tertiary form. As a contribution to the research program on antimalarial agents initiated at the beginning of World War II, the division organized a symposium on malaria at the 105th meeting in Detroit, April 12 to 16, 1943. Other antimalarial drugs developed during World War II were Paludrine [1-(*p*-chlorophenyl)-5-isopropylbiguanide], synthesized by the British, pentaquine [8-(5-isopropylaminoamylamino)-6-methoxyquinoline], Camoquine [4-(7-chloro-4-quinolylamino)-α-diethylamino-*o*-cresol], and chloroquine [SN7618; 7-chloro-4-(4-diethylamino-1-methylbutylamino)quinoline], which are more active than Atabrine. The accomplishments of this wartime research program on the development of antimalarial agents—work which involved the close cooperative efforts of chemists, pharmacologists, clinicians, industrial scientists, governmental research workers, scientists from private research institutes, and university investigators—were disclosed at the symposium sponsored by the division at the Atlantic City meeting, April 8 to 12, 1946.



Glass-lined equipment is used in the manufacture of intermediates for various sulfa drugs

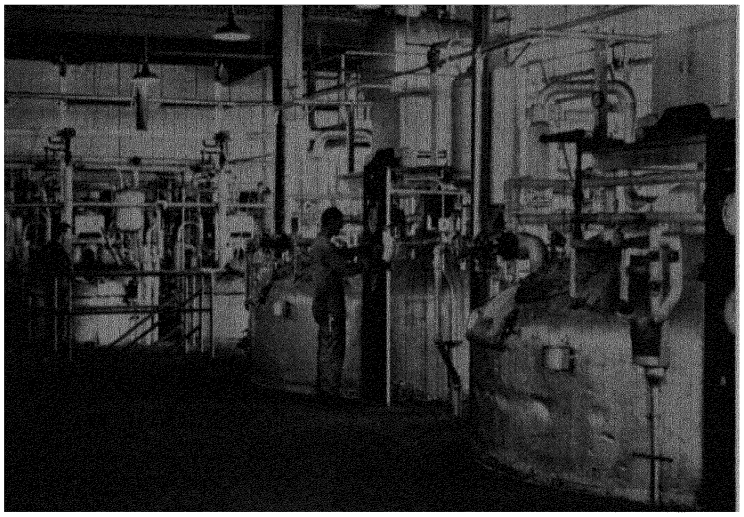
Interest in the treatment of tropical diseases was revived during the recent war, and research on antiparasitic agents was again stimulated. The problems and accomplishments in this field were reviewed at the divisional symposium held during the 107th meeting in Cleveland, April 3 to 7, 1944.

The aromatic amidines have been found to be useful chemotherapeutic drugs, and 4,4-diamidinostilbene has been shown to have therapeutic action in trypanosomiasis and leishmanial infections such as kala-azar.

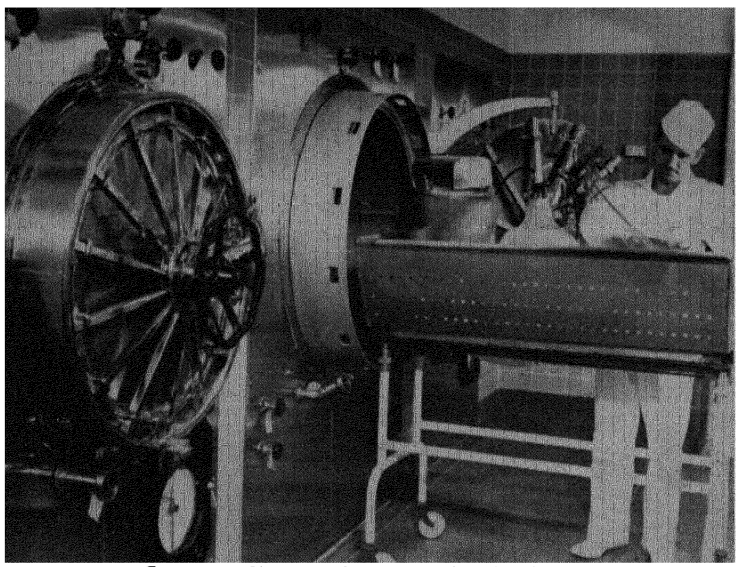
Sulfonamides

The early work in chemotherapy was most successful when applied to diseases of protozoal or spirochetal origin, while the chemotherapeutic treatment of bacterial infections seemed most discouraging. The first cure of a bacterial infection was reported by Morganroth and Levy in 1911, when they found that the quinine derivative, ethylhydrocuprein (also known as Optochin) was curative for mice infected with pneumococci. Results in humans were unsuccessful, and the compound was found to be very toxic. Dyes were investigated for antibacterial activity, and acriflavine and Rivanol were developed as chemotherapeutic agents for local applications because of their low toxicity for tissues. In an attempt to increase the bactericidal properties of quinine derivatives, dyes derived from hydrocupreine were prepared by Jacobs (1919), one of these being 5-(*p*-sulfamylphenylazo)hydrocupreine, which was obtained by diazotization of sulfanilamide and coupling with hydrocupreine. This work was reported at a meeting of the New York Section of the ACS. In 1930, it was thought that bacteria were not susceptible to chemotherapy because their metabolism was so similar to that of the host cells. The prevailing opinion was that any agent capable of toxic action against the bacteria was sure to be equally toxic to the host tissue. However, when the clinical trials reported in 1935 established the dramatic results with Prontosil against most hemolytic streptococcal infections, it was obvious that a chemotherapeutic agent for bacterial infection had been found. Prontosil (4′-sulfonamido-2,4-diaminoazobenzene) had been patented by the IG Farbenindustrie in 1932. After the publication of Domagk's experimental results, it was soon established by the investigators at the Pasteur Institute in Paris that in the host Prontosil was converted to *p*-aminobenzenesulfonamide (sulfanilamide), which was the active therapeutic agent.

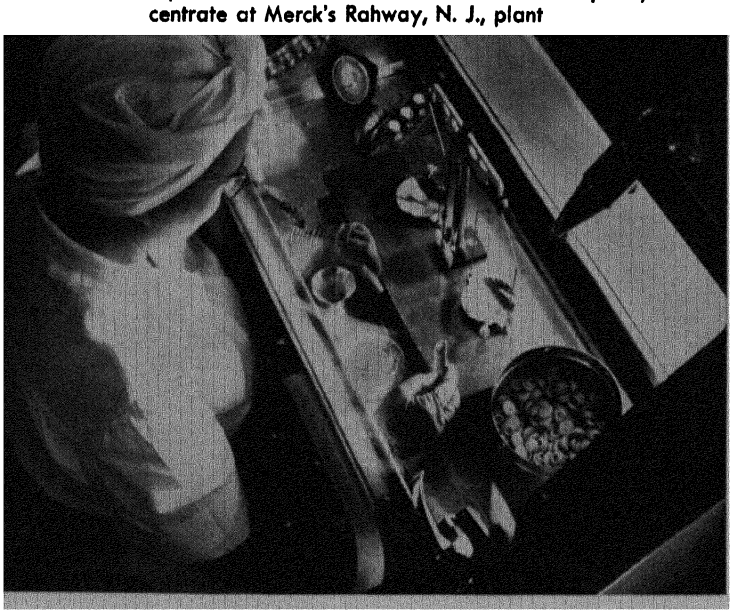
Intensive research in England, the United States, and other countries led to the preparation and investigation of a large number of compounds which were more active than sulfanilamide and which were found to combat a wider range of infections. Sulfapyridine (*N*′-2-pyridylsulfanilamide) was prepared by the British and found to be effective against pneumococcal infections. Work in the United States led to the introduction of sulfathiazole (*N*′-2-thiazolylsulfanilamide), which was first reported on the program of the Division of Medicinal Chemistry at the 97th meeting in Baltimore, Md., April 3 to 7, 1939. Subsequent work showed that sulfathiazole was an effective agent against staphylococcal infections. During the first part of the war, these drugs were quickly followed by sulfadiazine (*N*′-2-pyrimidylsulfanil-



Merck & Co. produces streptomycin in these large fermentation vessels at Elkton, Va.



Operator filters and mixes a batch of streptomycin concentrate at Merck's Rahway, N. J., plant



While exposed to ultraviolet light, vials of streptomycin are carefully filled and weighed

amide), sulfaguanidine (*N'*-guanylsulfanilamide), sulfamerazine [*N'*-(4-methyl-2-pyrimidyl)sulfanilamide], Sulfasuxidine (*p*-2-thiazolylsulfamylsuccinanilic acid), Sulfathalidine [4'-(2-thiazolylsulfamyl)phthalanilic acid], Sulfapyrazine (*N'*-2-pyrazinylsulfanilamide), and sulfamethazine [*N'*-(4,6-dimethyl-2-pyrimidyl)sulfanilamide], among others—all of which received wide acceptance in the treatment of human and animal diseases. The preparation and properties of most of these compounds were first disclosed at the meetings of the medicinal division. The clinical significance and the commercial importance of the sulfonamides were emphasized by John S. Zinsser, president of Sharp & Dohme, Inc., at the luncheon of the division during the ACS meeting in Detroit, April 12 to 16, 1943. Research in this field still continues as more active and less toxic drugs are found which are effective against a greater range of organisms.

Antibiotics

The inhibition of growth in one bacterial species by the presence of another microorganism is an established fact in bacteriology. Its possible application to the field of therapeutics was realized as early as 1877. Many bacteria and fungi had been found to produce substances with antibacterial action, but most of these materials proved too toxic for human use. In 1929, Fleming observed that the growth of *Staphylococcus aureus* on an agar plate was inhibited by a mold which contaminated the plate. He produced a filtrate from this mold which was found to be bactericidal and nontoxic. This he called penicillin and suggested that it would be a useful antiseptic for infected wounds. The clinical significance of this material was obscure until Florey and his coworkers isolated a water-soluble powder and established its remarkable antibacterial activity in 1941. Penicillin is highly active and nontoxic. Its activity is not affected by tissue proteins, breakdown products, or pus, and it is relatively unaffected by the number of bacteria present. It has widened the field of bacterial chemotherapy to an extent which would have been unbelievable a few years ago.

Two antibacterial substances, gramicidin and tyrocidin, have been isolated from *Bacillus brevis*. A mixture of the two, called tyrothrycin, as well as gramicidin itself have found clinical use as topical antibiotics. Streptomycin has been isolated from an actinomycete and found to have therapeutic value against tuberculosis. Bacitracin, an antibiotic from cultures of *Bacillus subtilis*, is used by topical application for local infections. Aureomycin, Chloromycetin [*d*-(−)-threo-2-dichloroacetamido-1-*p*-nitrophenyl-1,3-propanediol], and Terramycin—all derived from actinomycetes—are becoming increasingly important in the treatment of diseases caused by Rickettsia and the larger viruses. They are also useful in the treatment of bacterial infections and are effective on oral administration. Heretofore, all of the antibiotics had been produced commercially from the various microorganisms by fermentation processes. However, in 1949, the structure of Chloromycetin was established and its synthesis and commercial production by a synthetic process were achieved by the chemists of Parke, Davis & Co. This outstanding achievement was disclosed on the program of the medicinal division at the 115th meeting in San Francisco on March 29, 1949. The structures of penicillin and streptomycin were elucidated during World War II, and the synthesis of a minute quantity of benzylpenicillin was reported. The chemistry of the antibiotics is very complex; however, as emphasized at the Second National Medicinal Chemistry Symposium at Notre Dame in 1950, the clinical researches on these substances have opened up an entirely new approach to the treatment of numerous infections.

Anesthetics, Analgetics, and Hypnotics

A major field which received the attention of medicinal chemists immediately following World War I was that of inhalation

anesthetics. Ethylene has been used to some extent because of pleasant induction coupled with rapid recovery and low incidence of postoperative nausea. An anesthetic of great potency has been found in cyclopropane. Effective in low concentration, it allows the patient to inhale normal or greater than normal concentrations of oxygen while under anesthesia. For minor surgical operations of short duration, divinyl ether (Vinethene) has been supplied as an inhalation anesthetic. More recently, the field of anesthesia has been expanded considerably by the use of curare alkaloids, which have the ability to block the myoneural junction and thus produce muscle relaxation during surgical operations or shock therapy.

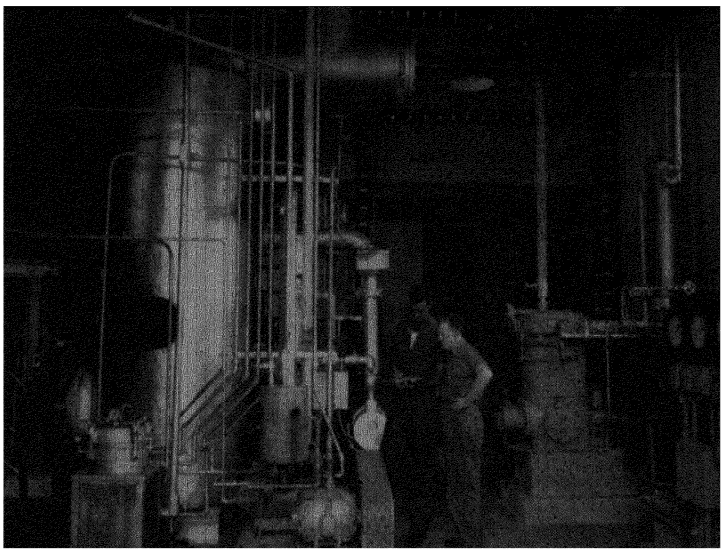
The effort directed toward the synthesis of new local anesthetics has indeed been prodigious, as can be seen from the report at the First National Medicinal Chemistry Symposium at Ann Arbor in 1948. Many excellent compounds have been described for use in this field, including Butyn (3-dibutylaminopropyl *p*-aminobenzoate), Pontocaine (2-dimethylaminoethyl *p*-butylaminobenzoate), Metycaine [3-(2-methyl-1-piperidyl)propyl benzoate], Surfacaine [3-(2-methylpiperidine)propyl *p*-cyclohexyloxybenzoate], Intracaine (2-diethylaminoethyl *p*-ethoxybenzoate), and others.

Many new compounds with a profound analgetic effect comparable to that of morphine have been prepared. Some of these products were obtained by chemical alteration of the opium alkaloids. Others were synthesized from materials not dependent upon botanical sources, but patterned after the structural features of morphine. Still others are simple organic compounds having no similarity to morphine but possessing analgetic activity. Thus in Demerol (ethyl 1-methyl-4-phenylpiperidine-4-carboxylate), we have the first synthetic drug which resembles morphine in its analgetic effect, although it has some spasmolytic action. This spasmolytic action is caused by the drug's papaverinelike action on smooth muscles. Methadone (6-dimethylamino-4,4-diphenyl-3-heptanone) has a morphinelike analgetic effect, although it lacks sedative action. Both have addiction liability and, though nonopiates, have been placed under the regulations of the Harrison Narcotic Act. Recently, there has been a re-emphasis of the need for a long-acting, less profound analgetic—free from any tendency to produce agranulocytosis or lesser blood damage—for use in chronic pain states. Studies on the metabolism of acetanilide have led to the introduction of *p*-hydroxyacetanilide, which has the analgetic effect of acetanilide but which cannot break down to release the toxic compound, aniline.

The therapeutic effects obtained with barbital and phenobarbital, agents which induce sleep of long duration, have led to the development of many other barbiturates, such as Butisol (5-*sec*-butyl-5-ethylbarbituric acid), Delvinal [5-ethyl-5-(1-methyl-1-butenyl)barbituric acid], and Ipral (5-ethyl-5-isopropylbarbituric acid), which produce sleep of moderate duration, and Amytal (5-ethyl-5-isoamylbarbituric acid), pentobarbital [5-ethyl-5-(1-methylbutyl)barbituric acid], and Seconal [5-allyl-5-(1-methylbutyl)barbituric acid], which produce sleep of short duration. A number of ultra-short-acting barbiturates have been developed, illustrated by Evipal [5-(1-cyclohexen-1-yl)-1,5-dimethylbarbituric acid] and Pentothal [5-ethyl-5-(1-methylbutyl)-2-thiobarbituric acid], which are used intravenously for the production of rapidly and pleasantly induced anesthesia for surgical operation of brief duration. For major surgical operations, inhalation anesthetics can be used to maintain anesthesia for longer periods of time, and muscle-relaxing curarelike compounds can be used to produce surgical relaxation.

Autonomic Drugs

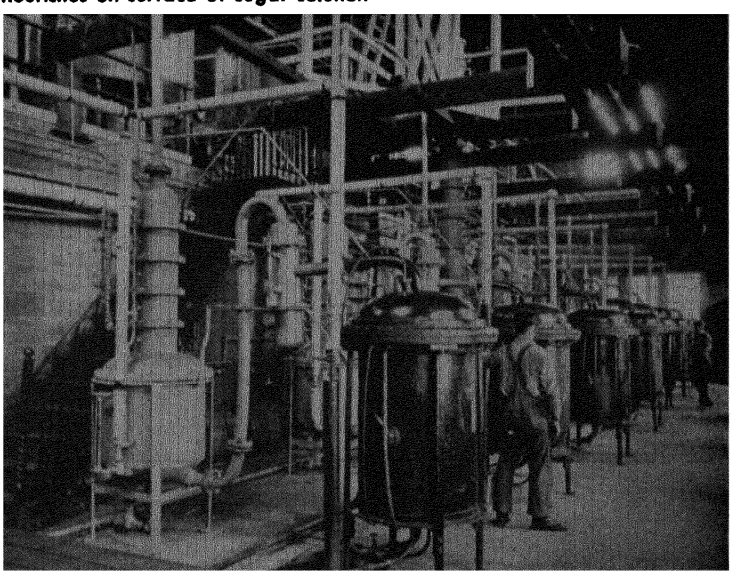
Drugs, such as Metrazol, Benzedrine (α-methylphenethylamine), and desoxyephedrine (*N*,α-dimethylphenethylamine), which are the pharmacological opposites of the barbiturates, have been prepared as analeptics and stimulants of the central nervous



In streptomycin process, vapor from sublimation dryer is frozen at —80° C. in condenser, then removed as snow



Golden droplets of penicillin are excreted by mold which flourishes on surface of sugar solution



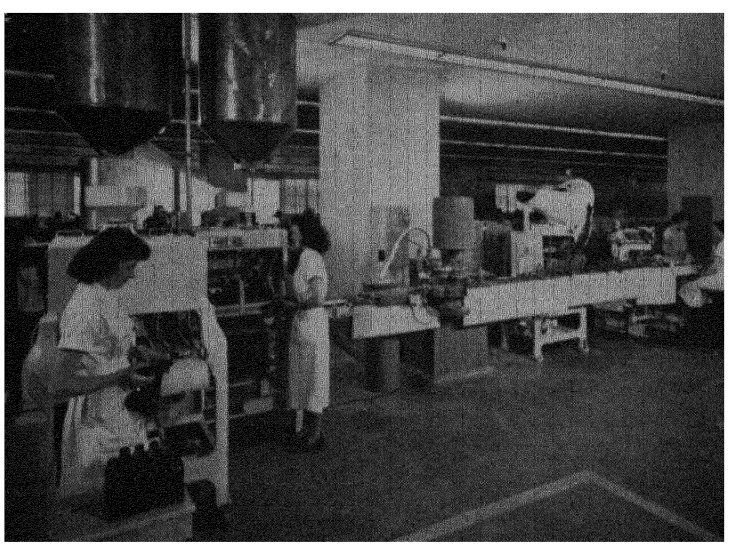
In 1912, E. R. Squibb & Sons used these stills in their production of ether, widely employed as an anesthetic



An active program of medicinal chemical research is conducted at Smith, Kline & French Laboratories



Equipment in manufacturing section of pharmaceutical plant is controlled from rear panel



Electronic machines count more than 10,000 tablets per minute in pharmaceutical packaging room

system. The latter two compounds combat drowsiness and mild states of depression and temporarily stimulate mental activity and sensory acuity. In addition, these drugs have effects upon the autonomic nervous system and, indeed, are generally classed as autonomic drugs. These drugs either mimic or oppose the peripheral effects of nerve impulses of the two divisions of the autonomic nervous system—namely, the sympathetic and parasympathetic. Benzedrine, ephedrine [α-(1-methylaminoethyl)benzyl alcohol], desoxyephedrine, Neo-synephrine [*m*-hydroxy-α-(methylaminomethyl)benzyl alcohol], Privine [2-(1-naphthylmethyl)-2-imidazoline], Propadrine [α-(1-aminoethyl)-benzyl alcohol], and Tuamine (1-methylhexylamine) are among the sympathomimetic drugs which have been of greatest therapeutic interest, as indicated at the symposium held during the 108th meeting in New York, September 11 to 15, 1944. They raise the blood pressure, constrict the congested nasal mucosa in rhinitis and sinusitis, relax the bronchioles in asthma, dilate the pupils of the eye, and usually increase cardiac rate and output. More recently, a series of alkyl arterenols has been reported which have only depressant action on the blood pressure. The isopropyl derivative known as Isuprel or Aludrine [α-(isopropylaminomethyl)protocatechuyl alcohol] is utilized in relaxing bronchioles without the hypertensive effect of epinephrine.

It has been known for some time that ergotoxin was able to reverse the effects of epinephrine on the blood pressure, but ergotoxin remained a pharmacological curiosity because it was too toxic to be considered for clinical use. A series of alkylaminomethylbenzodioxanes has been synthesized which possess sympatholytic and adrenolytic action in varying degree. Such compounds as Benodaine [2-(1-piperidylmethyl)-1,4-benzodioxan], dihydroergotamine, Priscoline (2-benzyl-2-imidazoline), and Dibenamine [*N*-(2-chloroethyl)dibenzylamine] are important milestones in our search for agents effective in the treatment of hypertension and peripheral vascular diseases.

Atropine and related belladonna alkaloids are the classic depressants of the parasympathetic system and have been used for the control of spasms of smooth muscles. A large number of antispasmodics have been synthesized, among which Syntropan (3-diethylamino-2,2-dimethylpropyl tropate), Trasentine (2-diethylaminoethyl diphenylacetate), and Pavatrine (2-diethylaminoethyl fluorene-9-carboxylate) have found wide clinical usefulness. Dibutalin, which has some chemical similarity to acetylcholine, has all the effects of atropine in blocking acetylcholine activity. One of the outstanding accomplishments of the past decade was the synthesis of a large number of compounds, such as Benadryl [(2-benzhydryloxy)-*N*,*N*-dimethylethylamine], Pyribenzamine {2-[benzyl-(2-dimethylaminoethyl)amino]pyridine}, Trimeton [1-phenyl-1-(2-pyridyl)-3-dimethylaminopropane], and Neo-Antergan {2-[(2-dimethylaminoethyl)-(*p*-methoxybenzyl)-amino]pyridine}, which counteract the effects of histamine. These antihistaminic agents have been found to be useful in the treatment of such conditions as serum sickness, nasal allergies, hay fever, and allergic dermatitis.

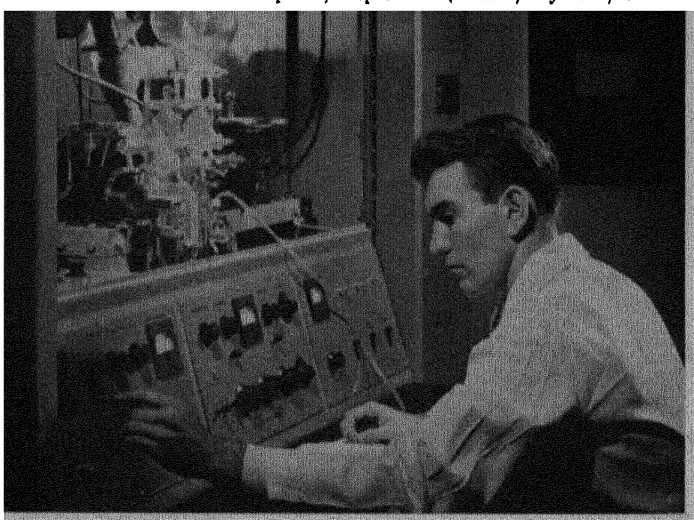
Cardiac Drugs

In the cardiac field, digitoxin and other highly purified glycosides derived from digitalis have been developed which digitalize the heart at low doses and with few toxic effects. Pronestyl (*N*-diethylaminoethyl *p*-aminobenzamide) has been found to have quinidinelike action in controlling ventricular tachycardia and the extra systoles. Recent work with khellin (2-methyl-5,8-dimethoxyfuranochromone) isolated from the plant, *Ammi visnaga*, has shown this compound to have marked activity as a coronary dilator and has led to its identification, proof of structure, and synthesis. Interest in the veratrum alkaloids has been revived by a thorough investigation of their hypotensive activity. This study has culminated in the introduction of a number of purified fractions of these alkaloids for the treatment of

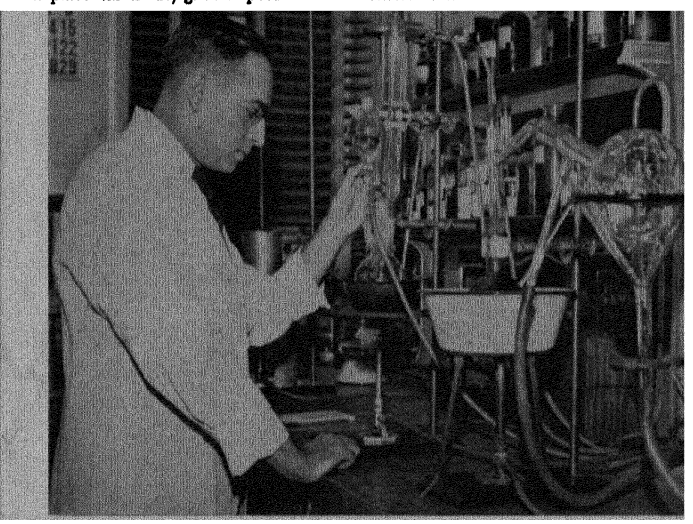
hypertension. Their structure is still obscure and their usefulness restricted because of undesirable side effects. The status of the chemical factors in hypertension was discussed at the 115th meeting in San Francisco, March 29, 1949.

Noteworthy advances have been achieved through the development of mercurial diuretics, such as Mercurophylline (sodium salt of β-methoxy-γ-hydroxymercuripropylamide of trimethylcyclopentanedicarbocyclic acid and theophylline), Salyrgan-Theophylline [sodium *o*-[(3-hydroxymercuri-2-methoxypropyl)carbamyl]phenoxyacetate], and Thiomerin [sodium *N*-(γ-carboxymethylmercaptomercuri-β-methoxy)propylcamphoramide] for the treatment of cardiorenal vascular diseases. Such synthetic compounds as Dilantin (5,5-diphenylhydantoin), Mebaral (1-methyl-5-ethyl-5-phenylbarbituric acid), Mesantoin (3,5-dimethyl-5-phenylhydantoin), Tridione (3,5,5-trimethyl-2,4-oxazolidinedione), and Prenderol have been prepared as anticonvulsants for use in the treatment of epilepsy.

Another compound, mephenesin (Tolserol, myanesin, 3-*o*-toloxy-1,2-propanediol), has been found to produce muscular relaxation and is useful in the treatment of a variety of spastic conditions. A number of new compounds such as Artane [3-(1-piperidyl)-1-phenyl-1-cyclohexyl-1-propanol], Panparnit (2-diethylaminoethyl 1-cyclopentanecarboxylate), and Diparcol [10-(2-diethylaminoethyl)phenothiazine] may have specific applications in this field.



The mass spectrometer has opened up new frontiers of medicinal chemical research



At Mellon Institute, chemist synthesizes a new antimalarial, an analog of Plasmochin

Hormones

The period since 1919 has been characterized by spectacular advances in the isolation, elucidation of structure, and synthesis of the hormones (the active principles of the glands of internal secretion). Prior to 1919, two hormones, epinephrine from the adrenal gland and thyroxine from the thyroid, had been isolated but only epinephrine had been produced synthetically. In general, endocrinologists firmly believed that a given endocrine gland produced only a single hormone, and it was not until 1928 (Kamm and coworkers) that multiple hormones were discovered. With the separation of posterior pituitary extracts into two hormones, vasopressin (which exerted the pressor and the antidiuretic effects of such extracts) and oxytocin (which exerted the typical stimulative effects on the uterus), it became apparent that a single endocrine gland is capable of producing a variety of hormones—at least six in the case of the anterior pituitary and six or more in the case of the adrenal cortex.

This period also has been characterized by advances in the elucidation of mechanisms whereby the glands of internal secretion exert their role in regulating many body functions. In large measure, these accomplishments have resulted not only from the isolation and chemical identification of many of the active hormones responsible for these regulatory mechanisms but also from biochemical investigations of their metabolic degradation products, their distribution in body fluids, and their pathways of destruction or excretion. Coincident with such progress has been the synthesis of many glandular principles on a scale large enough to permit the practical use of these substances in clinical medicine.

Since the isolation of epinephrine in 1901 from the adrenal medulla and of thyroxine from the thyroid in 1915, one of the most important achievements in endocrinology has been the preparation of purified insulin by Banting and coworkers in 1922. Abel and associates succeeded in obtaining this protein hormone in crystalline form four years later.

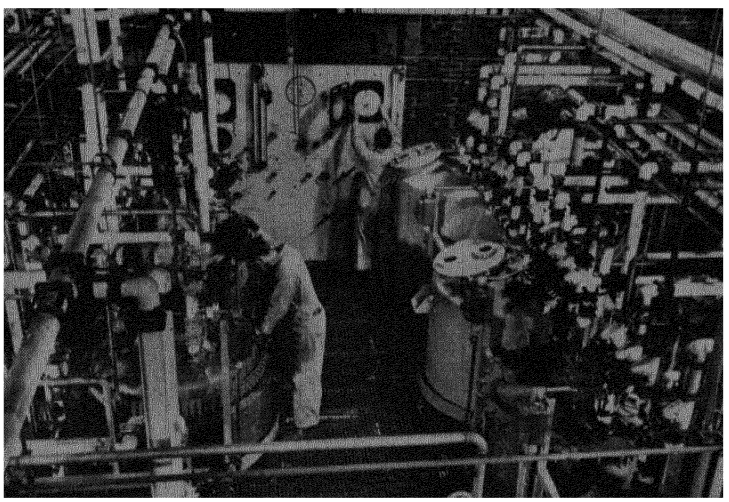
Isolation of crystalline estrone by Doisy in 1929 and estriol from human pregnancy urine in 1930, and their later preparation from placental tissue, gave impetus to considerable research on the active hormones of the ovary, an organ closely associated with reproductive mechanisms during pregnancy and in the normal menstrual cycle. Estradiol and estrone were separated from ovarian tissue itself in the period 1936–38. Progesterone, the hormone of the ovarian corpus luteum—synthesized from bile acids by Butenandt in 1934—was isolated from sow corpora lutea by several groups working independently in the same year. Total synthesis of equilenin, itself convertible to estrone, was carried out by Bachmann in 1939–40 as reported in the *Journal of the American Chemical Society*.

Male hormones were isolated first from human male urine. The androgens, androsterone and dehydroisoandrosterone, were obtained from this source in 1932–34. In 1935, testosterone was isolated from bull testes. Its synthesis and structural identification was followed quickly by partial synthesis from cholesterol.

The separation, purification, and, in some cases, the crystallization of the several protein hormones of the anterior pituitary have been among the major accomplishment of chemistry in the past two decades. Preparation of crystalline lactogenic (or luteotrophic) hormones was announced first in 1937 and its characteristics were presented in detail in 1942. The growth factor of the anterior lobe was isolated in pure form in 1944–45. Thus far, the interstitial cell-stimulating factor (ICSH) has not been obtained in crystalline form, but electrophoretically homogeneous fractions of maximal activity were announced by Evans' laboratory in 1940. Purified adrenocorticotrophic hormone (ACTH) was reported in 1924, and recently it has been shown

that this remarkable trophic factor will withstand considerable hydrolytic degradation without loss of biological activity. The follicle-stimulating hormone (FSH) and thyrotrophic principle of the pituitary have not been separated from crude pituitary extracts in pure form. Neither has the parathyroid hormone been obtained in pure form, although potent concentrates were produced in 1926.

Thyroxine was isolated in 1914, but it was not until the compound was synthesized in 1926 that its chemical structure was definitely established. Much progress toward a more complete understanding of both the thyroid function and the interrelationship between this organ and the pituitary gland has resulted from the discovery of antithyroid compounds and from the use of radioactive iodine as implements of laboratory study. Various papers presented at the Atlantic City meeting, April 17, 1947, focused attention upon the use of radioactive iodine, thiouracil, and propylthiouracil for the diagnosis and treatment of thyroid diseases.



Porcelain piping is required in several steps involved in the production of cortisone

Isolation and identification of the hormones of the adrenal cortex were undertaken in the early 1930's by three laboratories, two in the United States and one in Switzerland. Largely through the efforts of these laboratories, 29 steroids have been isolated to date, and many of these were described at the Symposium on Steroidal Compounds during the ACS meeting in New York, September 15 to 19, 1947. At least six of these exhibit adrenal cortical activity, several are androgenic, estrogenic, or progestational, and still others possess no known biological activity. Hand in hand with the isolation of the cortical steroids has been the partial syntheses of these factors, and of their assumed intermediate metabolic and excretion products, from bile acids and from plant and other steroids. The improved synthesis of cortisone (Kendall's Compound E, 11-dehydro-17-hydroxycorticosterone-21-acetate) from desoxycholic acid of bile through integrated endeavors of Kendall, Sarett, and others, as reported at the Second National Symposium on Medicinal Chemistry, has been a major accomplishment of chemistry, particularly because of significant role of cortisone in physiological and clinical investigations. The recent discovery of an enzyme mechanism which permits ready conversion of certain inactive steroids to active ones has given added interest in this field of endocrinology.

Amino Acids

Whereas most of the nutritionally important amino acids were isolated and characterized before 1919, comparatively little was known of their nutritional significance before 1935. In 1930, Rose began investigations with diets of purified amino acids and found that rats which ingested a ration containing nineteen of the known amino acids as the sole source of nitrogen sustained rapid losses in weight unless there was added another protein fraction which was subsequently found to be threonine. With the discovery of the nutritional significance of threonine, there was immediately available a method for establishing which of the amino acids could be synthesized by the living organism and which must be supplied in the diet. With this technique, Rose was able to establish that 10 amino acids are essential to normal growth in the rat: lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, threonine, methionine, valine, and arginine. On the other hand, glycine, alanine, serine, norleucine, aspartic acid, glutamic acid, hydroxyglutamic acid, proline, hydroxyproline, citrulline, tyrosine, and cystine are dispensable. These studies have now been extended to several species. For nitrogen balance in man, only eight protein constituents are necessary: isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. Ten grams of nitrogen were ingested daily; that portion not derived from the indispensable amino acids is highly nonspecific and can be supplied by ammonia, urea, or dispensable amino acids. The results of the investigations on amino acids have been the subject of numerous symposia at ACS meetings.

Vitamins

In 1920, the vitamin field was in its infancy. Only two substances were considered to be members of this group of essential nutrients: fat-soluble vitamin A and water-soluble vitamin B. These substances were characterized only by the syndromes produced in man and animals, resulting from their absence from the diet. Neither had been obtained in a homogeneous state. Consequently nothing was known of their structures. Funk considered them to be aminolike in nature and coined the term "vitamine," indicating their essentiality to life. Since 1920, the isolation, proof of structure, synthesis, determination of their role in nutrition and the establishment of the metabolic function of these substances have required the efforts of thousands of the most able chemists and biologists of the past three decades.

The development of xerophthalmia in both man and experimental animals by the dietary deficiency of a fat-soluble component was known as early as 1913. However, it was not until 1931 that a highly purified preparation of vitamin A was obtained by chromatographic methods and what is now the accepted structure of vitamin A_1 [3,7-dimethyl-9-(2,6,6-trimethyl-1-cyclohexen-1-yl)-2,4,6,8-nonatetraen-1-ol] postulated. The preparation of the crystalline vitamin was described in 1937. However, its preparation by synthetic means was not achieved until 1947, and its synthesis on a commercial scale was not announced until 1950.

Beriberi was recognized as a deficiency disease late in the 19th century. Later, experimental polyneuritis was cured by dietary means. Isolation of vitamin B as the curative agent was accomplished in 1926, and a proof of the structure and a method of synthesis was published in 1936. Thiamine was one of the first vitamins to be produced synthetically on a commercial scale. Its large scale production has made possible its widespread use as a therapeutic agent and as a fortifier of flour, bread, and other cereal products.

For several centuries, fresh vegetables and citrus fruits have been known to contain a preventive and curative substance for scurvy. When, during the first decade of this century, it was shown that scurvy could be produced in guinea pigs, an experimental method immediately became available for following the concentration of the antiscorbutic agent. In 1925, the vitamin was obtained in a state approaching homogeneity and many of its chemical properties were determined. A hexuronic acid was isolated in 1928 from the adrenal cortex and from orange juice

and cabbage. This acid was subsequently identified as the antiscorbutic principle. The structure of vitamin C (ascorbic acid) was established in 1933, and its synthesis was accomplished the same year.

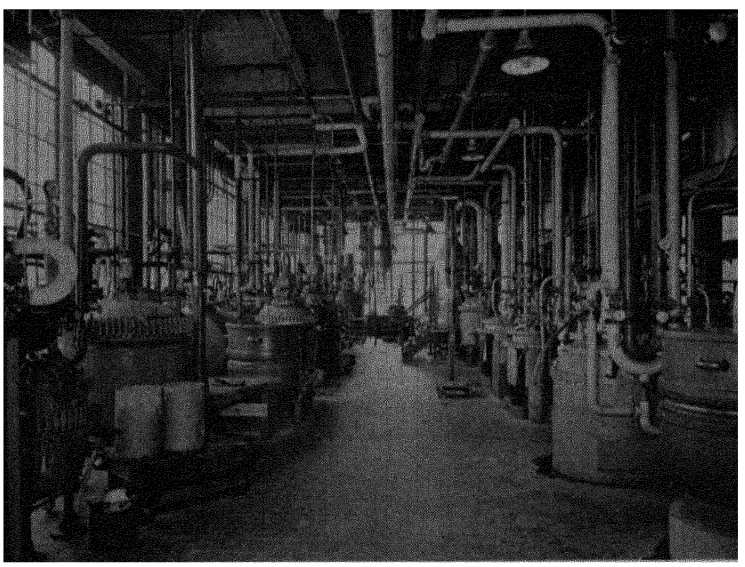
Early in the nineteenth century, it was suggested that rickets could be cured by the administration of cod liver oil or by exposure to sunlight. However, it was not until 1919 that the importance of sunlight became widely appreciated. At first, it was thought that the antirachitic factor was related to or identical with vitamin A, but data were gradually accumulated which proved that the antirachitic agent was not identical with vitamin A and that it was multiple in nature. In 1925, it was shown that a provitamin existed in foodstuffs which, by irradiation, could be converted to an antirachitic substance. This substance was named vitamin D. It evolved then that there existed several provitamins D which give rise to active compounds upon irradiation. Ergosterol and 7-dehydrocholesterol appear to be the most important members of this group. Ten provitamins D are known, but only four vitamins D have been isolated in essentially pure form. The structure of vitamin D has been established. However, the commercial material for use in the prevention and cure of rickets is obtained from marine animals or is produced by the irradiation of ergosterol or 7-dehydrocholesterol.

Subsequent to the isolation and identification of vitamin B_1, the following members of the so-called "vitamin B complex" were isolated and studied: Vitamin B_2, riboflavin [7,8-dimethyl-9-(1'-ribityl)isoalloxazine], isolated in 1934, was synthesized the following year. Niacin or nicotinic acid, known to organic chemists for years, was shown in 1938 to cure blacktongue in dogs. Very shortly thereafter, it was found to be a preventive and curative agent for human pellagra. Vitamin B_6, pyridoxine (5-hydroxy-6-methyl-3,4-pyridinedimethanol), was isolated in crystalline form by no less than five different groups in 1938. During the following year, its chemical structure was announced and its synthesis accomplished. Recent work has focused attention on vitamin B_{12}, the antipernicious anemia factor in liver. The isolation of the vitamin was announced in 1948 in the *Journal of the American Chemical Society;* its structure has not been fully elucidated, although it is unique in that it contains cobalt as well as the cyanide group. Vitamin E, α-tocopherol, which is essential for normal reproduction in rats, was isolated in crystalline form in 1936. The chemical structure was elucidated and its synthesis accomplished in 1938. The physiologic role of the tocopherols in man remains to be established. Vitamin K and K_2, the antihemorrhagic vitamins, were isolated in 1939. In the *Journal of the American Chemical Society*, the proof of structure and the synthesis of vitamin K (2-methyl-3-phytyl-1,4-naphthoquinone) were reported simultaneously from three separate laboratories. In 1933, a naturally occurring compound of unknown chemical composition was observed to stimulate the growth of yeast and was named pantothenic acid, indicating its wide occurrence in nature. The isolation and the establishment of the chemical nature of this vitamin were accomplished in 1938, and in 1940 it was synthesized independently by investigators in this country and in Germany. Pantothenic acid is of considerable importance in animal and poultry nutrition, but its place in human nutrition has not yet been established. Biotin was isolated in 1935, the structure clarified in 1936, and the total synthesis of the compound described in 1945. Folic acid (*N*-{*p*-{[(2-amino-4-hydroxypyrimido[4,5-β]pyrazin-6-yl)methyl]-amino}-benzoyl}glutamic acid), effective in the treatment of certain anemias, was isolated in 1945; the structure was determined and its synthesis accomplished in 1946.

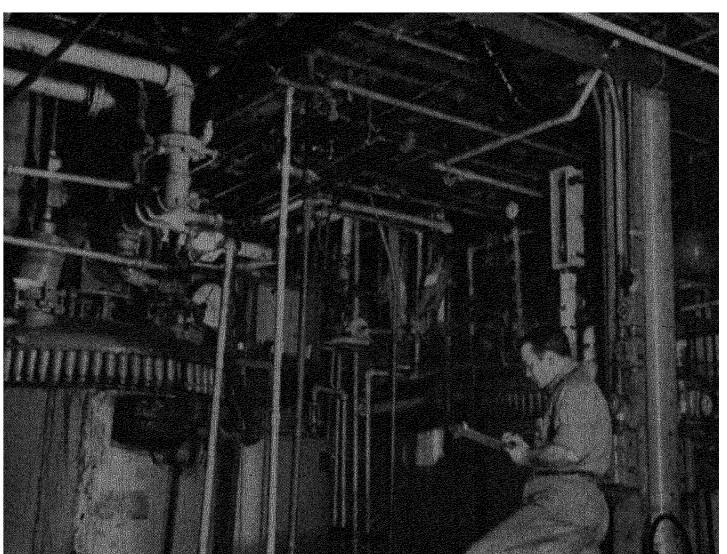
By arrangement with the Interallied Conference of Pure and Applied Chemistry, which met in London and Brussels in July 1919, the AMERICAN CHEMICAL SOCIETY was to undertake the production and publication of scientific and technical monographs on chemical subjects. The first edition of Sherman's text, "The



At National Cancer Institute, research chemist prepares an isotopically labeled amino acid



Atabrine, an antimalarial, is manufactured in this equipment at Winthrop Chemical Co.



Experienced operator records data while synthesizing a vitamin B_1 intermediate

Vitamins," was published in 1921 as a part of this monograph series. The preface to this first edition states:

Although the chemical nature of vitamins is still unknown, much of both scientific and practical importance has been learned regarding them. To those "who don't believe in vitamins because we have never seen one" or who hold that we know nothing about them chemically because no structural formula can yet be assigned, we would commend the view of Hopkins that it is easier to sympathize with the farmer who will believe in vitamins only when their price per hundredweight can be quoted in the market than with the scientific man who refrains from an endeavor to appraise their importance until they have been separated in pure form.

Although outstanding progress has been made, there still remain many problems to be solved concerning the role of carbohydrates, fats, proteins, vitamins, and minerals in human nutrition. Greater progress in the future may be expected because of the advances now being made in our knowledge of the intermediary metabolism of these essential factors in nutrition.

Conclusion

To an important degree, the fundamental achievements in medicinal chemistry during the past 75 years are the result of the more intimate cooperation that has developed during these years among chemist, pharmacologist, and clinician. Particularly in the United States, the growth of sound research in our pharmaceutical houses has engendered faith on the part of clinical investigators. This has greatly facilitated the very important preliminary studies which must precede the introduction of a new drug into clinical medicine.

The medicinal chemist has achieved a new and surer approach to the problem of developing better therapeutic agents. While he has not entirely discarded analogy, he has learned not to rely on it exclusively. Rather, he has become interested in biology and has come to regard the study of the mechanism of action as an essential part of his background of reference. He has made notable strides in the direction of the dictum set forth by John Locke in his "Essay Concerning Human Understanding" (1690):

Did we know the mechanical affections of the particles of rhubarb, hemlock, opium, and a man, as a watchmaker does those of a watch, whereby it performs its operations; and of a file, which by rubbing on them will alter the figure of any of the wheels; we should be able to tell beforehand that rhubarb will purge, hemlock kill, and opium make a man sleep.

In the language of our times, this prophecy means that if one wishes to change the course of a complicated biological process by chemical means, one needs to know something about biology as well as chemistry. It is the willingness on the part of pharmacologist and chemist to learn one another's language and the intimate cooperation between them that have given medicinal chemistry a separate character with not only its own aims but with its own approaches and methods. The meetings of the medicinal division, which have enlisted the joint efforts of chemists, pharmacologists, and clinicians, have played a prominent role in bringing together these groups and in establishing the very remarkable spirit of cooperation which exists among the pharmaceutical houses and the research groups in universities and medical centers.

With our accumulation of basic knowledge and increased efforts in this field, we can look forward confidently to the development of other medicinal agents which will aid in the control of those unsolved diseases such as cancer, tuberculosis, hypertension, asthma, allergies, and numerous others. The programs at the national meetings and symposia, and the publications sponsored by the Division of Medicinal Chemistry have contributed and will continue to contribute materially to the stimulation of this advancement in the future.

Because of the brevity of this report, many significant developments in medicinal chemistry have been omitted. However, it is hoped that a sufficient number of the achievements have been included to give the reader not only a reasonable picture of the remarkable accomplishments in this field during the past 75 years but also an indication of the contributions of the AMERICAN CHEMICAL SOCIETY and of the Division of Medicinal Chemistry to this progress.

Officers of the Division of Medicinal Chemistry, 1909–1951

Year	Chairman	Secretary-Treasurer
1909–1910	A. B. Stevens	B. L. Murray
1911–1913	B. L. Murray	F. R. Eldred
1914–1915	F. R. Eldred	A. P. Sy
1916	J. H. Long	G. D. Beal
1917	L. F. Kebler	G. D. Beal
1918	F. O. Taylor	G. D. Beal
1919–1921	C. E. Caspari	E. B. Carter
1922–1923	E. B. Carter	E. H. Volwiler
1924–1925	E. H. Volwiler	H. A. Shonle
1926–1927	H. A. Shonle	A. W. Dox
1928	A. W. Dox	A. E. Osterberg
1929	A. J. Hill	A. E. Osterberg
1930	A. E. Osterberg	A. D. Holmes
1931	A. D. Holmes	S. B. Foster
1932	Oliver Kamm	H. C. Hamilton
1933	H. C. Hamilton	John H. Waldo
1934	P. N. Leech	John H. Waldo
1935	John H. Waldo	D. L. Tabern
1936	R. Norris Shreve	D. L. Tabern
1937	D. L. Tabern	Walter H. Hartung
1938	George D. Beal	Walter H. Hartung
1939	Walter H. Hartung	Russel J. Fosbinder
1940	Frederic Fenger	Russel J. Fosbinder
1941	Russel J. Fosbinder	John H. Speer
1942	John H. Gardner	John H. Speer
1943–1944	John H. Speer	Maurice L. Moore
1945–1946	E. F. Degering	Maurice L. Moore
1947	Maurice L. Moore	L. A. Sweet
1948	F. F. Blicke	L. A. Sweet
1949	L. A. Sweet	Glenn E. Ullyot
1950	Kenneth N. Campbell	R. O. Roblin, Jr.
1951	R. O. Roblin, Jr.	M. G. Van Campen, Jr.

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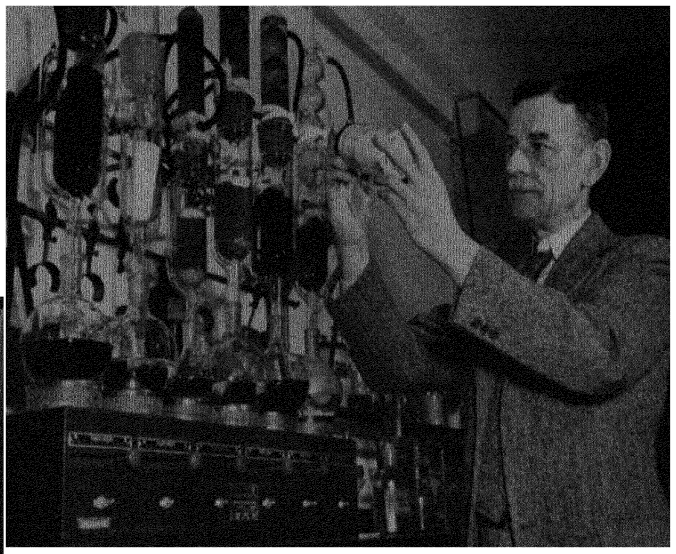
This paper was prepared by a committee of the ACS Division of Medicinal Chemistry consisting of:

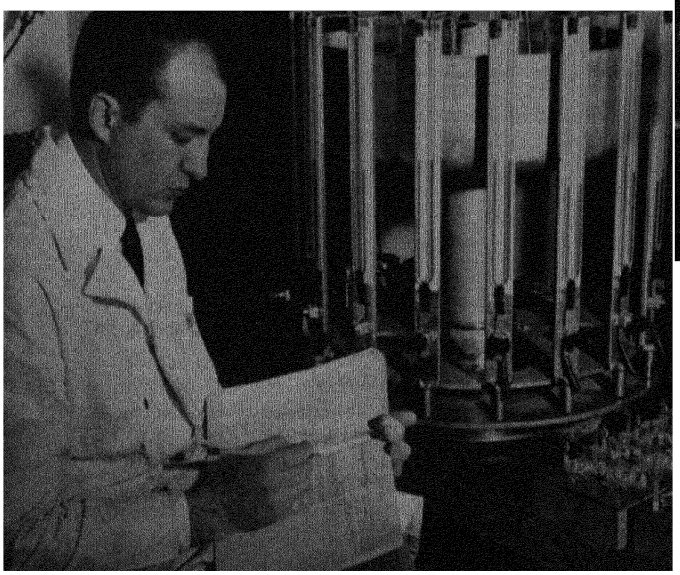
Maurice L. Moore, chairman, Smith, Kline & French Laboratories
Frederick F. Blicke, University of Michigan
Thomas P. Carney, Eli Lilly & Co.
Walter H. Hartung, University of North Carolina
George Rieveschl, Parke, Davis & Co.
Donalee L. Tabern, Abbott Laboratories
Frederick Y. Wiselogle, E. R. Squibb & Sons

and with contributions by:

Gladys A. Emerson, Stanton A. Harris, and Eugene E. Howe, Merck & Co., Inc.
Oliver Kamm and Daniel A. McGinty, Parke, Davis & Co.
William A. Lott, E. R. Squibb & Sons

Standing in front of equipment used to determine rutin in plants, scientist inspects sample from green buckwheat

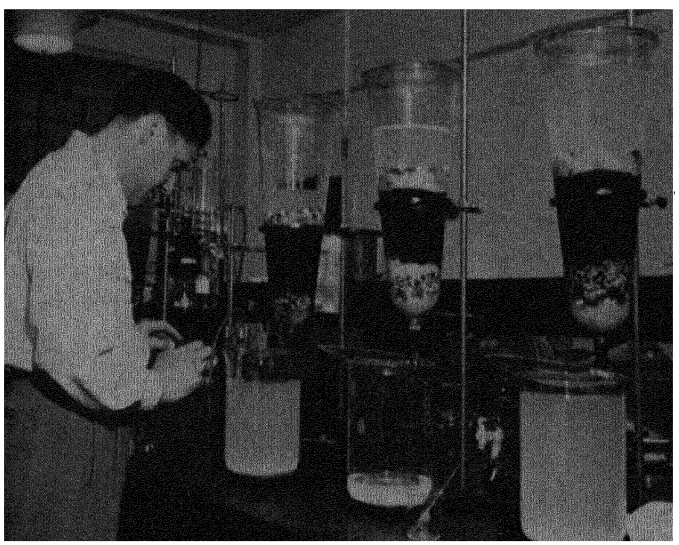




Biological

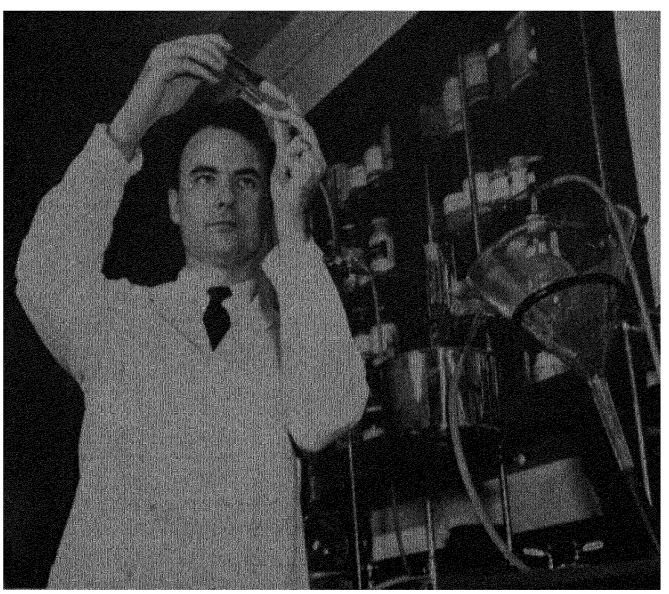
Man's deepest urge is to understand himself and his place in the universe and to fathom his own nature as a living organism

Biochemist at University of Wisconsin studies oxygen consumption of living cells



Purification of pectin by means of ion-exchange resins is investigated at Western Regional Research Laboratory

Department of Agriculture researcher examines two samples of crystalline tomatine obtained from tomato plants



Chemistry

M. X. SULLIVAN

Georgetown University
Washington, D. C.

CHEMISTRY is the field of science that deals with energy changes, the change of matter from one form to another. Because biological chemistry or physiological chemistry, or biochemistry as it is known now, deals with energy changes, growth, repair, digestion, absorption, elimination, and the effect of various agencies on the phenomena of vital activities, normal and abnormal, it is but natural that biochemistry has loomed large in the progress of chemistry from its earliest application.

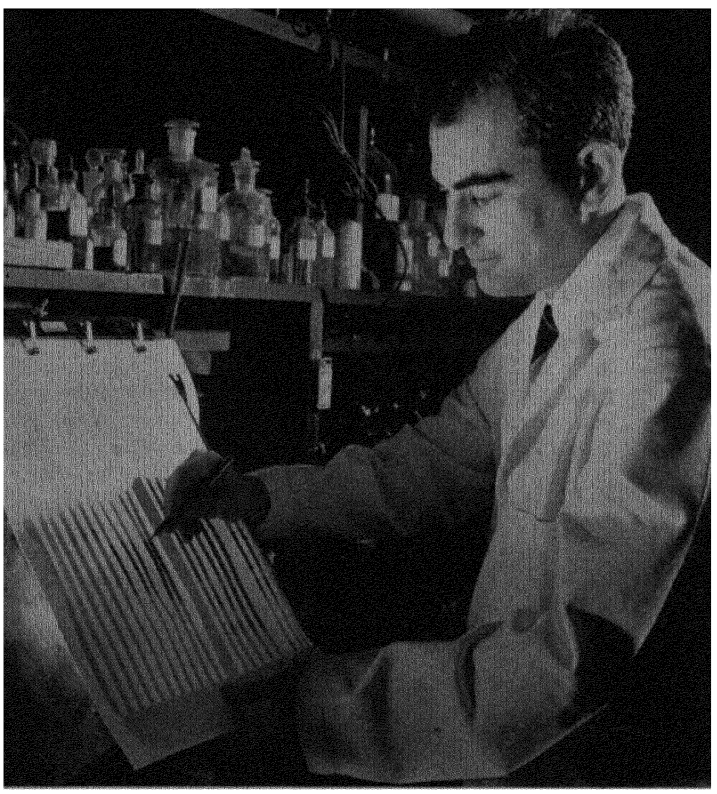
According to Chittenden (*2*), a course in physiological chemistry was early established at the Sheffield Scientific School at Yale University, where Chittenden was appointed professor of physiological chemistry in 1882. This course was designed for the instruction of students who intended to enter medicine. Physiological chemistry was regarded as the branch of chemistry dealing with the composition and reactions of substances having physiological significance, a limited view in the light of present-day studies. In America after 1890 there was a rapid development of physiological chemistry, bound more or less to physiology, which was emerging as an important field of study. In 1887 the American Physiological Society was established. Then in 1906 the separate American Society of Biological Chemists was created, and in 1913 a composite society was formed—the Federation of American Societies for Experimental Biology, which included physiology, biochemistry, pharmacology, experimental therapeutics, and experimental pathology.

With such a group of societies dealing with biochemistry and related subjects, why was there need for the Division of Biological Chemistry in the AMERICAN CHEMICAL SOCIETY? All the societies mentioned were, in the main, for specialists in the field of biochemistry and related studies and gave little opportunity for workers in other fields to present their experimental findings of possible value in solving problems of nutrition, physiology, bacteriology, and medicine. Moreover, the interest in biological applications was growing in many lines of chemistry, especially in physical and organic chemistry.

In the Division of Biological Chemistry, it became recognized that there exists a close relationship between all classes of chemical knowledge and that every branch of chemistry could be applied to the understanding of nature. In this division, men of different backgrounds could find a common interest in applying chemistry, physics, bacteriology, electronics, and what not to the elucidation of vital phenomena. And so, the urgent demand of workers in various fields called for the formation of a Division of Biological Chemistry as a separate division in the AMERICAN CHEMICAL SOCIETY. Many members of the American Society of Biological Chemists became active in the ACS Division of Biological Chemists. To some degree, the division was a preparation for membership in the more specialized American Society of Biological Chemists.

The Division of Biological Chemistry was authorized in 1913. The first chairman was C. L. Alsberg, 1914–17. From the outset, the division was closely related to the Divisions of Agricultural and Food Chemistry and Organic Chemistry, especially the latter. In fact, some of the leaders in the field of organic chemistry, such as Treat B. Johnson, became interested in biological chemistry. For example, Johnson (*1*) said in 1926: "The trend of organic chemistry is gradually toward a consideration of nature as a manipulation of energy. The continuity of all classes of chemical phenomena is being more and more recognized and, as a result, we are seeing the evolution of a new kind of chemistry—biochemistry. This is attracting the attention of some of our best workers in the fields of organic and physical chemistry. In no country is more progress being made today in this new field of chemical science than in America."

It is a glorious fact that the period 1910 to 1950 was an era of remarkable advance. Much progress was made not only in unraveling complex problems in biochemistry but also in opening up numerous new lines of attack. In addition to being an aid to physiology and medicine, biochemistry became a field of independent research aimed at explaining in chemical terms the action of enzymes and coenzymes, the intermediary metabolism of proteins, carbohydrates, and fats, and the nature of vitamins and antibiotics. New instruments of precision were developed and applied to the study of all kinds of reactions pertaining to vital phenomena. The organisms under study were increased in number to include bacteria, molds, plants, animals, and man.



A number of recent biochemical investigations have been greatly simplified by the use of paper chromatography

All this progress did not come suddenly. A firm foundation had been early laid by investigators in Germany, England, and the United States. Emil Fischer by 1908 had determined the structures of the common sugars and of amino acids and peptides, the building stones of proteins. Albrecht Kossel had made great progress in the purines and pyrimidines, and so had P. A. Levene in America; Hans Fischer had deciphered the chemical structure of the blood and bile pigments. Frederick G. Hopkins of England had made advances in the field of nutrition. Casimir Funk had added greatly to the vitamin field, while Jacques Loeb in the United States and Otto Warburg in Germany had stressed the fact that life processes could best be

understood by a study of what was common to all living species—plant and animal cells.

Notable Advances

In the 37 years since the establishment of the Division of Biological Chemistry, changes have come about in the field mainly through the development of more precise and highly specific tests and through the use of better and better instruments of precision. With no attempt to cover the advances in detail, the changes can be roughly indicated by the following:

1. Early analysis depended upon the use of relatively large amounts of material and laborious instrumentation. With time, microanalysis came into play with the introduction of microbalances, microapparatus, and other devices. These instruments required only small amounts of chemical substances—that is, in the quantities that normally occur in living things.

2. In colorimetric work, early tests were relatively nonspecific and instrumentation was comparatively crude. For example, balanced Nessler tubes were employed in color comparisons. Then came the Duboscq colorimeter. Later, with photoelectric instruments, smaller amounts of material could be estimated. By use of suitable filters, extraneous colors could be eliminated and degrees of change on standing could be followed. Finally came the spectrophotometer, which enabled workers to estimate a few thousandths of a milligram with high degrees of precision.

3. In tissue study, early work dealt with tissue in bulk. Modern studies deal with single cells, yeasts, bacteria, and blood corpuscles, and now with portions of a cell nucleus and mitachrondria. These investigations have been made possible by the extended use of precise instruments and by the sharpened outlook of the investigators, who not only accumulated data but also exercised proper judgment in interpreting their research findings.

4. Early work dealt largely with the beginning and end materials of metabolism. Modern work emphasizes intermediates and also the enzymes, hormones, vitamins, and minerals involved. Whereas formerly sugar as a substrate and alcohol or lactic acid as end products were the main components investigated, now most of the various enzymes and coenzymes involved in sugar metabolism (some 20 or more) have been deciphered. Over 10 intermediates have been determined. Even the compounds which play a role in muscle contraction have been discovered and isolated.

5. The action of vitamins was but vaguely understood up to 1920. Now many of them have been isolated and synthesized. Considerable knowledge has been obtained regarding their behavior, even their role as coenzymes and their interplay with antivitamins.

6. Enzymes and viruses have been crystallized. Viruses have been found to be high molecular weight nucleoproteins similar to those found in genes—the minute, fundamental, self-reproducing units of heredity. And now work is under way on the chemistry of the genes.

7. Formerly, carbon dioxide was considered an end product of metabolism—a waste product, in fact. Now, with the help of tracer isotopes, it has been found to play a significant role in synthesis. Thus, when carbon dioxide labeled with isotopic carbon is injected into an animal as bicarbonate, some of the labeled carbon is found incorporated in the glycogen of the liver. By using tagged elements and suitable detection instruments, such as Geiger counters, biochemists have made much progress in following the inner workings of the body. As stated by Meyerhof (*4*), "One may say that the use of isotopes has added a new dimension to biochemical studies; it allows us to follow reactions which cannot be seen by purely chemical means."

The first use of tracer isotopes in the investigation of metabolic reactions was made by George Hevesy in 1926 in his study of how plants absorb naturally occurring radioactive lead. By 1929, E. O. Lawrence had developed the cyclotron, which both he and Milton Livingston utilized to bombard nonradioactive atoms with high-speed particles. Thereby they produced artificial radioactive elements as well as nonradioactive isotopes. The resulting isotopes made possible the detailed study of complex biochemical changes—transamination, transmethylation, analysis, synthesis, and various intermediary changes. This work increased considerably our knowledge of life processes and revised our interpretation of metabolic activities. In the biological application of isotopes, Rudolph Schoenheimer and David Rittenberg were pioneers. In 1935, they began their study with deuterostearic acid; in 1937 they fed rats deuterostearic acid and isolated deuteropalmitic acid. Later, in association with other investigators, they employed N^{15} in the study of protein metabolism.

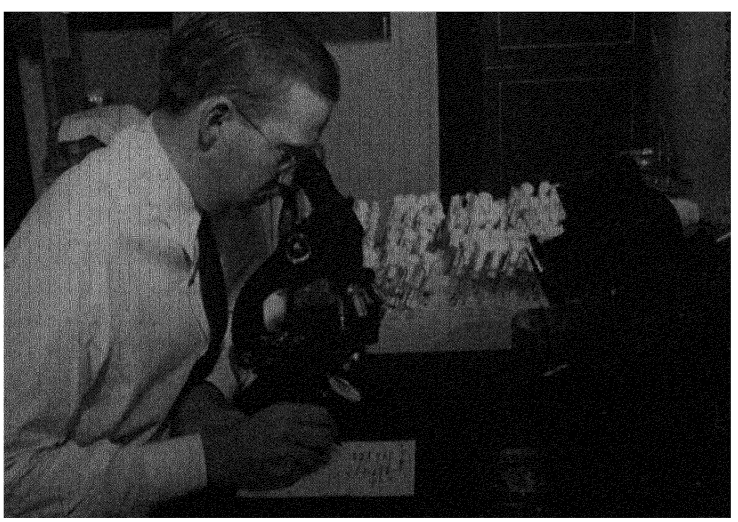
With the aid of isotopes, an interesting finding was made concerning the biological synthesis of cystine. Harold Tarver and Carl Schmidt, using S^{35} methionine in the diet of rats, found that the hair contained castine with radioactive sulfur. In order to determine whether or not methionine contributed the carbon chain to the synthesis of cystine, Vincent du Vigneaud and coworkers synthesized and administered methionine labeled with S^{34} and C^{13}. Cystine isolated from the hair of the rats contained S^{34} but no C^{13}. With the aid of radioactive sulfur in methionine and tagged carbon in serine, it was discovered that the formation of cystine in vivo was preceded by the interaction of homocysteine and serine to form cystathionine. The enzymatic splitting of cystathionine resulted in the production of cysteine which was oxidized to cystine found in the hair.

Many other detailed problems—oxidation-reduction, fermentation, polymerization, phosphorylation, photosynthesis, and the synthesis of fatty acids and nitrogen compounds—have been studied with the aid of tagged elements.

Study of Genetics

One field of biological chemistry that borders on the philosophical is the field of genetics, which has seen much progress in recent years. "Man's deepest urge," said Dobzhansky (*3*) "is to understand himself and his place in the universe—to fathom his own nature as a living organism and the interactions between heredity and environment that shape the development of his body and mind."

The Austrian monk, Gregor Mendel, founded the science of genetics in 1865 with his work on crossed varieties of peas. Studying the color of the flowers and the shape of the seeds, Mendel concluded that heredity was controlled by distinct units or particles transmitted by both parents to their offspring and reassorted in each generation. With the passage of time and



Molds of potential value in the production of antibiotics are studied under high-powered microscope

the efforts of many investigators, the genes were found to be particles of chromosomes. Their chemical nature became the subject of intensive investigation. In America, Alfred E. Mirsky (1943) applied ultraviolet spectroscopy and chemical extraction to the problem and found that the genes are made up of nucleoproteins. The chromosome is now known to possess a definite nucleoprotein structure, the activity of which determines the course of development: Each species has a characteristic gene configuration.

Imitation of genic effects can be produced by external agents—for example, there is a lack of metamorphosis in tadpoles which are fed diets deficient in iodine. Red eye pigments can be produced in insects by administering kynurenine, which is formed from the dietary essential amino acid, tryptophan. Kynurenine is now known to be the necessary component of the Drosophila V^+ gene hormone. In the biochemistry of the genes, we can estimate the effect of at least one biochemical substance on growth, normal and abnormal. Moreover, there is some indication that a study of gene stimulators, retarders, or imitators may lead to the differentiation of cancer tissue from noncancer tissue.

The complexity of the field covered by the Division of Biological Chemistry is well illustrated by the program of last year's 118th national meeting of the AMERICAN CHEMICAL SOCIETY at Chicago, Ill. Some 160 papers were presented, on fats, tracer elements, enzymes, hormones, amino acids, steroids, tumors, cancer, antibodies, toxins, antibiotics, nucleic acids and derivatives, microbiological assays, and chromatography. In addition, there were symposia on steroids and ACTH. The program covered biochemistry, health, disease, and public welfare—a multifaceted exposition of the applications of chemistry and physics to living processes.

Early Contributors

The tremendous growth of biochemistry in many fields makes it difficult to name originators or leaders. However, some mention should be made of a few early contributors.

Russell H. Chittenden, who conducted the first course in physiological chemistry in America, trained a number of research workers and teachers in the field. By studying how the growth curves of young rats are influenced by diet, amino acids, and vitamins, T. B. Osborne and Lafayette B. Mendel added much to our knowledge of what constitutes an adequate diet. Elmer V. McCollum did outstanding work in the vitamin field and in general nutrition.

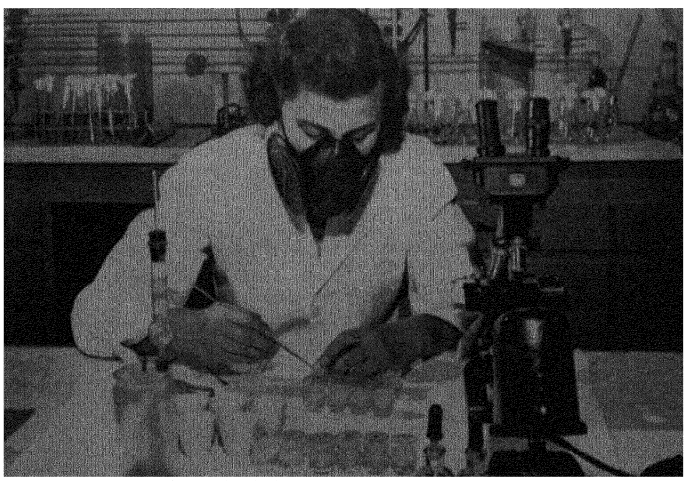
Alfred F. Hess conducted extensive investigations into infantile scurvy and suggested sunlight as a cure of rickets. Harry Steenbock found that irradiation with ultraviolet rays caused inactive vegetable oils to acquire antirachitic potency. Herbert M. Evans discovered the fertility vitamin which B. Sure labeled vitamin E. William C. Rose, by emphasizing the classification of amino acids into those required in the diet and those which are nonessential, added much to our understanding of nutrition.



Photoelectric quartz spectrophotometer is widely employed in the analysis of biochemical compounds



Researcher at National Institutes of Health prepares crystalline residues of sarmentosis glycosides



At Los Alamos Scientific Laboratory, samples containing radioactive carbon are used in tracer research

Otto Folin and Stanley R. Benedict were leaders in developing new methods for rapid analysis of important biological constituents, such as creatine, creatinine, and uric acid. John J. Abel did outstanding work on adrenaline and insulin. W. H. Howell became noted for his study of blood coagulation. Treat B. Johnson was a pioneer in the synthesis of compounds important in plant and animal metabolism. E. C. Kendall, a 1950 Nobel laureate, won acclaim for his work on thyroxin and steroids. Phoebus A. Levene was a master mind in elucidating the structural formulas of nucleic acids. H. B. Lewis, M. X. Sullivan, Erwin Brand, J. A. Stekol, and Vincent duVigneaud added much new knowledge concerning the role of sulfur compounds in health and disease.

H. B. Vickery studied plant and animal proteins. Robert R. Williams *et al.* synthesized vitamin B_1 or thiamine. R. J. Williams isolated pantothenic acid. H. H. Mitchell investigated the biological value of proteins. H. D. Dakin added considerably to our knowledge of chemical reactions in intermediary metabolism and oxidation-reduction. Donald D. Van Slyke developed procedures of great value to biochemists, especially those engaged in the study of blood gases, acid-base balance, and microanalysis. Lawrence J. Henderson was a noted applier of physical chemistry to biological problems, particularly problems relating to blood. P. B. Hawk did excellent work on digestion and is especially noted for his textbook, "Practical Physiological

Chemistry," which has gone through many editions and revisions and is still widely used. In 1932, C. G. King in the United States and A. Szent-Györgyi abroad, independently and almost simultaneously described the preparation of crystalline vitamin C.

Carl P. Sherwin was a pioneer in work on detoxication reactions in the body. Ross H. Gortner was noted for his work on colloids, proteins, and the sulfur compounds in proteins. Walter R. Bloor became an expert in the field of lipoid chemistry. Jesse F. McClenden did much original work on the effect of iodine in treating goiter. Henry C. Sherman, a highly productive worker in the field of nutrition, emphasized the importance of mineral elements in nutrition and the relation of nutrition to health and longevity. W. M. Clark studied the determination of hydrogen ions, as well as the reversible oxidation-reduction of organic compounds of importance in biochemistry. Conrad A. Elvehjem won praise not only for his investigation of nicotinic acid as a cure for black-tongue but also for his excellent work on the relation of various vitamins to nutrition. George Wald and Selig Hecht added to our knowledge of visual purple. Many others could be included among America's most outstanding biochemists.

Officers of the Division of Biological Chemistry, 1914–1951

Year	Chairman	Secretary
1914–1917	Carl L. Alsberg	I. K. Phelps
1918	W. J. N. Osterhaut	I. K. Phelps
1919	Isaac K. Phelps	R. A. Gortner
1920	R. A. Gortner	A. W. Dox
1921	A. W. Dox	H. B. Lewis
1922	H. B. Lewis	J. S. Hughes
1922–1923	J. S. Hughes	W. T. Bovie
1923–1924	W. T. Bovie	R. Adams Dutcher
1924–1925	R. Adams Dutcher	R. J. Anderson
1925–1926	R. J. Anderson	J. J. Willaman
1926–1927	John R. Murlin	Paul E. Howe
1927–1928	Paul E. Howe	M. X. Sullivan
1928–1929	M. X. Sullivan	W. R. Bloor D. Breese Jones
1929–1930	D. Breese Jones	Icie G. Macy
1930–1931	Icie G. Macy	L. A. Maynard
1931–1932	L. A. Maynard	J. B. Brown
1932–1933	J. B. Brown	Robert C. Lewis
1933–1934	Robert C. Lewis	A. W. Rowe R. E. Remington
1934–1935	Roe E. Remington	C. G. King
1935–1936	C. G. King	C. A. Elvehjem
1936–1937	C. A. Elvehjem	W. C. Russell
1937–1938	Walter C. Russell	J. J. Pfiffner
1938–1939	Joseph J. Pfiffner	G. O. Burr
1939–1940	G. O. Burr	Herbert O. Calvery
1940–1941	Herbert O. Calvery	Erwin Brand
1941–1942	B. H. Nicolet	Erwin Brand
1942–1943	H. A. Shonle	Erwin Brand
1943–1944	Elmer M. Nelson	Erwin Brand
1944–1945	Arthur Knudson	Erwin Brand
1945–1946	Arthur Knudson	Erwin Brand
1946–1947	Erwin Brand	John T. Edsall
1947–1948	Erwin Brand	John T. Edsall
1948–1949	John T. Edsall	Paul W. Preisler
1949–1950	M. A. Lauffer	Paul W. Preisler
1950–1951	John T. Edsall	Paul W. Preisler

Recent Investigations

When attention is given to recent work in biological chemistry in the United States, say within the past 10 or 15 years, a bewildering array of worth-while achievements is found. Progress has been so rapid, the fields of attack so widened, and the approach so ingenious, that it is difficult and, in fact, premature to select the most important investigators in the various lines of endeavor. New fields have been developed and old fields markedly advanced—for example, microbiological assay, chromatography, chemotherapeutics, antibiotics, immunochemistry, and the biochemistry of cancer.

While a host of productive workers must be left unmentioned in this brief history, notice should be taken of certain men whose publications within recent years have been significant—Jesse P. Greenstein and Charles Huggins in the biochemistry of cancer; S. A. Waksman, O. Wintersteiner, H. E. Carter, V. du Vigneaud, and R. Dubos in the antibiotic field; Michael Heidelberger and K. Landsteiner in immunochemistry; A. S. Keston, S. Udenfriend, R. K Cannan, S. Moore, W. H. Stein, E. Vischer, and E. Chargaff in chromatography; Esmond E. Snell and W. H. Peterson in microbiological methods for the assay of vitamins and amino acids; the Coris in sugar catabolism and anabolism; L. C. Craig in countercurrent distribution work; R. W. G. Wyckoff in the application of the electron microscope; R. J. Block in amino acid composition of food; and B. C. Knight, J. L. Stokes, V. R. Potter, and D. W. Wooley in biological antagonism and antimetabolites.

One of the striking features of biochemical investigation in the United States has been the cooperative effort among the several related fields of chemistry, physiology, nutrition, bacteriology, and medicine. This cooperation has been especially noted in the investigations of vitamins and antibiotics—their isolation, identification of structure, and physiological action. Jointly, organic chemists, biochemists, and medical specialists have diligently screened innumerable compounds of possible use in offsetting or relieving malaria, tuberculosis, arthritis, cancer, and various allergies. In this cooperative work, a number of manufacturing pharmaceutical firms have played and are continuing to play an outstanding role.

For publication of findings, the biochemist in the United States has been well taken care of by textbooks, review journals, and current periodicals. The *Journal of Biological Chemistry* has long enjoyed a high place in the world biochemistry. Likewise, the newer journal, *Archives of Biochemistry*, is well considered. The *Annual Review of Biochemistry* ably covers current topics. Through its publications, the AMERICAN CHEMICAL SOCIETY has brought together contributions from many divisions of chemistry. Through *Chemical Abstracts*, the world literature is reviewed. With its monographs, the AMERICAN CHEMICAL SOCIETY has done a great service to the wide field of chemistry, particularly biological chemistry. Of some 100 monographs published by the Society up to 1940, 20 have dealt with biological chemistry.

Within a short period, some nine scientists in the United States have been Nobel Prize winners in chemistry and related fields. Of these, seven worked in biochemistry: Doisy, vitamin K; Sumner and Northrop, enzymes; Gerty and Carl Cori, carbohydrates; Stanley, viruses; Kendall, steroids. This outstanding record underscores the statement made by Treat B. Johnson in 1926 that in no country is more progress being made in this new field of chemical science—biochemistry—than in America

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(2) Chittenden, R. H., "Development of Physiological Chemistry in the United States," ACS Monograph 54, New York, Reinhold Publishing Corp., 1930.
(3) Dobzhansky, Theodosius, *Sci. American*, 183, 55 (1950).
(4) Meyerhof, Otto, *Ibid.*, 183, 62 (1950).

Water, Sewage, and Sanitation Chemistry

Industry's indispensable raw material, water, rightly demands the constant vigilance of the chemical profession

A. M. BUSWELL

State Water Survey Division, Urbana, Ill.

CHANGES IN PURITY STANDARDS FOR DRINKING WATER

A. M. BUSWELL

IN 1880, the National Board of Health began an extensive study of tests which had been proposed up to that time for detecting pollution in water. The work was under the direction of J. W. Mallet, and one of the analysts was W. A. Noyes, then a graduate student at Johns Hopkins, later to become Secretary and then President of the AMERICAN CHEMICAL SOCIETY.

The results of this investigation were published in 1883 as the annual report of the board for 1882. The introduction conveys the notions which prevailed in the field of sanitation at the time. Mallet was convinced that the danger of pollution lay not in some chemical substance capable of causing disease but rather in the presence of living organisms in the organic matter carried by these waters.

One of the earliest tests for such organic matter was the effect of heat on the evaporated residue. In reviewing the previous literature on this test, Mallet quoted from Angus Smith, who expressed remarkable confidence in his ability to judge the quality of water by the appearance and odor of its burning residue. He claimed to "detect humous and peaty acids, nitrogenous organic substances, and nitrites," "to estimate their amount to a very useful point of accuracy," and to distinguish their "animal or vegetable origin."

The tests for nitrates, nitrites, chlorides, and ammonia were in use in substantially their present form, but the principal interest centered around the determination of carbon and albuminoid nitrogen. The Mallet report was, therefore, concerned mainly with a comparison of the combustion process advocated by Frankland and Armstrong, the permanganate process developed independently by Kubel, Schultz, and Tidy and the albuminoid process of Wanklyn. The combustion method consisted in determining the carbon and nitrogen in the

leakage of drains.

5. Local standards of purity based upon sufficiently thorough and repeated examinations may be established.

6. Careful determination of nitrites and nitrates in drinking water is extremely important.

7. In judging a large-city water supply, it would be wise to use all three methods considered for determining organic matter, and in no case should only one be used.

Early Bacteriological and Biological Work

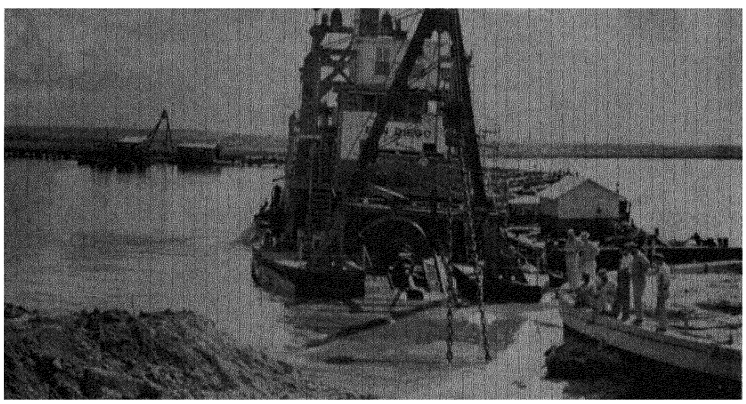
Mallet attempted to correlate bacteriological examinations with the chemical data, but the methods available were so cumbersome as to discourage routine examination. The status of bacteriological water examination in 1880 is indicated by the experiments of the German biologist, Emmerich, who tested polluted waters by swallowing them himself, by feeding them to animals, or by injecting animals subcutaneously with concentrates of polluted samples. Although he found that water generally considered unwholesome or even dangerous could often be drunk with impunity by one in good health, he produced fever and even death in animals by subcutaneous injection of concentrates.

Following the current practice, the biological portion of the work, under the direction of Martin, Sternberg, and Hartwell included a microscopical examination, culture studies, and pathological experiments.

For the microscopical examination, 200 ml. of the total sample were treated with 1 ml. of 1% osmic acid on the day of arrival, then set aside for the examination of sediment with and without staining (aniline violet) on the following day. The water was examined for organisms when received, and after a few hours' standing the deposit (if any) was examined with and without staining. Then, after thorough mixing of the sample, several specimens were evaporated to dryness and the residue was examined with and without staining.

For culture study, 1 liter of a water sample was evaporated at a low temperature to about 5 ml. without risk of contamination from the air and within a moderate time by a special low-temperature reduced-pressure method.

After filtration, part of the concentrated residue was inoculated with a tiny drop of a stale-hay infusion, containing a large variety of bacterial organisms. Part of the inoculated liquid was placed in an hermetically sealed flask and placed in a warm chamber at 40° C. The rest was put in the refrigerator. Next



Hydraulic dredge is used to excavate for river pumping station near chemical plant

Consequently, analysts of that time were deterred from undertaking routine biological water analyses.

Development of Standards for Illinois

During the next 30 years, various laboratories developed their own chemical standards for potable waters. These were applicable within the region for which they were developed. C. W. Mason (1910) summarized the commonly accepted standards in the eastern part of the country, and European practice was discussed by J. C. Thresh (1913) in their texts on water examination.

The development of chemical standards in Illinois is typical of this work. The first systematic study of water quality in Illinois was undertaken by A. W. Palmer, head of the department of chemistry at the University of Illinois, in 1895. On the basis of 1787 analyses completed up to December 1896, the Palmer standards of water purity for the immediate locality were published in 1897. They were prefaced by the following comment:

> Because of differences due to the nature of the strata from which waters are drawn or with which they have been in contact, the topography of the district, and the general environment of the sources, no fixed standards of purity for any and all potable waters can be justly established, yet for purposes of comparison, and for the information and convenience of those receiving our reports, the following limits have been provisionally adopted for ordinary shallow wells in the State of Illinois.

The maximum limits of impurities were stated as: total solids

500 p.p.m., no blackening or offensive odor on ignition of the residue, oxygen consumed 2.0 p.p.m., chlorine (as chloride) 15.0 p.p.m., nitrogen as free or saline ammonia 0.02 p.p.m., nitrogen as albuminoid ammonia 0.05 p.p.m., nitrogen as nitrites 0.001 p.p.m., nitrogen as nitrates 15.0 p.p.m.

The formation of a reasonable and just opinion regarding the wholesomeness of a water requires that all the data of the analysis be considered with the history of the water, the nature of the source, the character of the soil and earth or rock strata, and the surroundings. This is a task for the expert.

The Palmer standards were revised by Edward Bartow in 1907 in the last attempt to correlate chemical data with dangerous pollution. Bartow found it necessary to set up five different sets of limits and to include the newer bacteriological test as well.

By the turn of the century, the science of bacteriology was beginning to develop analytical techniques of increasing reliability. Within the next 20 years, these methods largely superseded the chemical tests for water safety, although the chemical determinations are still used in evaluating the amount of foreign matter present and the control of treatment processes. The development of bacterial standards was the result of the cooperation of laboratories from all parts of the country. This cooperative work is recorded in the successive reports of the Committee on Standard Methods of the American Public Health Association and the American Water Works Association.

By 1912, the 37° C. count on agar had been substituted for the 20° C. count on gelatin. Through the work of D. D. Jackson and others, lactose had been substituted for glucose in the fermentation test. Within the next decade, the use of sample volumes in geometric series was to be replaced by the use of a number of samples of equal size, which was shown to give a much lower probable error in the degree of pollution indicated.

Evolution of National Standards for Drinking Water

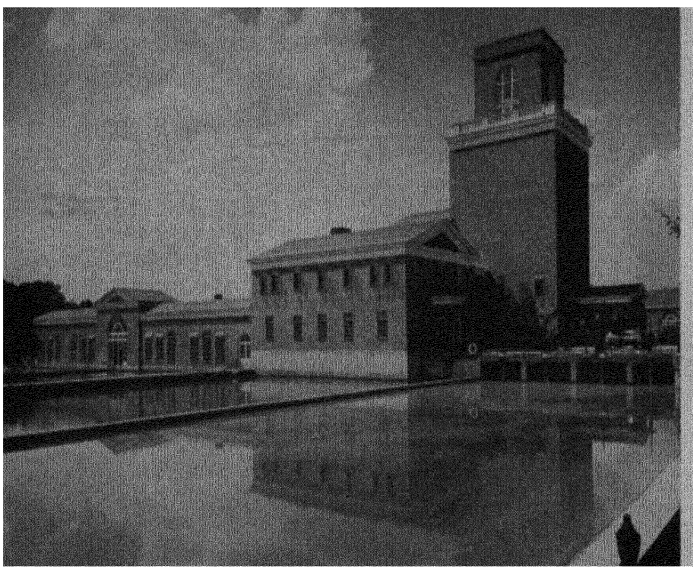
One year after the formation within the AMERICAN CHEMICAL SOCIETY of the Division of Water, Sewage, and Sanitation Chemistry and the formation within the American Water Works Association of a chemical and bacteriological section, the first bacteriological standard for drinking water was adopted by the Treasury Department on October 21, 1914. Fifteen of the leading chemists, bacteriologists, public health experts, and sanitary engineers of the country were its authors. Its specifications were designed only for drinking water supplied to the public by common carriers in interstate commerce.

The new standard was in no sense intended as a definition of purity; rather, it established "the furthest deviation from purity considered permissible," so that the health of the public could be protected, the prescribed quality of supply could be obtained without prohibitive cost, and the process of examination would not be too cumbersome. Because of the practical difficulty of securing first-hand information regarding the source and handling of supplies as offered to the public, it was necessary to rely almost completely on the information given by laboratory examination. Chemical impurities were considered of minor sanitary importance (in line with Mallet's thought some 30 years before). The definition of bacterial limits of impurity, on the other hand, was more readily accepted because of the greater knowledge of the disease-producing hazard of certain bacteria.

The standard was accordingly defined in terms of the total bacterial population and the prevalence of *B.(E.) coli*, while culture media and methods of detection and identification were specified to be those of "Standard Methods of Water Analysis," APHA 1912.

In May 1922, the new Surgeon General called for a revision of the 1914 standards. Indicative of the importance attached by that time to drinking-water standards, the advisory council included representatives of six federal departments, of ten scientific societies, including the ACS, AMA, AWWA, and AOAC, and 20 members-at-large, all experts in chemistry, bacteriology, sanitation, or public health.

The keynote of the new standards promulgated in June 1925 was safety. A satisfactory water was defined as "clear, colorless, odorless, pleasant to the taste" and containing no excessive amounts of soluble mineral substances nor of chemicals employed in treatment. Quantitative limits were set on turbidity and color. Concentration limits (with quantitative methods of analysis) were established for mineral substances naturally occurring in waters and for chemicals used in water treatment. Whereas in 1914 it was questioned "how far it is justifiable to tax the carriers to eliminate impurities whose deleterious effects are so doubtful," the early concern for expense and for the unpopularity of laboratory examination was gone, and the presence of lead, copper, or zinc in excess of prescribed limits was now recognized as grounds for rejection of a supply.



The Dalecarlia purification plant supplies Washington, D. C., with a large share of its water



Sand filter plant for water purification was installed by Washington Sanitary Commission at Burnt Mills, Md.

The bacteriological standard was changed to include only the test for organisms of the *B.(E.) coli* group (according to "Standard Methods," 5th edition, 1923) as being the most highly specific test and giving the most information as to fecal pollution and the potential presence of other pathogens from the intestinal tracts of diseased persons. The statistical basis for the technique of establishing both the limiting values for the mean density of *B.(E.) coli* and the allowed range and frequency of deviation from this mean was carefully and clearly treated with graphs in an appendix. In contrast to this degree of detail, neither the total number of samples to be submitted nor the intervals of collection were defined, both being left to the judgment of the certifying authority.

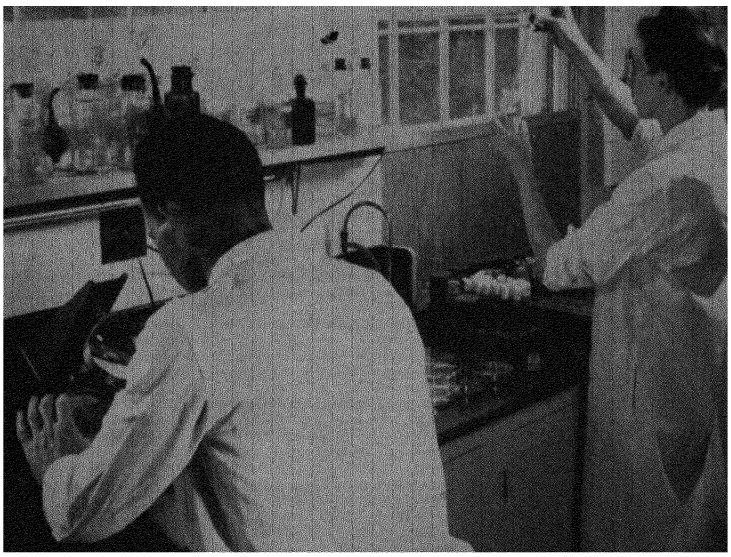
A further revision of drinking water standards was undertaken in 1941. The first report of the committee was found unworkable. Further study resulted in the present standards which date from February 1946. At this time, requirements as to the source and protection of a water supply and the condition of the entire water-supply system were established. The newer bacteriological sampling techniques based on statistical analysis and interpretation were redefined. The minimum number of samples, the collection, and the location of sampling points were respecified in terms of the population served. Because these standards are still in effect today, are nationally accepted, and are probably the highest national standards in the world, they deserve mention.

The chemical characteristics of a certifiable water were defined as: (*a*) the absence of any excessive amount of soluble mineral salts and of any chemicals used in treatment; (*b*) limiting concentrations of potentially poisonous elements as follows: lead 0.1 p.p.m., fluoride 1.5 p.p.m., arsenic 0.05 p.p.m., selenium 0.05 p.p.m., hexavalent chromium 0.05 p.p.m., with salts of barium, hexavalent chromium, heavy-metal glucosides, or other substances physiologically harmful being barred from use in drinking-water supplies; (*c*) limiting concentrations of undesirable elements where other more suitable supplies were available as follows: copper 3.0 p.p.m., iron and manganese together 0.3 p.p.m., magnesium 125 p.p.m., zinc 15 p.p.m., chloride 250 p.p.m., sulfate 250 p.p.m., phenolic compounds 0.001 p.p.m. in terms of phenol, and total solids 500 p.p.m. (or in the absence of a better supply up to 1000 p.p.m.). For chemically treated waters—i.e., lime-softened, zeolite, or other ion-exchange treated waters, or waters subjected to any other chemical treatments—the following three requirements are prescribed: (*a*) that the phenolphthalein alkalinity (calculated as $CaCO_3$) be not greater than 15 p.p.m. plus 0.4 times the total alkalinity, which limits the permissible pH to about 10.6 at 25° C.; (*b*) that the normal carbonate alkalinity not exceed 120 p.p.m., which can be accomplished (since the normal alkalinity is a function of the hydrogen ion concentration and the total alkalinity) by keeping the total alkalinity within the limits suggested below when the pH of the water is within the range given;

pH Range, 25° C.	Limit for Total Alkalinity (P.p.m. as $CaCO_3$), 25° C.
8.0 to 9.6	400
9.7	340
9.8	300
9.9	260
10.0	230
10.1	210
10.2	190
10.3	180
10.4	170
10.5 to 10.6	160

(*c*) that if excess alkalinity is produced by chemical treatment, the total alkalinity not exceed the hardness by more than 35 p.p.m. (calculated as $CaCO_3$).

Up to this time, these standards had been considered only in their application to water supplies of common carriers in interstate commerce. The 1946 revision was unique in that it contemplated for the first time the use of a standard for water quality



Laboratory technicians conduct precise tests to determine the quality of drinking water

generally acceptable and applicable to all public water supplies in the United States. The publication carried the full endorsement of the AWWA, which after study of the text resolved that it be voluntarily accepted by the association as the standard for all public water supplies. The association recommended that state boards of health and their sanitary engineering personnel, in constructive cooperation with water works management, make every effort to conform to these standards. The high quality of drinking water in the United States today is in no small way the result of the vigilance and the scientific cooperation of the AMERICAN CHEMICAL SOCIETY, which throughout the development of these standards has been consistently represented on every advisory committee for revision.

DEVELOPMENT OF ANALYTICAL METHODS

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THE most significant advance in theoretical chemistry from the standpoint of water was the new concept of hydrogen ion concentration, because this involved the ionization of water itself. In the practically simultaneous announcements by E. W. Washburn (1908) and S. P. L. Sorensen (1909) of the difference between titratable acidity and pH, the buffering properties of weak bases and weak acids were explained. The importance of this concept to coagulation, corrosion, and culture studies is obvious. There followed the colorimetric methods for determination of pH and later their standardization against the electrometric measurement of pH for culture media. Today in chemical work, the electrometric measurement of pH has almost entirely replaced the use of indicators.

The chemistry of the nitrogen determinations was explored in a sizable body of research, but in view of biochemical developments, these determinations were not of as great importance as once might have been thought. Certain inaccuracies and inconsistencies in the determinations of free and albuminoid ammonia were explained and rectified by the use of a phosphate buffer at constant at pH of 7.4 in place of sodium carbonate added before distillation. The colorimetric determination of nitrites

on treatment with sulfanilic acid followed by 1-naphthylamine and the determination of nitrates by treatment with phenol disulfonic acid were given extensive study with respect to the chemistry of the reaction, interference effects, and sensitivity. The formation of free chlorine by oxidation of the chloride ion present with the nitrate led to the use of alkaline reduction of nitrates with aluminum and sodium hydroxide when chloride concentration was high. However, in the case of highly polluted waters, the use of strong alkali makes this method unreliable because of the hydrolysis of urea.

Almost all public water supplies depend on the *o*-tolidine test for safety. Though the chemistry of the reaction between residual chlorine and the *o*-tolidine reagent is not complicated, the critical importance of this test to the safety of public water supplies has warranted much research to increase its reliability. The reaction is essentially an oxidation. Therefore, any ions present which have the proper oxidation-reduction potential to oxidize the *o*-tolidine reagent constitute an interference and source of false results. Also, the presence of nitrite, if high enough, may be sufficient to consume completely the amount of residual chlorine usually considered adequate protection. Coupled with this is the fact that nitrite itself, given sufficient reaction time, will develop a yellow color with *o*-tolidine, creating a false residual and hence a real hazard. The development of green, blue, and red compounds instead of the characteristic yellow was a confusing aspect of the test until it was known that blue was characteristic of very alkaline samples and represented insufficient acid present for complete oxidation to the yellow compound. Moreover, the red was indicative of insufficient *o*-tolidine for the amount of oxidizing agent present. This resulted in the formation of a chloride derivative of the yellow holoquinone. The yellow color caused by the nitrite was traced to diazotization followed by coupling with more *o*-tolidine, a reaction which could be reversed to the colorless diazonium salt by excess acid. The search for a reagent more specific to chlorine and giving a stable color development revealed that *o*-tolidine was the best to be found. The elimination of interference, the effect of pH, the order of addition of the reagents, the *o*-tolidine–chlorine and the acid–*o*-tolidine ratios, and the temperature effect have all been studied and these results incorporated in the procedure in the latest "Standard Methods" (1946). When it was found that the copper sulfate-potassium dichromate standards being used were no spectrophotometric match for the true yellow of the *o*-tolidine reaction, new standards of potassium chromate-dichromate were introduced. These were practically a perfect match both spectrophotometrically and visually. The meaningless results which came from using the method for low residuals on waters with high residuals led to the development of the drop dilution method (which uses a sufficiently small sample to give a residual of only 1.0 p.p.m.) and the equal volume method (which uses a sufficiently large amount of the *o*-tolidine reagent to react with the amount of oxidizing agent present).

Chloramines react more slowly with the *o*-tolidine reagent but give the same yellow holoquinone. The necessity for distinguishing chloramines from free chlorine led to the development of the *o*-tolidine–arsenite test, which measures the free available chlorine by removing interfering substances with arsenite and then allowing only 5 seconds for the reaction with *o*-tolidine, whereas 5 minutes are required for the chloramine reaction. The success of this test depends upon a rigorous adherence to the details of the procedure. A recent study of this reaction notes the interference of hydrochloric acid when used as the acidifying agent but lists a number of correction factors which, if applied, allow the determination of the true free chlorine concentration from the results of the *o*-tolidine–arsenite test.

Recently, a number of dangerous explosions in central Illinois were traced to methane in water supplies. Accordingly, a method was devised for the detection of methane in water supplies. In addition, safety-limit concentrations and corrective measures were prescribed, based upon consideration of the behavior of dissolved gases and the nature of water supply systems and storage reservoirs.

Probably the most significant recent advance in methods of water analysis is the widespread adoption of instrumental techniques. Two instruments in particular are making possible greater precision in shorter working time: the photelometer and the flame photometer.

The photelometer, then known as the photoelectric hemoglobinometer, was designed in 1929 by Sanford and Sheard as a means of determining the hemoglobin content of blood samples. Measurement was made of the percentage transmission of light, according to Lambert's law. Today maximum sensitivity of the instrument is produced by the use of a filter whose transmission band is as close as possible to that of the material in solution, so that practically all light which does not change in intensity with concentration is screened out. Thus, small differences in concentration cause noticeably different and reproducible readings. The simplicity and the accuracy of this technique gave considerable impetus to the development of colorimetric methods to replace some of the long and tedious gravimetric determinations. Copper, iron, chromium, arsenic, potassium, magnesium, tannins, orthophosphate, and silica can now all be determined in water by use of the photelometer. It has been a particular boon in the case of silica, which has become very important in scale and corrosion studies. Such studies have been necessitated by the conditions which exist in the new higher-pressure boilers, which require in general more attention to the quality of boiler feed water.

For some years, flame photometers were not susceptible to the degree of accuracy required by most analysts. However, persistent research has explored most of the troublesome aspects of interference effects and has both encouraged improvement in the construction of the instrument and brought to light interferences which were previously unsuspected. Increased knowledge of the instrument and of the precautions which are a part of intelligent operation is making possible the rapid and precise determination of sodium, potassium, lithium, and calcium on very small samples which require no previous preparation.

The abandonment of the "temporary hardness" determination has eliminated many misleading or meaningless data. Various attempts to improve the soap-hardness test were not sufficiently successful, but the versenate-hardness test seems to provide a satisfactory, rapid method for hardness determinations.

The B.O.D. determination for pollution load has been the subject of many important papers before the Division of Water, Sewage, and Sanitation Chemistry, and the reproducibility and accuracy of the test have been greatly improved.

CHEMISTRY AND SEWAGE TREATMENT

F. W. MOHLMAN
Sanitary District of Chicago, Chicago, Ill.

CONDITIONS of filth and disease became so rampant in England that finally the use of water to dispose of sewage was introduced early in the 19th century. But although this was a great advance in convenience and safety, new difficulties developed. The classical references to the condition of the Thames and the Rhine indicate that there also existed the urgent need for effective ways to dispose of sewage prior to its discharge into streams.

A Royal Commission was established in England in 1857 and several others continued their studies of the problem until the turn of the century. Frankland was the leader in these early investigations, before the germ theory of decomposition was fully established. Because of a general lack of understanding, chemical methods of precipitation were developed, in which lime, alum, ferrous sulfate, ferric salts, zinc salts, and—of all combinations—alum, blood, and charcoal (ABC) were used as precipitants. Acting as adsorbents, other inert solids were added, notably clay, marl, paper, and peat.

However, unable to stabilize the putrescible organic matter, these costly processes fell into disrepute. When biological methods of treatment were discovered and evaluated by the Royal Commissions, chemicals were almost entirely abandoned and such processes as contact beds, trickling filters, and sand filters supplanted the methods then in vogue.

The Royal Commission of 1857 was followed by others in 1868, 1882, and 1898. Frankland turned to biological filters but without much success. At Lawrence, Mass., the State Board of Health started experiments in 1886. This date marks the birth of sand filters, contact beds, and trickling filters in the United States. All conceivable combinations of depth, area, size of stone, and rate of dosing were studied, and by 1900 biological filters were well established in America.

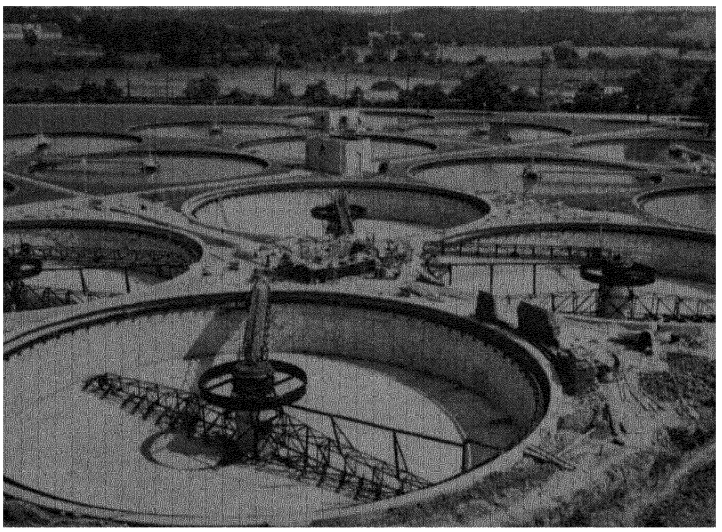
One of the most impressive results of this development was the discovery of the role of nitrification in stabilizing sewage. In fact, nitrification was considered absolutely essential to satisfactory sewage treatment, and not until after 1930 did sewage technologists agree that stabilization might be possible with little or no nitrification.

The use of contact beds never became very common in the United States, but intermittent sand filters dominated the scene in Massachusetts and wherever suitable sand could be found. Trickling filters became the most approved type of treatment by 1910, but flow rates of less than 3 million gallons per acre per day were adopted. Moreover, complete nitrification was expected in summer by the use of such installations. The large areas that were required created concern, but no investigator had the temerity to suggest that higher rates might be possible.

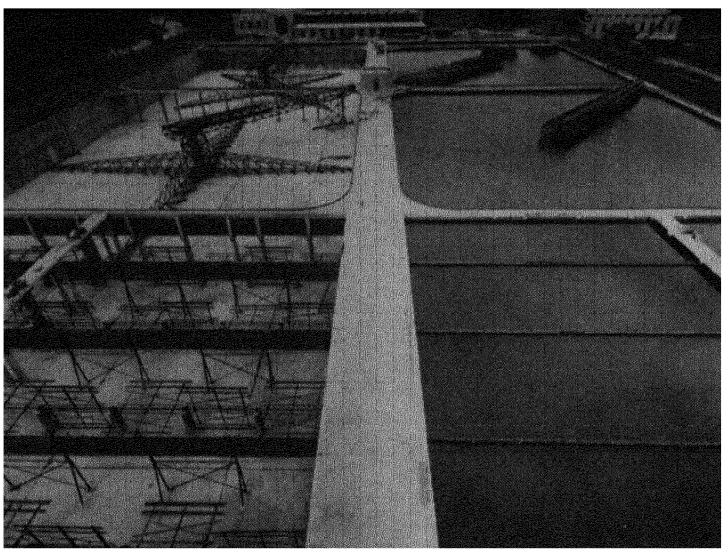
The introduction of the activated sludge process in 1913, following its discovery by Ardern and Lockett at Manchester, England, completely overturned American practice. In America, this process was much more fully developed than in England, and soon America was dotted with activated sludge plants. The fine effluent, the high capacity despite small areas, the freedom from odors and flies, and the simple mechanical control of the operation so captured the fancy of American engineers and chemists that all other processes declined and filters were well-nigh forgotten.

However, early enthusiasm for the activated sludge process was tempered when the difficulties of sludge disposal were recognized. Activated sludge was very low in solids content, averaging only 1 to 2%. Before the process could be considered a success, much research had to be done to improve the disposal of the sludge which accumulated in large quantities. Milwaukee pioneered in studies in pH control and heating in the pretreatment step before vacuum filtration. However, filtration was made practical only after the superlative value of ferric chloride as a conditioner was discovered in Chicago in 1927. Now all activated sludge plants use this chemical for dewatering undigested activated sludge.

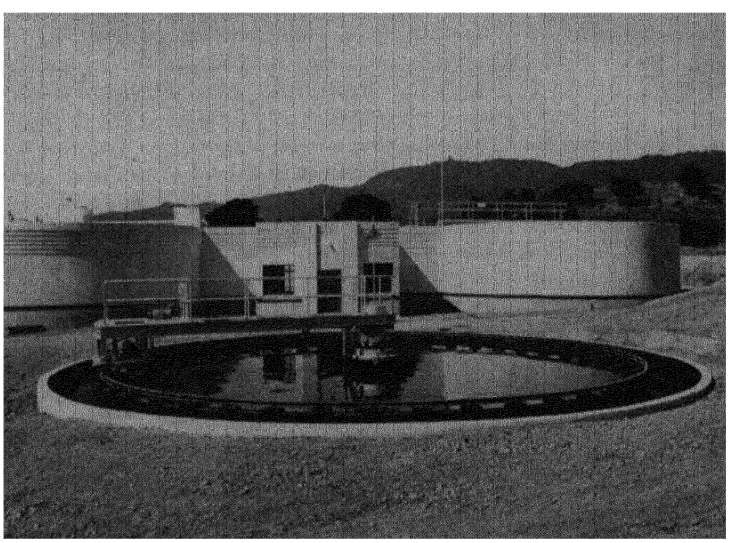
"Digestion" is a magic word in sewage disposal development. Ever since Imhoff tanks were installed in America in 1909, the advantages of digestion in the disposal of sludge have been recognized. Digestion changes the foul, greasy character of fresh sludge to homogeneous, gas-filled, loamlike solids which will air-dry quickly and without odor. The digestion process, accomplished by anaerobic methane-producing bacteria, gives off



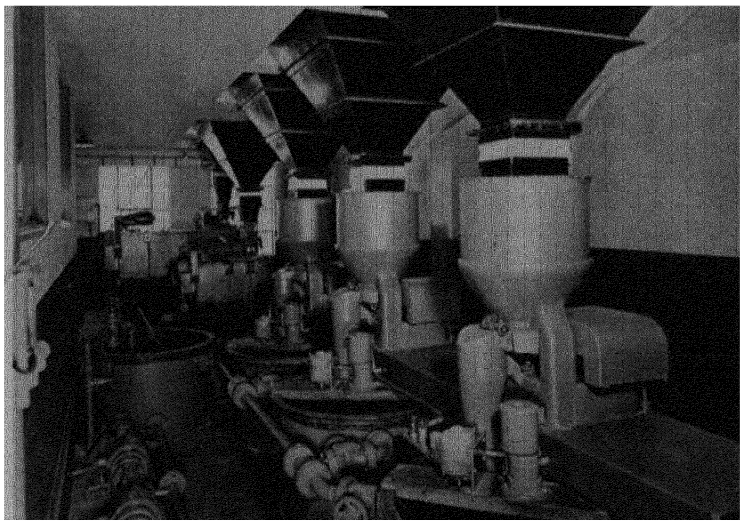
Increased city population required the installation of four new sedimentation tanks at sewage plant



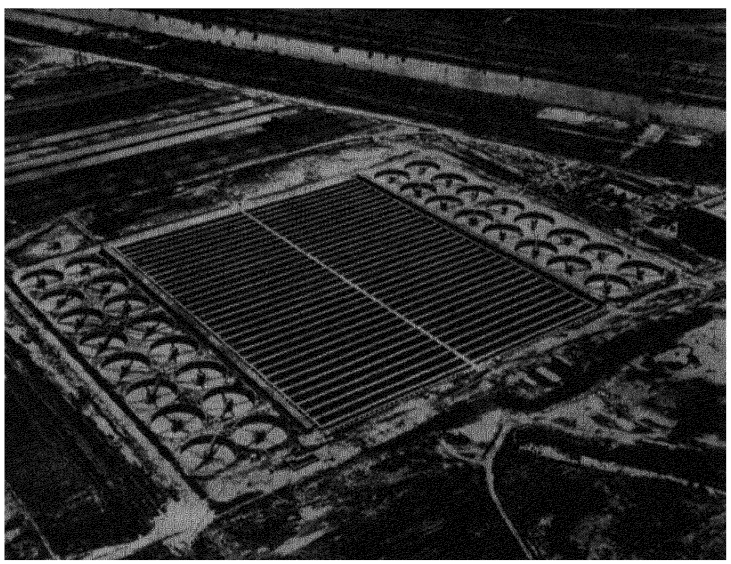
By introducing gelatinous solids into turbid water supplies, flocculator improves settling and filtering characteristics



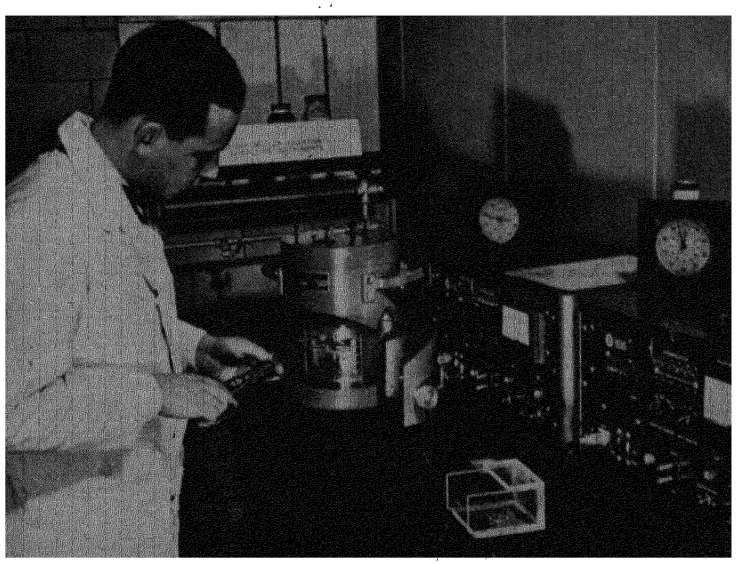
In foreground is automatic magnetite filter at the Eldridge, Calif., sewage works; clarifier and digester in background



Section of the Clayton sewage plant in Atlanta, Ga., contains a battery of chemical feeders



Activated sludge plant in Chicago Sanitary District has capacity for 400 million gallons of sewage a day



Studying atomic energy wastes, research assistant removes radioactive specimen from its lead container

weights of gas equal to or actually greater than the weight of organic matter destroyed, and this gas has been used to heat the digesters and run gas engines which, in turn, light and heat sewage disposal plants. The production of gas and the advantages of heating sludge were well established in America, notably by chemists Buswell and Rudolfs, and by the extensive research carried on in Illinois and New Jersey. Today digestion is standard practice in the disposal of sewage solids, unless certain cities elect to filter and dry activated sludge for sale as fertilizer or to be burned as fuel.

The fertilizing value of activated sludge is well established by its content of 6% nitrogen and 3% phosphorus pentoxide. Digested sludge, on the other hand, contains about half this content of fertilizer constituents and is suitable only for disposal as a dry filler or compost. However, this use is adopted in some cases, although the material is too low grade to warrant shipment for any great distance. For local disposal, even the wet sludge is useful, but its value hardly equals the cost of disposal.

The waste disposal problem has become a paramount concern of industrial chemists. The importance of treating wastes from industry is recognized as being almost equal to the importance of sewage treatment, if our streams and lakes are to be maintained in decent condition. Industrial chemists are developing such processes as neutralization of acids, precipitation of solids, screening of food products wastes, and biological treatment of liquids, in efforts to eliminate the undesirable qualities of industrial wastes. Notable examples are the plants of the Dow Chemical Co., Calco Chemical Division of American Cyanamid Co., Celanese Corp., American Viscose Corp., Upjohn Co., and Lederle Laboratories. Many other chemical manufacturing plants neutralize, stabilize, or evaporate their wastes inside the factory and thus do not have to install final treatment plants. These companies include Du Pont, National Aniline, Corn Products, Commercial Solvents, Koppers, and various distillers or alcohol manufacturers.

Industry's acceptance of its responsibility for proper waste disposal has developed largely during the past 20 years. During this same period, sewage disposal engineers have markedly improved one of the basic biological methods of treatment. The old stereotyped trickling filter has been streamlined and now is in common use at rates five to 10 times higher than those employed formerly. This process is moving to the forefront and now is almost on a par with the activated sludge treatment in terms of space requirements, freedom from odor and flies, and, to some extent, quality of effluent. Chemists and bacteriologists found that continuous, rather than intermittent, dosing of stone beds is feasible and that, except for nitrification, almost comparable effluents can be produced. The theory is that the sewage should be applied continuously to the entire surface of the filter in a raindrop type of spray, rather than intermittently at higher rates. This theory seems to be substantiated, and the high-rate filters appear to be well adapted to organic types of industrial wastes.

Some development of high-rate anaerobic digestion of concentrated organic wastes has occurred, although such treatment still resides in the experimental category. Because of the large tank capacities required, this process is rather expensive.

Chemists still have many unsolved problems ahead, particularly those involving the disposal of wastes from atomic energy plants. This is a momentous problem, but it is being attacked widely and thoroughly and does not appear unsurmountable. So far, the methods adopted have proved their worth. Those who have worked or lived among the wastes have done so with almost complete safety. This criterion may be modified as time elapses, but in the meanwhile there is evidence that processes will be available in time to prevent danger from untreated subatomic wastes.

Chemists thus are challenged by many unsolved problems, but the notable advances during the past 75 years permit the confident forecast that future progress will continue at an accelerated pace.

WATER SOFTENING

A. S. BEHRMAN, Chicago, Ill.

By definition, water softening is the art of removing (or modifying) those substances in water which make it hard—that is, difficult to form a lather with soap. Essentially, therefore, water softening is the art of removing calcium and magnesium ions.

The two principal methods of removing calcium and magnesium ions from water are precipitation and ion exchange. The most common and most expensive example of a precipitation process is the metathesis which is employed when one attempts to make a lather using a hard water and an ordinary sodium soap; the soap is wasted until enough has been added to precipitate the insoluble soaps of calcium and magnesium.

The most important commercial precipitation process, however, is the lime-soda process, in which carefully controlled amounts of lime and/or soda ash are employed to precipitate the calcium in the raw water as calcium carbonate, and the magnesium as magnesium hydroxide. The residual hardness is determined chiefly by the solubility of these two compounds under the conditions employed in the precipitation.

Precipitation of calcium and magnesium as highly insoluble phosphates, usually by means of trisodium phosphate, is also practiced. Because of chemical and cost limitations, this method is employed chiefly for household use or for the internal treatment of relatively soft waters in steam boilers (including those waters already softened by the lime-soda method).

In the ion exchange method of water softening, the calcium and magnesium ions are replaced with sodium ions. The reagent is an insoluble, highly porous, resinous or siliceous solid material which has the surprising power of exchanging adsorbed sodium ions for calcium and magnesium ions in the hard water. When the readily available supply of adsorbed sodium ions has been exhausted, the material is regenerated with sodium chloride, which drives out the calcium and magnesium ions and puts in a fresh supply of sodium ions. Under normally favorable conditions, the residual hardness of water softened in this manner is substantially zero.

This method of softening water by ion exchange—i.e., cation exchange—was known until recent years as the "zeolite" or "base exchange" process. The advent of organic materials for cation exchange and for anion exchange has led to increasing acceptance of the generic term "ion exchange."

A very small, but important, fraction of the total volume of water softened utilizes the principle of "sequestration." In this case, the calcium and magnesium are not removed from the water, but are sequestered as complex ions, in which form they cannot react with the fatty acid anions of sodium soaps. The most commonly used sequestering agents are the polyphosphates, such as sodium hexametaphosphate, sodium tripolyphosphate, and tetrasodium pyrophosphate; but organic agents, such as certain polyamino acids and their salts, are beginning to attract considerable attention.

An obviously effective method of water softening, which is only mentioned here, is distillation. This process operates by physically removing the water from the hardness (and other dissolved solids) instead of chemically and selectively removing the hardness from the water. We are concerned here only with chemical methods of hardness removal.

Although the fact that certain hard waters could be softened by lime treatment was known almost 200 years ago, and although Clark's patent (British) on this subject was granted in 1841, comparatively few softening plants were installed anywhere until near the end of the 19th century. The use of soda ash to supplement lime treatment was covered by another British patent in 1878. The period of 75 years with which we are concerned witnessed the development of virtually all the basic principles of lime-soda softening, and in addition, all the modern improvements in both the mechanical and chemical features of this type of softening.

The basic elements of the lime-soda process are (1) mixing the raw water with the correct amounts of reagents; (2) facilitating the formation of the precipitate; (3) separating the precipitate from the water as far as practicable by gravitational expedients; and (4) finally filtering this water to remove residual suspended matter.

In England, in the last years of the 19th century, Archbutt and Deely added the important step of stabilizing the softened water by recarbonating it—that is, by adding to it the proper amount of carbon dioxide to prevent "afterprecipitation." This practice has become practically standard in municipal softening plants in the United States, although it did not really get under way until after World War I. The carbon dioxide utilized for this purpose has been derived chiefly from waste stack gases or from the burning of coke, oil, or gas for that specific end use. Most recently, there has been some tendency toward the employment of liquefied carbon dioxide, or of dry ice in pressure "converters," particularly in smaller plants. Weighed against the higher cost of carbon dioxide from these sources is the elimination of the need for scrubbing and cooling the gas, as well as for compressors or blowers to apply it to the softened water.

One modification of lime-soda softening which was facilitated by recarbonation was the "excess lime treatment." The use of this excess lime accelerated somewhat the precipitation of calcium carbonate but especially of the magnesium hydroxide, which otherwise tends to form fairly stable supersaturated solutions. The excess calcium hydroxide was precipitated as calcium carbonate by the applied carbon dioxide. Furthermore, the highly alkaline environment brought about by the excess lime treatment was very effective in reducing the bacteria count of a contaminated raw water. The excess lime treatment is still used to a considerable extent, primarily because of the beneficial effect of the resultant high pH on the completeness of precipitation of the insoluble reaction products. However, it is not now practiced to any great degree for its bactericidal effect, because other and simpler methods of sanitizing water are readily available.

The extensive use of the lime-soda softening and recarbonation processes in municipal water plants in the United States owes much to the pioneering and indefatigable efforts of the late Charles P. Hoover of Columbus, Ohio. His death in 1950 marked the passing of one of the outstanding chemists and chemical engineers from the American—and international—water purification scene.

The reactions of the lime-soda softening process take place much more rapidly in hot water than in cold. The conventional continuous cold process softener typically provides a total retention period for mixing and settling of about four hours; the hot process softener, about one hour, when operating around boiling temperature. And it has taken the use of coagulants, such as aluminum and iron compounds, in cold-process softening, to narrow the retention time gap even to this extent. Hot process softeners are obviously limited in their application, principally to the softening of water for steam boilers and for similar purposes.

The most spectacular development in lime-soda softening in the past 20 years has been in methods and apparatus for approaching, in cold-process softening, the completeness of reactions previously found only in hot-process softeners and in about the same time—roughly one hour. Experimenters achieved this objective by causing the softening reactions to take place in the

presence of a large quantity of previously precipitated sludge which provided an enormous amount of reaction surface. A coagulant was usually an aid here, also.

The basic idea of using previously precipitated sludge as an adjunct to the softening reactions is far from new; but the improved methods and ingenious apparatus developed in recent years have made the idea practical, dependable, and economical. The new type of softener (which, incidentally, is also being used to an increasing extent for clarification alone) is sometimes called generically an "upflow" or "sludge blanket" softener. Actually, these terms are far from definitive. In practically every lime-soda softener—conventional or modern—the flow of clarified water is upward to the effluent launder or overflow; and a sludge blanket is not essential in at least some of the new softeners. A more accurately descriptive designation, though not a completely happy one, has been suggested by Committee W-4 of the American Water Works Association. It is "suspended solids contact softener."

In the field of softening by ion exchange, practically all but the very genesis of the process has occurred within our Diamond Jubilee span. In 1850 J. Thomas Way, consulting chemist to the Royal Agricultural Society, reported that bovine urine was deprived of its color and ammoniacal odor when passed through certain soils, that "in fact. . . it went in manure and came out water." He found that the effluent liquid contained calcium that was equivalent to the ammonia removed; and he synthesized sodium aluminum silicates which effected this remarkable "base exchange."

Interest in ion exchange came to a virtual standstill that lasted almost until the beginning of the 20th century. Then, suddenly, there was a burst of activity in the field, particularly in Germany. In 1896 Harms obtained a patent covering the base-exchange treatment of beet sugar juice with a siliceous earth. In 1901 Rumpler reported experimentation in the same field with natural and synthetic exchange materials, and suggested the removal of calcium, magnesium, and potassium from solution.

In the first decade of the 20th century, Gans in Germany prepared his first synthetic, fused, sodium aluminum base-exchange silicates (with chemical compositions resembling those of natural zeolites), which he used for water softening and which he christened Permutit. And thus the base-exchange or zeolite water softening industry was launched. The Permutits were brought to the United States shortly afterwards and the American Permutit Co. was formed. The first paper on zeolite softening in the United States was presented by Edward Bartow before a meeting of the AMERICAN CHEMICAL SOCIETY in 1914.

The success of zeolite softening in the United States was immediate and the growth of the process rapid. Competition for the Gans fused, slow-regenerating Permutits soon developed. The first really important one was processed glauconite, or greensand, originally sold under the trade name Borromite, after the late George Borrowman, a Chicago chemist. Almost concurrently with greensand appeared Refinite, prepared from a baked and rehydrated weathered bentonitic clay found in Nebraska. In the mid-twenties, there appeared the "gel zeolites," whose high softening capacity, low salt consumption, and rapidity of softening and regeneration made them especially well suited for household softeners and for many, but not all, types of industrial and municipal softening installations.

All these zeolites were siliceous, a fact which imposed certain limitations on their applicability. This was particularly true in the softening of water for boiler use, because of the danger of silica scale from silica dissolved from the zeolite. Even so, the zeolite water-softening industry had grown tremendously by 1930. A zeolite water softener was by then considered standard equipment for a laundry or for other uses where "zero hardness" was the first requirement.

The decade of the thirties was a notable one for ion exchange. This period saw the practical development of organic cation exchangers, and, even more revolutionary, the discovery of anion exchange and the preparation of anion exchange materials. The fact that certain types of organic matter possessed cation exchange properties was not new. In fact, Hepburn, a British chemist, obtained a United States patent in 1922 for softening water with peat. Such a scheme was obviously not very practical. A little later, Borrowman was granted a patent on softening water with lignite. Here the practical limitation was the low exchange capacity of the lignite.

Then, in the early thirties, came the sulfonated coals or "carbonaceous zeolites." These materials had reasonably high exchange capacity, a rapid rate of exchange, economical use of salt for regeneration, and a long active life under normal conditions. Obviously, also, they were nonsiliceous, and therefore eminently suitable for softening boiler feedwater.

Most important, however, was the ability of these carbonaceous zeolites to be regenerated with a strong acid (such as sulfuric or hydrochloric) without disintegration. The siliceous zeolites could not. For the first time, therefore, replacement of metal ions by hydrogen ions from such a "hydrogen zeolite" became practical. The result was a greatly expanded range of usefulness of ion exchange in water treatment and in a wide variety of other industrial fields.

The greatest stimulus to ion exchange, however, came in 1935, when the British chemists, Adams and Holmes, first reported the phenomenon of anion exchange, and described the first preparation of purely synthetic resins for cation exchange and for their newly demonstrated anion exchange. Although their work was basic, the patent rights they obtained in the United States were not broad enough to bar others from the field. As a result, there has been an intensive development by a number of companies and individuals of highly active cation exchange resins and anion exchange resins. High capacity, economy of chemicals for regeneration, and long life have already been achieved by synthetic cation exchange resins. The active life - and consequently the economic applicability - of the higher priced present-day anion exchange resins still affords considerable room for improvement, while a good anion exchange resin at a price comparable with that of the cation exchange resins would greatly expand the possible uses of both.

The organic cation exchangers (both the resins and the carbonaceous zeolites) permit the softening of hard water in either one of two ways. When the exchanger is regenerated with salt, the calcium and magnesium of the hard water are replaced with sodium from the exchanger, just as in the case of the siliceous zeolites. When the exchanger is regenerated with an acid, however, the calcium and magnesium are replaced by hydrogen. If the hardness of raw water is due solely to calcium and magnesium bicarbonates, and if bicarbonates are the only dissolved solids present, this hydrogen exchange will result in the complete elimination of dissolved solids, since the end products of the exchange will be carbon dioxide and water.

If, however, the raw water contains sulfates and chlorides, hydrogen exchange will convert these to the corresponding free acids—namely, sulfuric and hydrochloric. By passing the water containing these free acids through a bed of an anion exchange resin (which has been regenerated with an alkali to give it a supply of adsorbed hydroxyl ions), the sulfate and chloride ions are replaced with hydroxyl ions, with the formation of water. By this two-step process of hydrogen exchange followed by anion exchange—to which may be added, if desired, degasification (usually after cation exchange) for the removal of carbon dioxide—it is now possible to prepare deionized or demineralized water from most normal natural waters at an operating cost a great deal less than that for distillation and with comparable purity.

The past few years have seen the development of several new types of ion exchange resins, such as the high capacity sulfonated

polystyrene cation exchange resins, the strongly basic anion exchange resins (especially adapted to the direct removal of silica), and the "carboxylic acid" type of cation exchange resin, as well as new techniques of operation, such as deionization with a mixed bed of cation exchangers and anion exchangers. A more detailed description of these current developments scarcely seems in order at this time.

This brief historical sketch of water softening by ion exchange should not close without at least mention of the outstanding contributions to the theory of ion exchange which have been made in the last decade, chiefly by workers in the field of nuclear fission. The separation of fission isotopes by ion exchange solved a very difficult and pressing problem.

The succession of symposia on ion exchange—on both the theoretical and practical aspects—held by the AMERICAN CHEMICAL SOCIETY in the past few years attests to the growing importance of ion exchange in water treatment and especially in new industrial applications. If the curve of progress is projected through the next 75 years, the historian for the anniversary meeting at that time will no doubt find it vastly more difficult than has even the present writer to compress so much history into so little space.

DISINFECTION

H. C. MARKS

Wallace and Tiernan Products Inc.
Belleville, N. J.

THE history of disinfection in the field of water, sewage, and sanitation chemistry over the past 75 years has been very largely the history of the chlorination of water and sewage. Following numerous European examples of the use of hypochlorite to destroy contamination in water supplies, George W. Fuller applied the technique in Louisville, Ky., in 1896. In 1906, Phelps used chlorine compounds to treat sewage in Boston, Mass., and in Red Bank, N. J. At about the same time, Kellerman, Pratt, and Kimberly also used hypochlorite to treat sewage effluent.

G. A. Johnson initiated continuous chlorination for the routine protection of water supply in 1908 at the Bubbly Creek filter plant. He also set up an installation to protect the water supply at Boonton, N. J.

High cost and laborious application would have prevented hypochlorite from adequately protecting the modern public drinking water supply. Great advances in the elimination of water-borne diseases resulted from the development of liquid chlorine production and equipment for its application. In the United States, the first use of liquid chlorine was made by C. R. Darnall at Fort Myer, Va., in 1911.

A chlorine-control apparatus which served as a basis for much of the future technological advance was installed for the first time by M. F. Tiernan and C. F. Wallace at Dover, N. J., on February 22, 1913.

From the beginning, chlorination of drinking water required a delicate balance between sterilizing doses of chlorine on the one hand and concentrations below the taste threshold on the other. Improvements were necessary not only in control equipment but also in sterilizing efficiency and in minimizing tastes and odors. The first improved technique involved the joint use of ammonia and chlorine. On the American continent, this was first tried by Joseph Race at Ottawa, Ont., in 1916.

It was believed that the chloramine process gave better sterilization, and it was demonstrated that it minimized tastes and odors. The method was quickly taken up and used widely. At the same time, the chemistry of the process was investigated by Chapin and others. While chloramine is now known as basically less efficient than hypochlorous acid, the greater persistence of the chloramine residual has been of value. In fact, the process is still being used today to very great advantage. In swimming pool sterilization, the stability of the chloramine has been of particular importance.

A second improved technique was superchlorination with or without subsequent dechlorination. After favorable reports from England, N. J. Howard applied the process at Toronto and in 1926 was the first to observe that the chlorine requirements were related to the amount of nitrogenous material in the water. In 1928, R. D. Scott discovered the apparently unrelated fact that, under certain conditions, increasing chlorine dosage caused a decrease in the residual. He also pointed out that this phenomenon occurred correspondingly close to the point at which there was a sudden reduction in phenolic tastes. Another piece of the puzzle was contributed by E. Watzl in 1929, when he discovered that a suitable degree of superchlorination would oxidize nitrogenous materials to nitrogen gas and thus remove them from the water.

A certain time had to elapse before these apparently isolated phenomena were connected in any way. In 1939, H. A. Faber called attention to a possible interrelation. At about the same time, A. E. Griffin demonstrated that the initial rise in residual followed by a dip and then by a secondary and permanent rise as the dose was increased was a rather typical pattern. In 1940 C. K. Calvert started unification of the picture by showing that the quantitative aspects of this curve were closely related to the ammonia nitrogen content of the water.

Following these scattered beginnings, the reactions encountered in superchlorination have been investigated in great detail. This has led to the widespread application of superchlorination and realization of the great advantages of "free available chlorine residual." Of great aid in practical application has been the "break-point" technique—that is, the method of controlling the degree of chlorination by a study of the chlorine residual–chlorine dose curve.

The successful maintenance of the delicate balance in chlorination practice has also depended upon the availability of analytical methods for the control of dosage. Of greatest importance were the origination of the *o*-tolidine method and its development by Ellms and Hauser in 1913 and Wohlman and Enslow in 1919. While refinements in analytical methods have been basic throughout, the great progress made in recent years—in superchlorination, in the break-point technique, and in choosing the correct type of residual to do the job—has, in large part, been brought about by the development of tests, such as the Laux *o*-tolidine test and the Hallinan *o*-tolidine arsenite test.

While chlorine dioxide was suggested for water purification in the 19th century, its use on any sizable scale developed only after sodium chlorite was made available commercially. Then it was recommended mainly for taste and odor control in phenolic waters in a paper given by Synan, MacMahon, and Vincent at the national meeting of the AMERICAN CHEMICAL SOCIETY in September 1944. It was realized that chlorine dioxide was of some value in disinfection and, in recent years, this reagent has found a place both in taste and odor control and as an adjunct to chlorine in disinfection.

Bromine as a possible sterilizing agent for water was investigated by T. D. Beckwith and J. R. Moser in 1933. Their finding of an activity not very different from chlorine was subsequently confirmed by F. W. Tanner, G. Pitner, and J. A. McCarthy. Because bromine is relatively expensive and conveniently applied only on a small scale, its use has been confined to swimming pools.

After a flurry of interest in the early 20th century, the ozone process was held back by high costs and operating difficulties. The method was given renewed attention just prior to World War II, but mainly for use in odor and taste control.

Recently, ozone has been considered for sterilization, but serious drawbacks have yet to be surmounted.

DIVISION OF WATER, SEWAGE, AND SANITATION CHEMISTRY

PRIOR to 1913, chemists interested in water supply, sewage disposal, and related subjects were presenting papers before several sections of the AMERICAN CHEMICAL SOCIETY and before the general sessions of related associations. Chemists of none of the groups were satisfied, nor were superintendents and engineers, when papers of interest to them were scattered among the more numerous papers on general chemical and bacteriological subjects at national meetings.

Accordingly, a request was presented by Edward Bartow to the Council of the Society in Milwaukee on March 24, 1913, for the formation of a section devoted to water problems. In due course, such a section was formed and given the name, Section of Water, Sewage, and Sanitation Chemistry, corresponding to Division 14 of *Chemical Abstracts*. The first meeting was held in Rochester, N. Y., in September 1913. The division was authorized at the New Orleans meeting of the Council in 1915. The first officers elected were Edward Bartow, chairman, E. B. Phelps, vice chairman, and H. P. Corson, secretary.

The emphasis of the programs has always been on laboratory and plant research as opposed to operating data and routine tests. The consistent growth in the scope and number of papers as well as the increased interest of members has been proof of the service rendered and of the progress made. Through joint symposia with other divisions of the AMERICAN CHEMICAL SOCIETY, the Division of Water, Sewage, and Sanitation Chemistry has sought to encourage cooperation in solving the problems of water and waste treatment and analysis.

In 1929, the Division of Industrial and Engineering Chemistry and the Division of Gas and Fuel Chemistry were invited to join this division in a symposium on the subject of boiler-room chemistry. In 1934, Section A of the Division of Physical and Inorganic Chemistry met with this division to discuss the inorganic chemistry of water supply. The Baltimore program in 1939 held in conjunction with the Division of Colloid Chemistry was devoted to colloids and wastes in water treatment. The Division of Industrial and Engineering Chemistry has convened with this division four times since the 1929 meeting: to discuss the nature and treatment of industrial wastes (1939), the treatment of water for distilleries, carbonated beverages, canning, ice manufacture, and dyestuffs (1943), the control of scale and corrosion (1944), and sewage and trade-waste analyses (1946).

The period of the division's existence has seen the large scale application of the lime and soda softening process and the development of base-exchange processes for household softening as well as for laundry and industrial purposes and municipal supplies. Sterilization methods have progressed from the use of bleaching powder to the use of liquid chlorine, the chloramines, and break-point chlorination. Various pH-control methods for coagulation and softening have been introduced. The activated-sludge method of sewage purification has been developed from the earliest American experiments reported at the division's first meeting to the recent completion of the largest installation of this type in the world in a plant of the Chicago Sanitary District.

Studies of stream pollution have shown the necessity for treating sewage and industrial wastes. Treatment of industrial wastes within the factory has resulted in additional profits to the factories concerned. Radioactive natural waters have been found. As fluorine in drinking water has been suspected as the cause of mottled enamel on teeth, surveys of the fluorine content of waters throughout the United States have been made. The removal of tastes and odors from water by activated carbon and chloramines has been developed.

In the 37 years of its existence, the Division of Water, Sewage, and Sanitation has presented at 70 meetings of the AMERICAN CHEMICAL SOCIETY a total of 972 papers. At the present time, research in every phase of water, sewage, and sanitation problems is producing so many papers that the value of the national meeting (with its problems of housing and meeting facilities) is again becoming questionable, as the sessions devoted solely to the division extend through practically the entire convention time. Thus it may be that the regional meetings within the Society will soon offer all the services of the National meeting without the problems of travel and housing.

Officers of the Division of Water, Sewage, and Sanitation Chemistry, 1915–1951

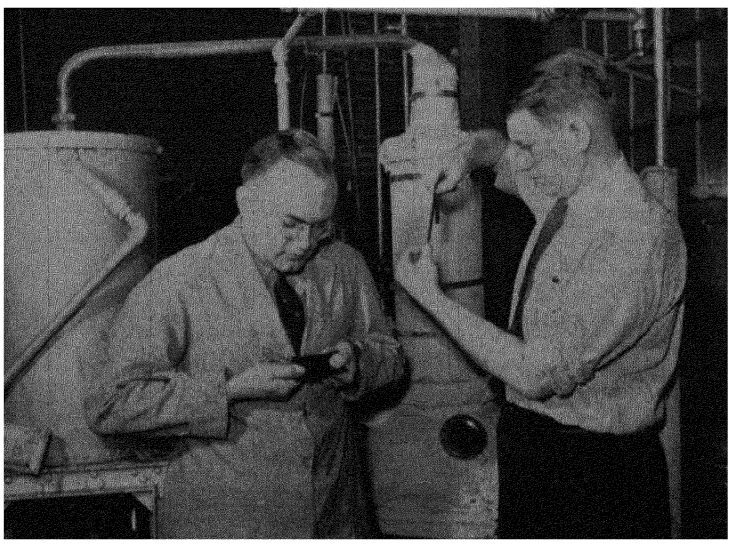
Year	Chairman	Secretary
1915–1916	Edward Bartow	H. P. Corson
1917	R. B. Dole	H. P. Corson
	E. H. S. Bailey	
1918	R. S. Weston	H. P. Corson
1919	R. S. Weston	W. W. Skinner
1920	J. W. Ellms	W. W. Skinner
1921	W. P. Mason	W. W. Skinner
1922–1923	A. M. Buswell	W. W. Skinner
1924	W. W. Skinner	F. R. Georgia
1925–1926	F. W. Mohlman	F. R. Georgia
1927	W. D. Collins	W. D. Hatfield
1928–1929	S. E. Coburn	W. D. Collins
1930	W. D. Hatfield	W. D. Collins
1931	W. D. Hatfield	E. J. Theriault
1932	A. S. Behrman	E. J. Theriault
1933	A. S. Behrman	C. S. Boruff
1934–1935	E. S. Hopkins	C. S. Boruff
1936–1937	R. C. Bardwell	C. R. Hoover
1938–1939	A. P. Black	C. R. Hoover
1940	O. M. Smith	F. G. Straub
1941	C. R. Hoover	F. G. Straub
1942	C. S. Howard	H. Gladys Swope
1943	L. F. Warrick	H. Gladys Swope
1944	W. Rudolfs	H. Gladys Swope
1945–1946	C. C. Ruchhoft	H. Gladys Swope
1947	W. W. Hodge	H. Gladys Swope
1948	H. Gladys Swope	T. E. Larson
1949	William Stericher	T. E. Larson
1950	S. K. Love	T. E. Larson
1951	J. J. Dwyer	T. E. Larson

The Future

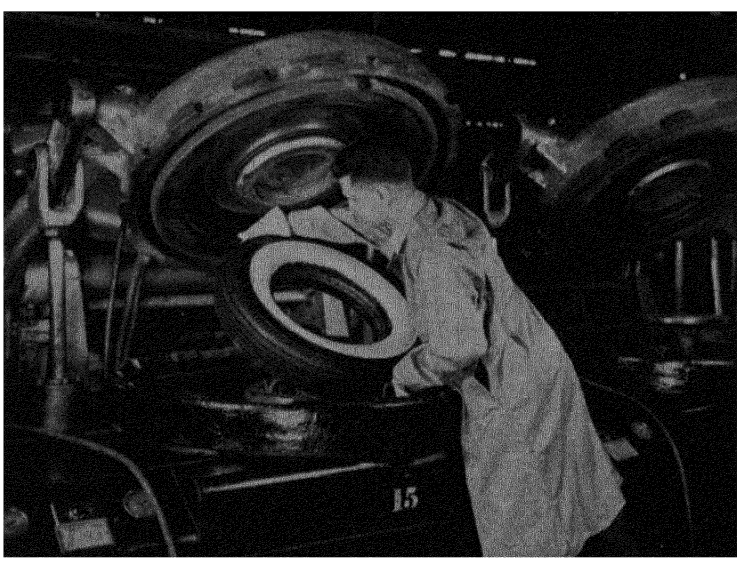
The treatment of waters containing radioactive wastes from atomic energy developments in national laboratories will be one of the most immediate and most challenging problems of the future. But of even greater importance is the problem of adequate water supply to meet the tremendously increased demands of industrial plants, sanitation, and modern conveniences (such as air conditioning), especially in large municipal areas, which are already reusing their water supplies many times over. The future problem is water not treatment.



Rubber Reserve technician demonstrates the proper type of cut to be made on Brazilian rubber tree



Department of Agriculture chemists test the stretch of rubber substitute made from soybean oil



Operator removes vulcanized tire from automatic mold at Firestone Tire & Rubber Co.

Rubber Chemistry

Like steel and concrete, rubber in a hundred diverse forms is an all-important part of contemporary living

R. P. DINSMORE

Goodyear Tire & Rubber Co.
Akron, Ohio

THE purpose of this brief history is to supply the continuity and some of the salient background for those developments in rubber chemistry which are conceived by the author to have been of greatest importance in promoting the progress of the rubber industry. Actually, the art preceded the science by many years. It has seemed logical, therefore, to include some references to the early phases of the industry prior to the organization of the Division of Rubber Chemistry, and even before the foundation of the AMERICAN CHEMICAL SOCIETY itself.

At no time has it been intended to supply a complete bibliography even of those sections of the subject which are specifically discussed, nor has it been considered possible to list the names of the important contributors to the progress of rubber chemistry. The intent has been to write for the general interest of the chemist, whether in the industry or not, and to touch only upon those milestones of progress which appeal to the author as being the most significant. This has been done by a series of snapshots rather than a continuous panoramic picture. The names that occur are not necessarily those of the most important contributors, but are those which happen to appear on the scene which is depicted. The author regrets that it is beyond the scope of this article to name the scores of pioneers and brilliant contributors to the development of our rubber chemistry. He offers them a sincere if anonymous salute.

Rubber was conceived by nature, but it has been the ingenuity of man which has transformed this material into the basis for one

of the largest industries in the world. Although rubber had attracted the attention of the early chemists prior to 1839, it was the discovery of vulcanization by Charles Goodyear in that year which laid the cornerstone of our modern industry. Statistics can best show the phenomenal expansion of rubber from a slow and feeble beginning.

World Consumption of Natural Rubber

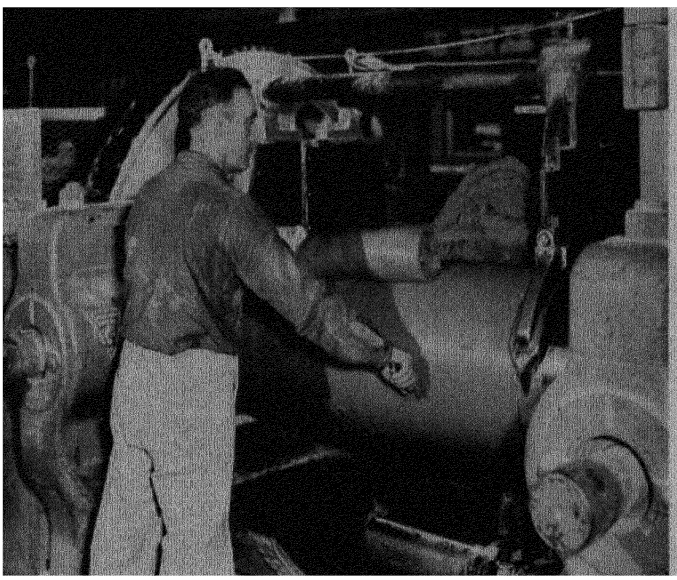
Year	Tons
1860	1,500
1875	9,000
1890	30,750
1900	49,181
1910	66,000
1915	155,000
1920	310,000
1925	525,000
1930	684,993
1935	873,000
1940	1,110,000
1945	262,500
1947	1,100,000
1949	1,427,500

also because of a growing demand for military rubber products and the continuing needs of the rubber stockpile, allocation of new rubber was further curtailed for civilian uses, particularly with respect to natural rubber. The industry gave considerable thought to the elimination of many premium articles which consume an excessive amount of natural rubber—as, for example, white sidewall tires. In fact, product specifications limiting the amount of natural rubber used in some 50,000 different end-products went into effect on April 1, 1951.

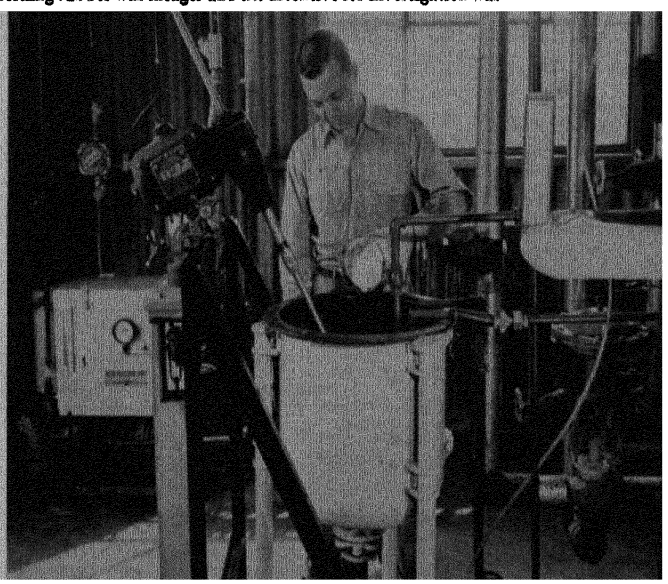
Rubber Progress Prior to 1876

To understand the part that rubber chemistry has played in the development of the industry, it is necessary to note what took place in its earlier years. It will be possible to see that certain basic discoveries and developments greatly accelerated the industry's expansion and improvement.

Prior to the discovery of vulcanization, useful knowledge concerning rubber was meager and the incentive for investigation was



Goodyear's Chemigum is rolled into sheets in conventional rubber mill, then converted into finished product



Production of "cold" rubber is thoroughly investigated in pilot plant at Phillips Petroleum Co.

Since the spring of 1950, the rubber situation has become extremely tense as a result of international conditions. Political affairs in Indonesia and the threat of Communism in Malaya are jeopardizing the sources of 90% of our natural rubber supply. However, the events of World War II proved that such crises can be successfully met through the cooperation of government and industry—if prompt and adequate steps are taken to increase the output of synthetic rubber and to build up a large natural rubber stockpile. Measures in this direction were adopted last year. In June 1950, the President approved the Senate-House compromise bill continuing government ownership and operation of the wartime-built synthetic rubber plants. Under the terms of the compromise bill, the Government will operate these plants until July 1952. About September 1, the Rubber Division of the Department of Commerce took another step toward increasing the federal stockpile. This measure consisted of a general limitation on the use of new rubber, whether it was crude rubber purchased from abroad or synthetic rubber made at home. This general limitation, voluntarily agreed upon, was to continue until January 1, 1951, or until control specifications could be worked out in cooperation with the industry for the more precise regulation of rubber consumption. After January 1, because of the delay in realizing full production from the synthetic plants and

rather low. In 1791, Samuel Peal, an Englishman, took out the first patent in connection with rubber. It involved the use of dissolved India rubber as a textile waterproofing agent. Dissolved in spirits of turpentine, the rubber was spread over the fabric with a brush. The first U. S. patent was obtained by J. F. Hammel in 1813 for a rubber varnish which made leather shoes waterproof. It is believed that the first rubber factory was established in Vienna in 1811 by J. N. Reithofer, who had deviseb a process whereby rubber threads were woven together with linen, silk, or woolen threads. Considerable pioneering work in the coating and proofing of fabrics was done not only by Thomas Hancock, who established a factory in England in 1820, but by Charles McIntosh at Glasgow in 1823.

It was not until 1839, however, that Charles Goodyear, by his vulcanisation process, was able to solve the chief difficulties of these early investigators. Although Goodyear was not a chemist, his discovery certainly merits the recognition of all rubber chemists, considering that he investigated the precise amount of heat and the exact quantity of sulfur that were required to cure rubber. Furthermore, because he employed white lead in conjunction with sulfur, he may be said to have been the first to employ an "accelerator." In fact, he originated the dry heat process of vulcanization.

The next outstanding discovery was that of the cold vulcanization process by Alexander Parkes in 1846. In this process, rubber is immersed in a solution of sulfur chloride in carbon disulfide, no heat being required. Although only thin-walled articles could be prepared by this method, it was capable of furnishing vulcanized articles in a soft or hard state and in a variety of colors.

For the next 50 years, work centered around the development of new articles of manufacture. Rubber began to replace leather for many purposes. Articles such as flexible tubes, bottles, and hose were introduced. Rubber or rubberized casings were being applied to inflated objects such as pillows, cushions, beds, and life preservers. Rubber was also being used for door springs, railway buffers, and carriage tires. Likewise, purely scientific investigations were not being neglected. In 1860, Granville Williams isolated from distilled crude rubber a liquid which he called isoprene and which slowly turned sticky. Later, G. Bouchardat converted the liquid isoprene, by treatment with hydrochloric acid, into a solid which did not contain chlorine and which resembled rubber.

Rubber Progress from 1876–1906

Two events of importance occurred in 1876. That year witnessed the beginnings of the rubber plantation industry and the establishment of the AMERICAN CHEMICAL SOCIETY. In that year, Sir Henry Wickham transported 70,000 seeds of the Hevea tree from Brazil to Kew Gardens in London. Of the 2800 plants which were raised, 2000 were sent to Malaya, Ceylon, and Singapore. Statistics show that the trend of the world production of natural rubber over a period of years has been as follows:

Year	Tons
1890	28,867
1900	53,931
1910	70,500
1920	370,000
1930	821,315
1949	1,487,500

In 1949, 671,600 tons were produced in Malaya and 431,000 tons in Indonesia.

The bicycle was beginning to become a popular means of transportation about 1886, and the consequent manufacture of bicycle tires stimulated the still youthful industry. The introduction of the pneumatic tire by Dunlop in 1888 served as an important step in the development of rubber in transportation.

The reclaiming of scrap rubber began almost as soon as vulcanized articles were made. Various methods for destroying the attached fabric and for plasticizing the rubber were adopted.

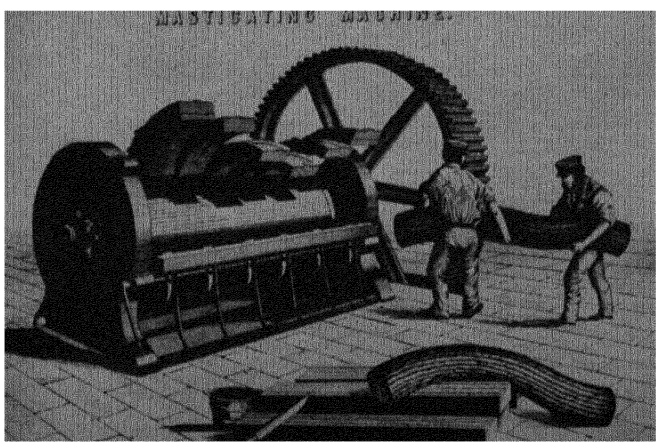
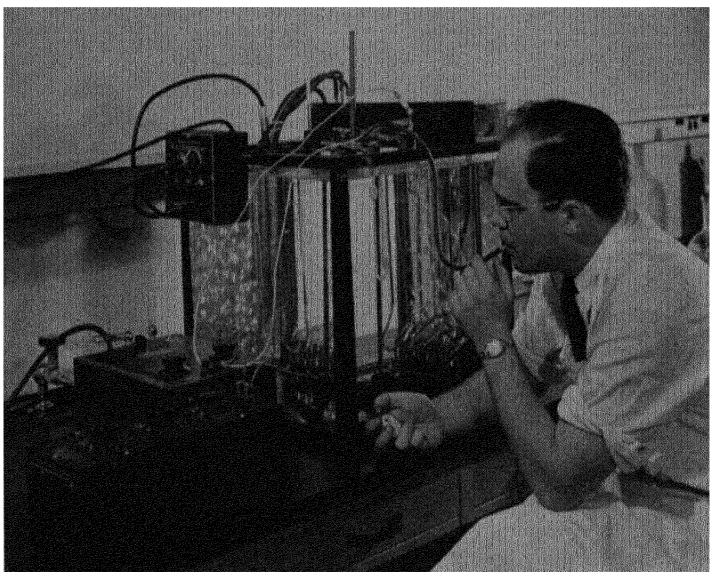


Illustration appeared in book, "Personal Narrative of the Origin and Progress of the Caoutchouc or India-Rubber Manufacture in England" (1857)

The best known and probably the most important was the alkali process invented by Marks and Price (1895–96). The procedure involved hydrolysis of the fabric, extraction of the free sulfur, and heat depolymerization of the vulcanized rubber. This and other processes are fully described in the book, "Reclaimed Rubber," by John Ball.

Within this period, the scientific studies were primarily devoted to investigations of the analysis and structure of rubber. Among the early investigators were Faraday, Himley, Williams,



Firestone researcher determines viscosity of synthetic latex sample held in constant-temperature bath

Tilden, and Bouchardat. Recognition should also be given to the work of Gladstone and Hibbert, who, as a result of their research on the optical and chemical properties of rubber, established the fact that rubber was an unsaturated hydrocarbon.

The work of C. O. Weber in 1902–06 and his development of the "coefficient of vulcanization" represented the first direct and thoroughgoing application of chemical research to the rubber industry (*65, 66*). He investigated the influence of time and temperature on the sulfur vulcanization of rubber and defined the term "degree of vulcanization" as the percentage of fixed sulfur that can be estimated by analysis of the washed product. He came to the conclusion that "the process consists in the formation of a continuous series of addition products of sulfur and polyprene; the upper limit is probably represented by the formula $C_{100}H_{100}S_{20}$, the lower by $C_{100}H_{100}S$. This series is characterized physically by the loss of expansibility and increase of solidity from the lower to the higher members. The temperature and time of vulcanization, as well as the amount of sulfur added, determine which members of this series are produced." The investigations of Weber stimulated further research in this field, as evidenced by a series of papers by Spence and his collaborators on the theory of vulcanization (*51–57*).

Nevertheless, until the early part of the 20th century, the development of the rubber industry stemmed almost exclusively from the efforts of practical rubber men. The industry had little or no appreciation of the part that rubber chemists might and later would play in its advancement. The contributions of the chemists up to that time resulted chiefly from their scientific curiosity about an obscure material.

Rubber Progress from 1906–1919

The automobile industry, which made its first commercial U. S. appearance in the early nineties, was by now growing with suffi-

cient rapidity to assume and thereafter maintain a dominating role in the growth of the rubber industry. In 1910, the demands of automobile manufacturers produced a shortage of rubber which increased the price of fine para from about 85 cents to $2.90 per pound. The rising demand for better tires, as well as the rising costs of production, encouraged rubber manufacturers to put chemists to work solving the industry's problems. The era of the rubber chemist had, in fact, commenced.

The use of organic accelerators for the vulcanization process, in place of the inorganic materials such as lime, litharge, and magnesia employed by Charles Goodyear in shortening the vulcanization period, was proposed by Oenslager in 1906 (*23*, *27*). Laboratory records show that he experimented with aniline oil and a long list of other organic compounds (including thiocarbanilide, the reaction product of aniline with carbon disulfide) with the definite purpose of hastening the time of vulcanization. In these early experiments, thiocarbanilide was used as the accelerator in the tread portion of the tire and aniline in the rubber compound which was calendered on the fabric. A decided decrease in the time of cure was effected by the use of these accelerators. In addition, there was a definite improvement in the physical properties of the vulcanized product. Manufacturers who had been using the old mineral accelerators began to experiment with these new organic catalyzers and found that output could be increased without an expensive increase in steam pressure and without danger of impairing the product by high temperature. Since the time of Oenslager's early work, thousands of organic accelerators have been recommended for general and specific rubber applications.

The development of organic accelerators was a major contribution to rubber technology. It gave immediate quality assistance to tires and other rubber products, and set the stage for further vital progress.

The reinforcement of rubber with carbon black was another epoch-making event in the rubber industry. The first real investigation of the reinforcing action of carbon black was made by Mote in 1904 at the Silvertown factory in England (*58*). Its use in this country, however, lagged for another decade. Until 1914, most automobile tires were white in color, but about that time the American rubber chemists began to note the advantages of carbon black as a reinforcing agent in the manufacture of tires. Impetus in this direction may have been supplied by the rising price and scarcity of zinc oxide and the investigations of Ditmar (*20*), who studied the effect of zinc oxide on the physical properties of rubber. In any event, the use of carbon black as a reinforcing agent in the manufacture of tires progressively increased. Practical tests showed that the resulting tires were tougher and more durable and had greater resilience and better road traction. The scientific investigation of this reinforcing phenomenon of carbon black did not receive much attention until Wiegand made a study of the rubber stress-strain curve (*70*) and devised a method of calculating the extent of reinforcement by measuring the area under the curve.

During World War I, the need for special rubber products for military purposes stimulated scientific thought which, in turn, led to major technological advances in the years immediately following.

Rubber Progress from 1919 to World War II

From 1920 to 1924, Bedford, Sebrell, and collaborators (*1–4*, *49*) studied ultra and semiultra accelerators, such as the thiuram disulfides, mercaptobenzothiazole and its derivatives, and the dithiocarbamates and their zinc salts. Much more powerful than their predecessors, these accelerators functioned over a wide range of temperatures and even without added heat. Investigation of the mechanism of their accelerative action produced useful information which helped pave the way for future developments. Bruni and Romani also worked in this field at the same time (*7–10*, *31*, *32*).

The development of the ultra and semiultra accelerators had great technological significance. They effected economies by shortening vulcanization cycles, they tended to produce more uniform physical characteristics over a range of curing temperatures, and they increased product durability. It is safe to say that they made a practical pneumatic truck tire possible and added materially to the life and quality of passenger tires and other products.

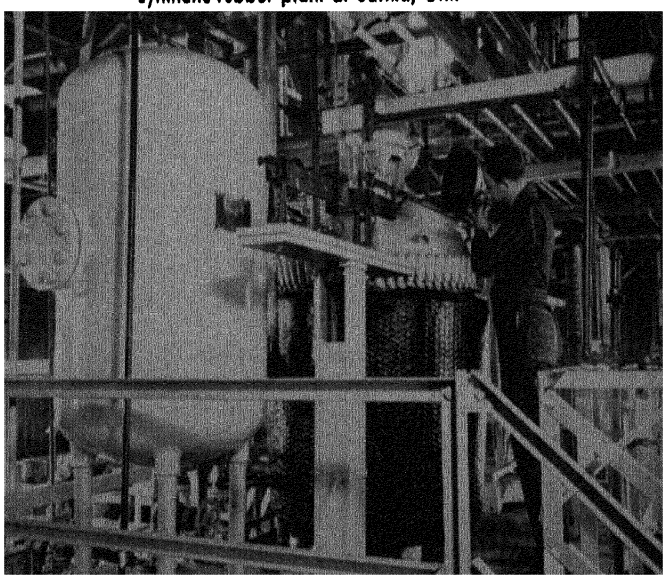
The frequent modifications in rubber compounding accentuated the need for accelerated life tests for the vulcanized products. The Geer oven aging test (*22*) and, later, the Bierer-Davis oxygen bomb test (*6*) went far to satisfy this need. Geer's method, published in 1916, involved heating the samples in a hot-air oven and plotting the change in ultimate tensile and elongation against time. The Bierer-Davis method involved measuring the oxidation of rubber subjected to oxygen under pressure and at a slightly elevated temperature. A direct result of these new methods was a general stimulation of interest in the aging of rubber and in means of retarding its more deleterious effects.

Observations had previously been made that the rubber hydrocarbon deteriorates as a result of oxidation and that organic accelerators have a tendency to impart to the vulcanized compound the property of increased resistance to deterioration. In fact, it was shown that stronger accelerators usually imparted better aging properties to the vulcanized compound. This observation induced the research chemist to seek compounds whose specific property would be to inhibit the oxidation of rubber. Aldol-α-naphthylamine, introduced by Winkelmann and Gray (*72*), and the condensation product of acetaldehyde and aniline, recommended by Cadwell (*12*), were among the first antioxidants to be used on a commercial scale. As a result of extensive investigations in this field, Mourcu and Dufraisse proposed a basic theory for antioxygenic and pro-oxygenic activity (*25*). The subsequent discovery that many antioxidants specifically retard flex-fatigue cracking created a heavy demand for materials which increase the resistance of tires to tread cracking. Once more the quality of rubber goods had been improved through the efforts of the rubber chemist.

Fatty acids were related to the vulcanization of rubber by Dannerth (*18*), who discovered that several mineral soaps (the



Operator checks one of 25,000 valves installed in 125-acre synthetic rubber plant at Sarnia, Ont.



Soap make-up and monomer weigh tanks are part of Phillips' synthetic rubber plant at Bartlesville, Okla.

oleates and stearates of lead, magnesium, and calcium) were cure accelerators for rubber-sulfur compounds. Russell introduced stearic acid as a commercial ingredient for rubber (*47*). Later, Whitby (*88*) showed that the acetone extract of rubber contained fatty acids that are of prime importance when vulcanization is carried out with the aid of either inorganic or organic accelerators. According to Bedford and Winkelmann (*5*), both metallic oxides and organic acids are inactive one without the other. They found that the natural or added acids in rubber dissolve the inorganic accelerators to form metallic soaps and that the solution of the metallic radical in the rubber is a prerequisite to its action as an accelerator.

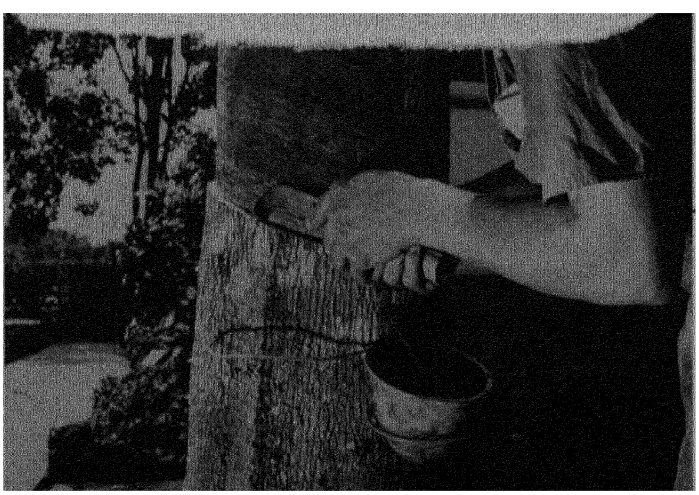
The direct use of latex by the rubber industry began about 30 years ago. In 1928–29, natural latex accounted for under 1% of United States new rubber consumption. In 1934–35, it accounted for 2.8%; in 1940–41 natural and synthetic latices represented 4.3%. In 1949, they had grown to 6.1% of the tonnage of rubber used in the United States, compared with 5.2% in 1948, establishing new records in each year. In 1948–49, the total consumption of latices increased, although total new rubber consumption declined; consumption of natural latex increased, while the use of synthetics declined slightly (*61*).

Consumption of Rubber Latices

Year	Long Tons
1924	2,157
1930	4,458
1935	13,500
1941	33,150
1942	9,392
1945	25,186
1949	61,367

Although normal latex contains an average of from 30 to 38% rubber, both economy and specific industrial needs have required that the latex be concentrated prior to shipment. The treatments include creaming, centrifuging, and evaporation. In the usual creaming procedure, an alkaline agent is added and allowed to stand at an elevated temperature. Numerous patents have been issued with respect to this treatment. The basic work of Wescott (*67*, *68*) and Utermark and his collaborators (*63*, *64*) led to the preparation of concentrated, purified, and reversible latex creams by centrifugation. The concentration of latex by evaporation is the basis of the Revertex process (*30*, *48*). The latex is treated, on collection, with a nonvolatile alkaline preservative which stabilizes the latex until it is subjected to the evaporation process. The evaporation is effected by a rotary dryer of special design.

The processes in which latex is used for the production of rubber goods include spreading, dipping, electrodeposition, chemical deposition, and froth or foam formation. These processes are applied to the manufacture of such products as cements, paints, footwear, rubber-textile combinations, flooring, pavements, and porous and foamed products. Today the foamed-rubber indus-



At Ford rubber plantation in Brazil, natural latex slowly drips into plastic cup

varying degrees of success. Progress was hampered because relatively long periods of natural aging were required before results could be compared.

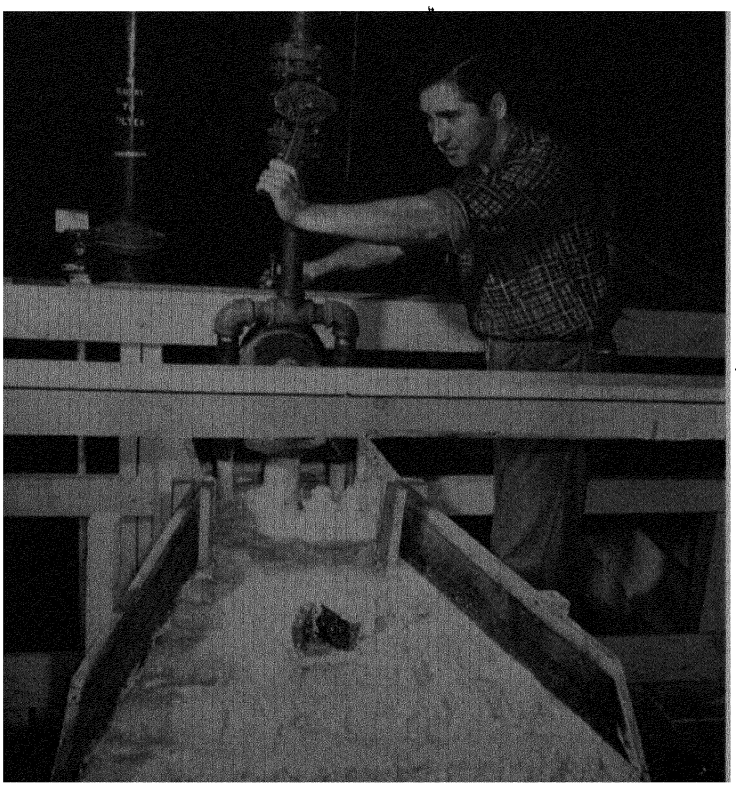
Accelerated aging tests hastened progress and, today, the personal bias of the rubber compounder is but a minor factor in determining "best cure."

It was recognized that in the vulcanization of heavy rubber goods—such as tires—the poor conductivity of rubber resulted in heat gradients throughout the mass, and hence, in varying states of cure. Cranor referred to one phase of this problem in an article in 1919 (*16*). In 1923, Ira Williams (*71*) discussed the influence of the geometrical shape of the vulcanized article. In the same year, Cranor (*17*) reported the valuable method of using thermocouples during vulcanization for determining temperatures in various parts of a tire.

In 1924, F. J. Dugan made a series of tire heat-flow curves from vulcanizing tires, and duplicated these effects in laboratory sheets cured in an electric press. That same year, W. W. Vogt presented before the ACS Division of Rubber Chemistry a method (never published) for plotting rate of vulcanization, obtained by thermocouple measurements, against time and using the slope as the "temperature coefficient of vulcanization." The method was fully described by Sherwood (*50*) in 1928. In 1932, Park and Maxwell (*28*) reported a coefficient of vulcanization for compounds accelerated with mercaptobenzothiazole.

These pioneering efforts made it possible to interpret the actual time-temperature effects obtained in various parts of bulky or irregular-shaped objects in terms of standard laboratory sheet cures made at fixed temperatures. The importance of this development in equivalent cure determination cannot be overemphasized. The fact that vulcanization coefficients are constant over a fairly wide range of curing temperatures points to control by chemical reaction. The variation in coefficient caused by the use of different accelerators is not fully understood.

The commercial usage of various chemical derivatives of natural and synthetic rubbers is another example of the ingenuity of the rubber chemist and has resulted in extensive practical applications. The Thermoprenes (rubber cyclized with sulfuric, sulfonic, or chlorosulfonic acids) were the first rubber derivatives to be used commercially (*21*). These products are used for adhesive purposes and for chemical-resistant paints. Plioform and Pliolite are other cyclized derivatives prepared by the use of agents such as tin tetrachloride or chlorostannic acid (*11*) and are used in adhesives, paints, coatings, and resin mixtures. The chlorinated rubber derivatives are exemplified by the Parlon products, which may be used in printing ink, coatings, and adhesives. The reaction of rubber with hydrochloric acid furnishes a product known as Pliofilm, which is used in sheet form for packaging purposes (*13*). Rubbone, an oxidation product of rubber, is used for coatings and cements (*59*). A tough thermoplastic product known as Isolac is produced by the catalytic condensation of rubber with 2-naphthol (*26*); it is primarily used as a compounding ingredient for rubber.



Operator regulates rapid flow of synthetic latex at Polymer Rubber Corp., Sarnia, Ont.

Synthetic Rubber

The practical development of the synthetic rubbers is a striking and comparatively recent triumph of rubber technology. It is a page of history of great importance, on which there is much remaining to be written.

Synthetic rubber is essentially a development of World War II, although it was made on a production scale by the Germans during World War I. They manufactured "methyl rubber" from 2,3-dimethylbutadiene, and it has been stated that about 2350 tons were manufactured at Leverkusen during the war period. However, the product was of poor quality, such as would be used only under the stress of necessity.

The first rubberlike materials to be used on a commercial scale in the United States were the reaction products of ethylene dichloride and sodium polysulfide. These were introduced by Patrick in the early 1920's and are known as the Thiokols (*24, 29*). Neoprene was the first actual synthetic rubber which was developed successfully in this country. It was introduced by Carothers in 1931 (*14, 15*) and is the polymer of the addition product of hydrogen chloride to vinylacetylene. The attempt to prepare a synthetic rubber hydrocarbon by the emulsion procedure was first described by Dinsmore in 1929 (*19*). In this process, a diene hydrocarbon was treated with an oleic acid soap and a protective colloid containing a protein.

The international hostilities of 1939 brought to a focus the fact that rubber would be the most critical material shortage of the United States in the event that this country became a belligerent. Consequently, in June 1940 the President declared rubber a strategic and critical material. The Rubber Reserve Co. was set up to acquire an adequate stockpile of rubber as quickly as possible.

Also, prior to the entry of the United States into World War II, some practical progress had been made in the synthetic rubber field. In 1940, construction was started on a neoprene plant which would have an annual capacity of 10,000 tons, compared with production in 1939 of about 2000 tons. Certain patent rights for the butadiene-styrene type rubbers had been obtained from the Germans. Butyl rubber, an interpolymer of isobutylene with isoprene, was discovered in 1937, and construction of a plant to produce it had been started. In addition, there were a few small plants producing butadiene-acrylonitrile type rubbers.

However, more rubber was needed. Consequently, in May 1941 the Rubber Reserve Co. was assigned the responsibility of developing an American synthetic rubber industry. The growing emergency in 1942 resulted in the appointment of the Baruch Committee, which recommended the appointment of a Rubber Director with broad powers. Under this centralized direction, the wartime synthetic rubber industry was built and operated. The following statistics illustrate the growth of this emergency industry:

United States Production of Synthetic Rubbers (60), Long Tons

Period	GR-S	Butyl	Neoprene	N-Type	Total
1941	227	....	5,692	2,464	8,383
1942	3,721	23	8,956	9,734	22,434
1943	182,259	1,373	33,603	14,487	231,722
1944	670,268	18,890	56,660	16,812	762,630
1945	719,404	47,426	45,672	7,871	820,373
1946	613,408	73,114	47,766	5,738	740,026
1947	408,858	31,495	68,824	6,618	515,795
1948	394,170	32,903	34,348	7,908	489,329
1949	295,166	52,337	35,215	11,072	393,790

Since World War II, the attention of the rubber industry has been largely directed toward the development of "cold" rubber, new types of black, and new elastomers and high polymers.

Cold rubber has been the result of efforts to improve the deficiencies of standard GR-S. Observations had been made that when GR-S was polymerized at temperatures lower than the standard 122° F. there was an improvement in some of the properties of the rubber—notably its toughness at elevated temperatures. Subsequent temperature researches finally led to the pilot plant production in 1946 of a cold rubber whose recipe was similar to that of GR-S except that the polymerization temperature was 41° F. and involved a different method of initiation.

The output of cold rubber during 1949 was 67,512 long tons (*61*). Inventory was built up during the third quarter of the year and in October the production exceeded that of regular GR-S. By September 1950, Rubber Reserve Co. shipments were approximately one-third cold rubber.

In most of its properties, cold rubber is superior to GR-S but still inferior to natural rubber. Cold rubber has greater resistance to growth of tread cracks than GR-S when used in tires. It shows better wear resistance. Like GR-S, cold rubber is not as yet suitable for truck tire carcass stocks because of the tendency for heat build-up, and the requirement of black reinforcement.

The recent introduction of high-abrasion furnace blacks is a development which has closely followed that of cold rubber. In fact, the desirable properties of cold rubber are, to a large extent, dependent upon the use of a high-abrasion black as a reinforcing ingredient. The ease of dispersion is one outstanding advantage of these new blacks—in addition to the fact that they have the ability of imparting high abrasion resistance and long flex life to its compounds. Much higher moduli are produced by these furnace blacks than is normally the case with channel black in both natural and synthetic rubber. All data indicate that the high-abrasion furnace black improves wear, whether the medium is natural rubber, GR-S, or cold rubber and that the degree of improvement is substantially the same in each case.

High polymers have been of considerable interest to the rubber industry because of the close relationship which exists between these substances and rubberlike materials.

DIVISION OF RUBBER CHEMISTRY

In 1909, when the rubber industry was still in its infancy, the India Rubber Chemistry Section was organized to encourage the exchange of ideas and thus the solution of mutual problems. By 1919, the scientific accomplishments of this section were recognized by the national Society and the organization of the Division of Rubber Chemistry was authorized.

Most frequently, the meetings of the rubber division have been held along with the national meetings of the Society, but because of the constantly increasing membership of the division and the increasing attendance at meetings, it has been preferable in recent years to hold some of the meetings independently of the national society. At the present time, the Division of Rubber Chemistry is the largest division of the AMERICAN CHEMICAL SOCIETY. Except during World War II, when transportation facilities were limited, technical meetings have been held twice a year, in the spring and in the fall.

Although the prime purpose of the division has been the dissemination of technical information, there are other ways in which its meetings aid the development of the individual. They give him the opportunity to meet rubber chemists in all kinds of work, thus broadening his knowledge. The practical knowledge of the individual can be further enhanced by the tours through industrial plants, which are usually provided.

Officers of the Division of Rubber Chemistry, 1919–1951

Year	Chairman	Secretary
1919	J. B. Tuttle	A. H. Smith
1920	W. K. Lewis	A. H. Smith
1921	W. W. Evans	A. H. Smith
1922	C. W. Bedford	A. H. Smith
1923	W. B. Wiegand	A. H. Smith
1924	E. B. Spear	A. H. Smith
1925	C. R. Boggs	A. H. Smith
1926	J. M. Bierer	A. H. Smith
1927	R. P. Dinsmore	A. H. Smith
1928	H. L. Fisher	H. E. Simmons
1929	A. H. Smith	H. E. Simmons
1930	S. Krall	H. E. Simmons
1931	H. A. Winkelmann	H. E. Simmons
1932	E. R. Bridgwater	H. E. Simmons
1933	L. B. Sebrell	H. E. Simmons
1934	Ira Williams	H. E. Simmons
1935	S. D. Cadwell	H. E. Simmons
1936	N. A. Shepard	C. W. Christensen
1937	H. L. Trumbull	C. W. Christensen
1938	A. R. Kemp	C. W. Christensen
1939	G. K. Hinshaw	H. I. Cramer
1940	E. B. Curtis	H. I. Cramer
1941	R. H. Gerke	H. I. Cramer
1942	J. N. Street	H. I. Cramer
1943	J. T. Blake	H. I. Cramer
1944	Harold Gray	H. I. Cramer
1945–1946	W. A. Gibbons	H. I. Cramer
1947	W. W. Vogt	C. R. Haynes
1948	H. E. Outcault	C. R. Haynes
1949	H. I. Cramer	C. R. Haynes
1950	F. W. Stavely	C. R. Haynes
1951	J. H. Fielding	C. R. Haynes

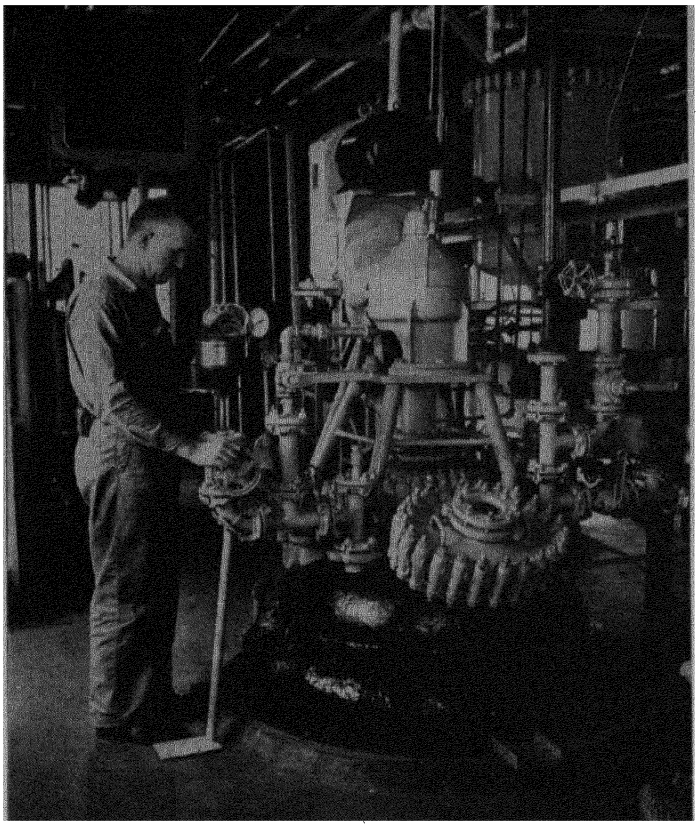
In 1927, authorization for the formation of local rubber groups was granted by the Division of Rubber Chemistry, which agreed to sponsor them after they were organized. At the present time, there are 13 such local groups: in Akron, Boston, Buffalo, Chicago, Connecticut, Detroit, Los Angeles, New York, northern California, Philadelphia, Rhode Island, southern Ohio, and Washington, D. C. The various committee projects sponsored by the division are concrete examples of how the division has assisted in the advancement of the industry.

In 1912, the Rubber Section established an Analytical Committee and also asked all the members of the section to submit their best methods for analyzing rubber goods. The committee then selected and published the most reliable methods. In the meantime, the committee revised these adopted methods from time to time, so that any chemist who needed to analyze rubber goods would have at his disposal reliable methods of procedure.

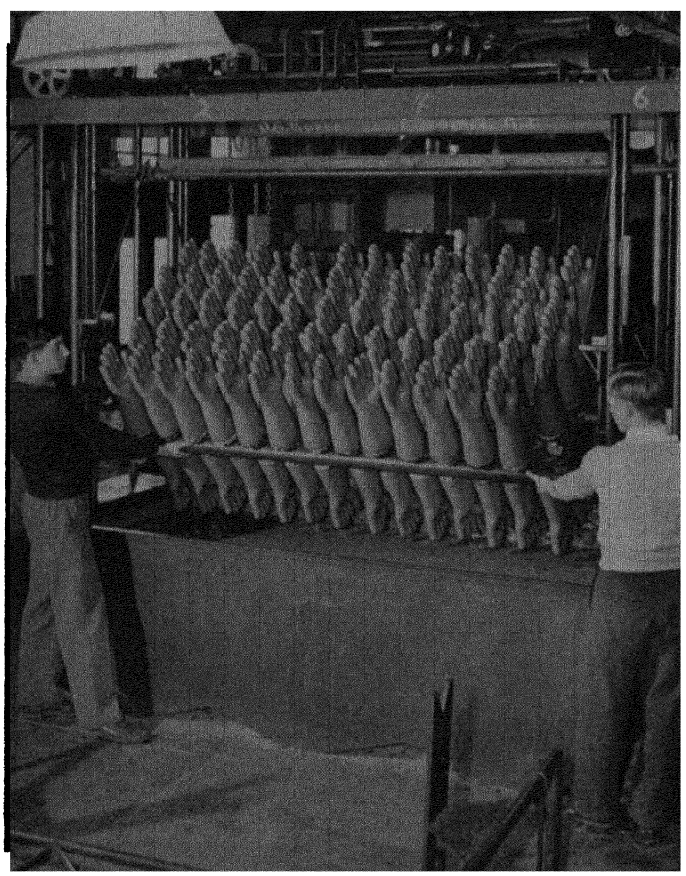
The first report of the Analytical Committee (1914) was prepared in cooperation with Joint Rubber Insulation Committee and related to determinations of acetone extract, free sulfur, total waxy hydrocarbons, and total sulfur (*46*). In 1922, the Analysis Committee held a joint meeting with the committee of the American Society for Testing Materials and adopted and published additional methods of rubber analysis (*34, 35*).

At the time when organic accelerators were beginning to be used on a commercial scale, a Committee on Organic Accelerators published a list of the products in current use, along with their properties, and called attention to the fact that disagreeable factory experience might very possibly result unless due precautions were taken (*33*).

A rather comprehensive paper was published in 1925 by the



Polymerization of rubber is carried out at temperatures down to 0°F. in 260-gallon refrigerated kettle



Gloves are rendered impervious to chemicals by brief immersion in bath of neoprene

Physical Testing Committee with respect to the methods of preparation and testing of experimental vulcanizates by the so-called tension tests (*36*). This report pointed out sources of error and made recommendations which would lead to further improvement in routine and experimental mechanical testing. Later publications were issued by this committee on "Importance of Temperature and Humidity Control in Rubber Testing" (*39*) and "Recommended Standard Practice for the Gear-Oven and Oxygen-Bomb Aging of Rubber Stocks" (*40*).

Information on the "Measurement of Crude Rubber Consistency" was published in 1925 in the form of a method proposed by the Crude Rubber Committee (*37*). In 1935, a new Crude Rubber Committee was established for the purpose of promoting a better understanding between the producers and consumers of crude rubber, to act as a clearinghouse between the two groups for information on the quality requirements of various crude rubbers, including latex, and to exchange opinions on the value of new types of crude rubber.

The activities of this Crude Rubber Committee have been extensive, and they have issued numerous reports on a variety of subjects, including "Proposed Testing Recipe" (*41*), "Tentative Testing Recipe" (*41*), "Testing Recipe; Data on Several Rubbers; Copper and Manganese; Plasticity" (*41*), "Copper and Manganese Procedures" (*41*), "Latex Specifications; Plasticity" (*41*), "Dirt; Plasticity" (*41*), "Latex Procedures" (*41*), "Procedures for Testing the Variability of Normal and Concentrated Latex" (*38*), "General Report of the Crude Rubber Committee" (*42, 44*), and "Properties, Processing, and Use of Wild Rubbers" (*45*).

Another project of the Division of Rubber Chemistry which receives the unanimous appreciation of the rubber industry is the publication of *Rubber Chemistry and Technology*. This quarterly journal contains reprinted articles in the field of rubber technology and is available to members and to others who become associate members by payment of the annual dues. This publication has been continuous since 1928.

"The Chemistry and Technology of Rubber," edited by C. C. Davis and J. T. Blake and sponsored by the Division of Rubber Chemistry, is one of the most authoritative and complete treatises ever published on the subject of rubber.

In 1940, the Nomenclature Committee issued a report (*43*) which summarized the more pressing problems, suggested some remedies to avoid confusion, and indicated the need for both the elaboration and simplification of terminology.

The activities of the Bibliography Committee have resulted in the publication of two volumes of "Bibliography of Rubber Literature" for the years 1940–41 and 1942–43. This is still an active committee.

One of the more recent projects of the division, and one which was initiated in 1947, has been the sponsoring of a Rubber Library at the University of Akron. In cooperation with a number of industrial libraries which submitted lists of their holdings, the division is attempting to establish a central rubber library for the benefit of the industry. This is accomplished by the purchase of journals not possessed by the cooperating libraries and by the purchase of additional publications. The holdings of this Rubber Division Library may be borrowed on interlibrary loan upon request from the librarian at the University of Akron.

International cooperation has been specifically evidenced at the Rubber Technology Conferences in London in 1938 and 1948. A goodly number of the technical papers were presented by rubber chemists from the United States.

The Charles Goodyear Medal is an award which was founded by the Division of Rubber Chemistry in commemoration of the 100th anniversary of the discovery of rubber vulcanisation by Charles Goodyear. The recipient of the award is selected on the basis of his contributions to the science of rubber and receives an honorarium of $200, in addition to a suitably inscribed medal. The award may be presented annually and the recipient may or

may not present a lecture at the time of the presentation. The following is a list of the Charles Goodyear Medal recipients, along with the titles of their lectures and publication references.

1942 David Spence.
1943 Lorin B. Sebrell. The Second Mile, *Ind Eng Chem.*, **35**, 736 (1943).
1944 Waldo L. Semon. (lecture delivered in 1946), Research Leading to Commercial Butadiene Synthetic Rubber, *Chem. Eng. News*, **24**, 2900 (1946).
1947 Ira Williams. Vulcanization of Rubber with Sulfur, *Ind. Eng. Chem.*, **39**, 901 (1947).
1948 George Oenslager.
1949 Harry L. Fisher. Rubber Research and the Need for a Rubber Research Institute in the United States.
1950 C. C. Davis.

The use of rubber has become as intimately interwoven into the fabric of our modern civilization as has the use of steel or concrete. Its applications are fully as varied. Hence, the future of rubber is, to a marked extent, dependent upon the trends of our civilization.

It is apparent that in a world at peace there will be a determined effort by countries less fortunate than ours to follow as fast and as closely as possible our path to industrial prosperity. There is little doubt but that this country would encourage and assist such a trend within practicable limits. There are certain indications that even today the trend of industrialization in other countries is such that the demand for rubber is outrunning any visible supply. In the past war, for example, we imported considerable quantities of wild rubber from South America. Today, South America is a heavy importer of plantation rubber.

There is no doubt but that the stockpiling of rubber—gathered as a safeguard against a war deficiency—has served to create a demand which is temporarily inflated and which must one day decrease. However, if no general war occurs, increased industrial demand will soon take up the surplus. Indeed, it is possible that rubber plantations will be unable to expand rapidly enough to take care of the rising demand, and it may be necessary for the synthetic rubber industry to grow further.

The versatility of rubber applications depends to a considerable degree on price and supply, but it likewise depends upon the degree of our knowledge of rubber properties. It has already been discovered that certain desirable characteristics can be obtained from synthetic rubbers by control of the conditions under which they are made and used. Rubber chemists in the future will certainly know how to carry this adaptability further, not only with synthetic rubbers of the present kinds but with others as yet untried.

Our knowledge of long-chain synthesis and polymerization of hydrocarbons is gradually shedding some light on the nature of the rubbers and the mechanism of vulcanization and of pigment reinforcement. It can be confidently predicted that studies aimed at determining the underlying reasons for the behavior of vulcanized rubber of varying compositions will yield much useful information.

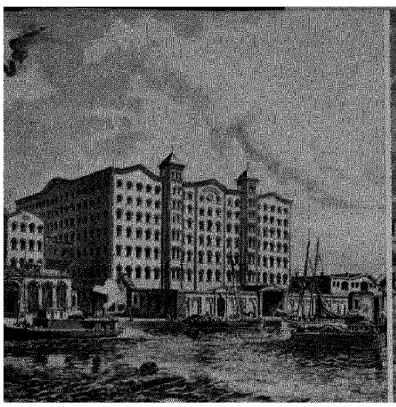
In any event, the rubber compounder of the future will have an even more bewildering array of rubbers and reinforcing materials than he has to choose from at present. The expansion of the rubber industry and, along with it, rubber technology – which in the past half century has been closely associated with the growth of the automobile industry—may perhaps be equaled or exceeded in the future. This expansion will come about as a result of the development of innumerable new rubber applications, of which we now have little or no conception.

Acknowledgment

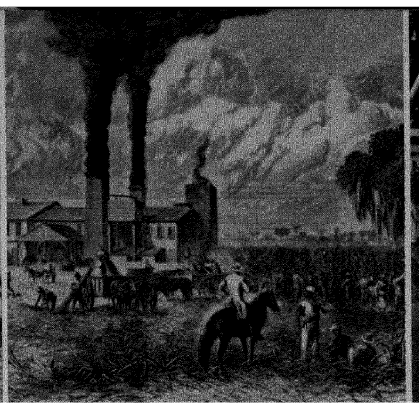
Thanks go to Leora Straka for invaluable assistance in the preparation of this article; also to C. C. Davis, 1950 Charles Goodyear medalist, for permitting the author to refer to his manuscript; and to various members of the development staff of the Goodyear Tire & Rubber Co. for their help and criticisms.

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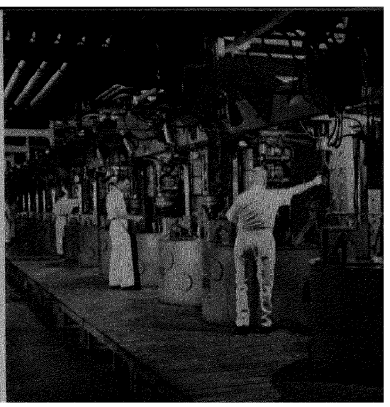
(1) Bedford, C. W., and Gray, H., *Ind. Eng. Chem.*, **15**, 720 (1923).
(2) Bedford, C. W., and Scott, W., *Ibid.*, **12**, 31 (1920).
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In 1870, sailing vessels laden with sugar anchored near Havemeyers and Elder's refinery



Harper's Weekly of Oct. 30, 1875, contained a drawing that illustrated the harvesting of sugar



Battery of high-speed centrifuges is used in the processing of sugar in modern refinery

Sugar Chemistry

Sugar, known in antiquity, has found a wealth of new applications within our own century

W. D. HORNE, Nassau Club, Princeton, N. J.
S. M. CANTOR, American Sugar Refining Co., Philadelphia, Pa.
R. W. LIGGETT, Sugar Refining Co., Philadelphia, Pa.

SUGAR as such was unknown in Europe until 326 B.C., when one of Alexander the Great's admirals brought some, in primitive raw form, back to Greece from India. But even the Orientals never learned how to refine sugar until a successful process was developed by the Persians in 500 A.D. The Persians kept their refining technique a closely guarded secret, while at the same time they promoted a growing sugar trade with Europe. Sugar cane was first taken to Europe in 1000 A.D. and grown in Sicily. The government of Venice offered 100,000 crowns to anyone who not only could discover a way to refine raw sugar but would make known the process. At length, this was accomplished in 1470, and Venice became Europe's foremost supplier of sugar. England succeeded 74 years later in developing a refining process of her own and moved into first place as European dispenser of the refined product.

Meanwhile, Columbus had taken sugar cane to San Domingo on his second trip to the New World. And in 1511, Diego Velasquez started the cultivation of cane at the eastern end of Cuba. The natives, severely overworked, died off rapidly. To keep his plantations going, Velasquez ordered that shiploads of slaves be sent over from Africa. Thus began the institution of slavery in the New World. Sugar cane was introduced into Puerto Rico in 1515, and by 1650 it had been taken into all of the West Indian islands. New York built a sugar refinery in 1689, a full 145 years after London had entered the field. Louisiana did not introduce sugar cane until 1751, a century after all the West Indies had begun to raise it. The U. S. sugar industry grew rapidly. Improved production techniques were developed continuously.

In 1812, Derosne developed boneblack. Howard invented the vacuum pan in 1824 and Rillieux the multiple-effect evaporator five years later. The polaroscope was devised in the early 19th century, while the centrifugal was introduced in 1853 and the filter press and crystallizer in 1880 And so it went New methods and improvements on old techniques followed each other in rapid succession as more intensive study was devoted to sugar manufacture.

After Margraf found in 1747 that beets contained 6% sugar, it was only 22 years until Achard established in Austria the world's first beet sugar factory. Because of the complicating presence of nonsugars in the juice, sugar was originally much more difficult to obtain from beets than from sugar cane. This led to elaborate study of beet sugar chemistry. By 1900, sugar beets were supplying half of the world's sugar. In turn, the cane

sugar producers were encouraged to intensify their own scientific studies, with the result that by now cane sugar amounts to two thirds of the world's supply.

Against this background of a highly developed and expanding sugar technology, the AMERICAN CHEMICAL SOCIETY was founded in 1876. This was just eight years before Emil Fischer began publishing the work which was to have such a tremendous effect upon the subsequent development of sugar chemistry and technology all over the world.

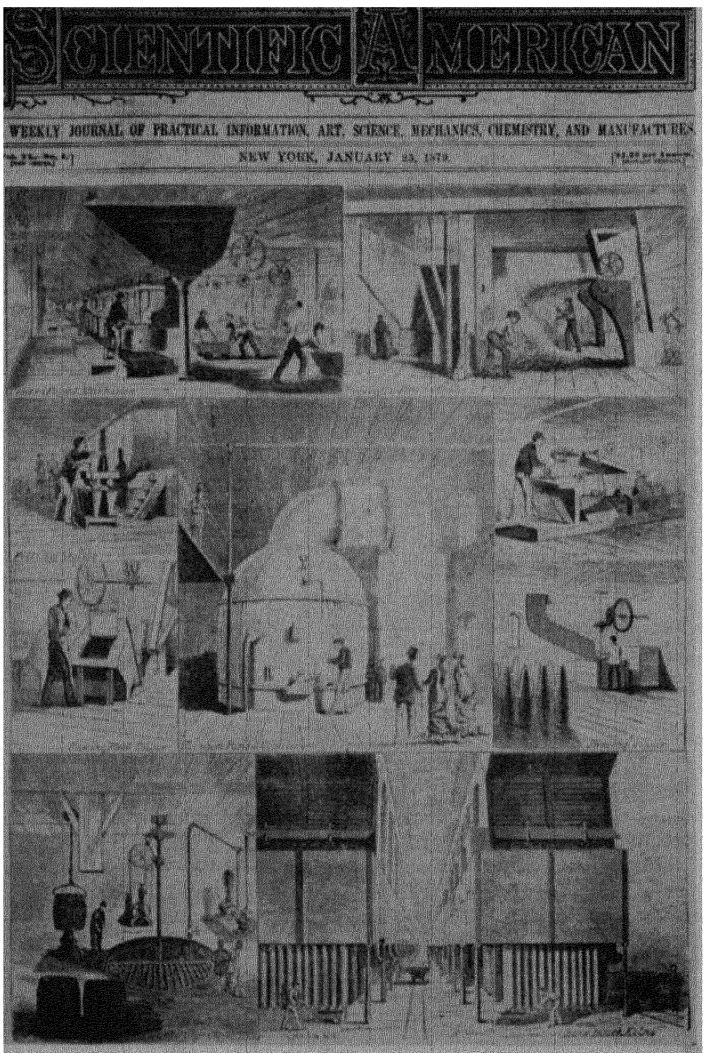
Several prominent sugar chemists, including Arno Behr, H. E. Niese, and Paul Casamajor, were among the group which gathered in New York City in 1876 to form the AMERICAN CHEMICAL SOCIETY. Chemists of the sugar industry were staunch supporters of the Society from the very start. Most of these men did not publish their research findings, and one of their few contacts with scientists other than their immediate associates was through the Society.

A most important development in the industrial field was the production of sweetening materials from sources other than sugar cane. Many of the men who received their training in the cane sugar industry laid the groundwork for the beet sugar and dextrose industries.

The chemistry of starch hydrolyzates was greatly accelerated at approximately the time the sugar division was founded in 1921. The development of a successful process for making refined dextrose from cornstarch was reported at various meetings of the sugar division in its early years. Improvements in technology as well as fundamental researches are always important parts of the division's programs. As with so many other advances, the dextrose development grew from the application of fundamental chemistry to the technology of an established industry.

The early production of dextrose by wood saccharification was based on fundamental scientific research originally conducted in the 19th century. During World War II, this reaction was recommended as a source of alcohol and as insurance against possible grain shortages during times of emergency. It may well be that the greatly expanded use of alcohol in the synthetic rubber program will bring about the large scale utilization of such carbohydrate values. Several reports on this subject were presented in a symposium on wood sugars before a joint session of the Divisions of Sugar Chemistry and Cellulose Chemistry in New York in 1944.

One of the latest developments in the milk processing field has been the commercial recovery of lactose from milk by-products. Aside from its general use in foods, lactose is of value in the production of antibiotics, because it is fermented comparatively slowly by most microorganisms, particularly the Penicillia. The notable work of C. S. Hudson on milk sugar resulted in his receiving the Borden Award in 1941 at the Sugar Division's St. Louis meeting.


SCIENTIFIC AMERICAN

WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES

NEW YORK, JANUARY 13, 1879

Cover of *Scientific American* in 1879 showed centrifuges, bone black kilns, and vacuum pans in sugar refinery

Modern Technology

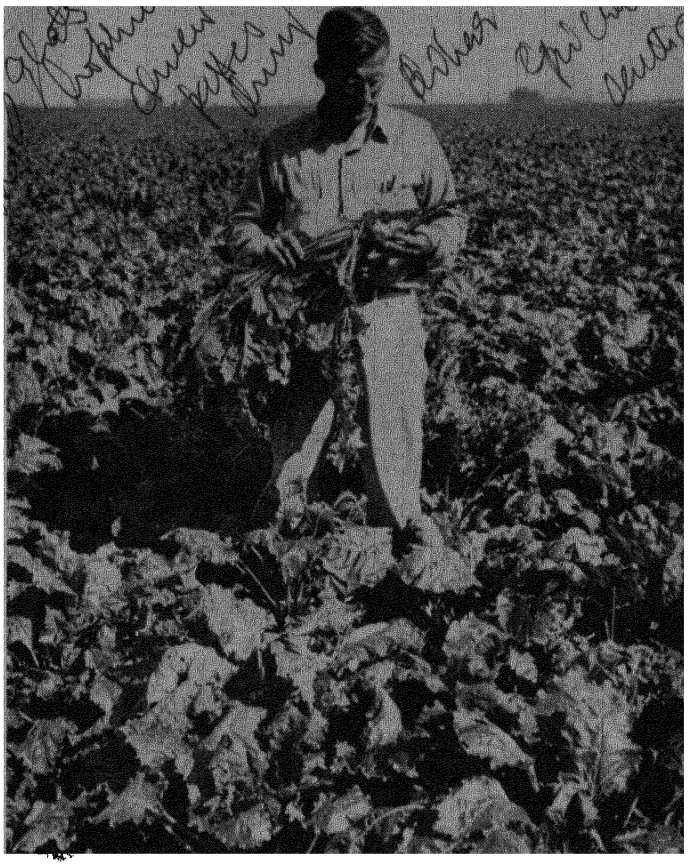
The sugar industry's equipment for such unit operations as crystallization, drying, conveying, transit, and storage has in many cases been adapted from designs used in other types of manufacture. In line with the general industrial trend toward the use of liquid materials, the industry has developed liquid sugars and inverted sugar sirups. Distribution of these commodities would not have been feasible before the advent of continuous processes in the food industries and the improvement of refrigeration facilities for perishable foods. At the other end of the process, the mechanization of sugar cane and sugar beet farming has markedly affected the relative economic position of sugar produced in America as compared to sugar obtained from foreign sources. Mechanical harvesters are now used to harvest approximately 50% of the nation's sugar beets. Traditional methods of shipping and handling raw sugar in bags have been challenged by modern bulk handling methods.

Early papers presented at ACS meetings dealt with the problem of color and its determination. Sugar chemists studied techniques of decolorization and purification with boneblack and decolorizing carbons. Among the early symposia was one on sugar refining, held jointly with the Divisions of Cellulose and Organic Chemistry at Philadelphia in 1926. In the following year, the symposium topic was colloids in sugar products. Papers on the technological advances have continued, and as recently as the spring of 1950 a symposium was held on the purification of sugar juices.

Because the removal of inorganic and organic salts is one of the primary problems of sugar refining, the development of ion exchange resins and more recently the growing knowledge concerning their properties and utility (published in such diverse fields as water conditioning and rare earth separations) has excited considerable interest among sugar chemists. Ion exchange resins offer an entirely new means of processing sugar-containing raw materials.

Full-scale plants based on ion exchange processes are already producing dextrose and corn sirup. Large-scale pilot plants have been operated as basic or supplementary equipment for producing beet and cane sugar. Many of the data that have been reported on these processes have been presented at the sugar division's meetings during the past 10 years.

Ion exchange has also been used for the recovery of sugars



Farmer inspects crop of sugar beets growing profusely in field near Gilby, N. D.



Mother and child display sugar cane grown on plantation north of Tingo Maria, Peru

from other sources—such as citrus wastes, beet sugar pulp, and pineapple wastes—which could not be successfully processed by earlier methods. As the future of most of these processes is dependent upon the recovery of by-products which, in some cases, are potentially more valuable than the sugars themselves, it is safe to predict that there will be many more papers on ion exchange prominently featured at forthcoming sugar division programs.

In common with the greater part of American industry, the sugar industry in all its branches has been gradually turning to a more efficient utilization of its own by-products. Probably the first instance of this was the use of the bagasse (the residual cellulosic cane fiber) as a fuel for processing cane juice. In recent years, there have been many attempts to find other outlets for this material, the most successful of which has been in the production of wallboard. Bagasse has also been used for paper. Combination processes have been suggested which involve treatment of the bagasse by acid to convert the pectins and hemicelluloses into furfural and, at the same time, to produce a cellulose more suitable for fiber use.

Traditionally, the by-product molasses and, to some extent, hydrol (the corn sugar equivalent) have been fermented to produce alcohol. More recently, molasses has been used to produce glycerol and citric acid on a large scale. Because of the heterogeneous nature of molasses, attempts to recover from it material other than sugar have not been successful. Recently, when aconitic acid was found to be present in sufficient quantities to justify its extraction, attention was turned to this substance. Similarly in the case of beet molasses, glutamic acid is being isolated on a large scale. Other carbohydrate industry by-products which have attracted considerable interest have been calcium phytate and inositol from corn solubles (steep water) and sugar cane wax from raw sugar filter press muds. All these substances have from time to time been the subject of papers presented to the sugar division. The circulation of this type of information through the various media of the AMERICAN CHEMICAL SOCIETY has been of immense aid to the sugar industry.

For some time, molasses has been used directly as a food source for cattle and swine. In fact, 6.5 gallons of molasses provide food value equal to a bushel of corn. During the fiscal year 1949, the volume of cane and beet molasses utilized in livestock feeds increased about 35% over the previous year. Recent studies in the field of animal nutrition have shown that it is possible to incorporate into feeds more molasses than has been used formerly —for example, up to 5% in poultry feed where none was used previously, and up to 35% in beef cattle feeds.

Sucrose and dextrose are remarkably low in cost, considering that they are essentially pure. This is particularly striking when one compares these sugars to basic organic raw materials important in many industrial syntheses. The economic health of the carbohydrate industries would be considerably improved if their basic products could find other than the traditional applications. Although no current industrial use for these materials requires the quantities involved in food production, it seems probable that eventually the world must turn to such sources when supplies of other basic resources, such as coal and oil, become further depleted. One sign is the recently announced plan to produce adipic acid from furfural rather than from benzene.

Other products, such as sorbitol and mannitol, have been prepared by the reduction of glucose or invert sugar. These have been on the market for some time. More strenuous reduction of glucose or sucrose produces low molecular weight glycols, including glycol. Conceivably this synthesis could be used when glycerol and ethylene glycol are in short supply.

The degradation of hexosic carbohydrates by strong acid leads to the production of hydroxymethylfurfural. This process is analogous to furfural production from pentoses. The properties of hydroxymethylfurfural make it a potentially useful intermediate

for organic synthesis. The chemistry of this substance was discussed at a symposium on fundamental carbohydrate chemistry held at Detroit in the spring of 1950. The major breakdown product of hydroxymethylfurfural, levulinic acid, has been under study for some time and has been available in limited commercial amounts. At the symposium on the role of sugar in nonenzymatic browning, held by the division in New York in 1947, some of these compounds were discussed from the standpoint of the role they play in the deterioration of foods.

Small in quantity but large in importance are the vitamins which have been synthesized by the use of a simple sugar as one of the raw materials. Particularly noteworthy is the production of vitamin C or ascorbic acid, which is now frequently used in food processing. Synthetic riboflavin also requires a simple sugar, desoxyribose, as one of its raw materials. Glucurono-lactone has been commercially produced in a pure crystalline form suitable for pharmaceutical use.

Dextran, the polysaccharide produced from sucrose by various bacteria of the genus *Leuconostoc*, has recently been shown to be a very effective fibrinogen substitute, after suitable degradation by acid. Administered by intravenous infusion, it relieves shock and prevents loss of body fluids after extensive surface burns. Dextran has been introduced commercially in this country, and the expectation is that its production will be rapidly accelerated as an adjunct to blood plasma stockpiling for the treatment of disaster casualties.

The use of the glucose solution for intravenous feeding was made possible by the production of extremely pure glucose from starch. Recently, it has been found that invert sugar is equally suitable for intravenous feeding and processes have been developed for making an invert sugar of suitable purity.

A less direct but equally important contribution of the carbohydrate processing industries has been the introduction of lactose and corn steep liquor into the fermentation media for producing penicillin. This innovation has made possible a sharp reduction in the cost of penicillin manufacture.

Along with these industrial advances which have marked the activities in the carbohydrate field and which have been reported regularly to the AMERICAN CHEMICAL SOCIETY have been the extremely important academic researches without which industrial progress could not have taken place. From modest beginnings, university and government laboratories have grown into important centers of carbohydrate research which have not only provided the fundamental knowledge necessary for a progressive industry but also—and of equivalent importance—the men needed to carry on industrial work.

Officers of the Division of Sugar Chemistry, 1920–1951

Year	Chairman	Secretary
1920	C. A. Browne	F. J. Bates
1921	C. A. Browne	F. J. Bates
1922	S. J. Osborn	F. J. Bates
1923	W. D. Horne	F. J. Bates
1924	F. W. Zerban	F. J. Bates
1925	W. B. Newkirk	F. J. Bates
1926	W. B. Newkirk	F. J. Bates
1927	Chas. E. Coates	L. A. Wills
1928	F. J. Bates	F. W. Zerban
1929	H. C. Gore	J. K. Dale
1930	Wm. L. Owen	J. K. Dale
1931	J. K. Dale	E. W. Rice
1932	W. L. Howell	E. W. Rice
1933	H. W. Dahlberg	E. W. Rice
1934	Otto A. Sjostrom	E. W. Rice
1935	H. C. Gore	E. W. Rice
1936	J. K. Dale	E. W. Rice
1937	W. R. Fetzer	E. W. Rice
1938	Horace S. Isbell	E. W. Rice
1939	A. R. Nees	E. W. Rice
1940	J. M. Brown	E. W. Rice
1941	R. Max Goepp	F. G. Straub
		E. W. Rice
1942	S. M. Cantor	E. W. Rice
1943	George H. Coleman	E. W. Rice
1944	G. E. Hilbert	E. W. Rice
1945	R. C. Hockett	E. W. Rice
1946	R. C. Hockett	E. W. Rice
		J. M. Brown
1947	W. W. Moyer	J. M. Brown
1948	Melville L. Wolfrom	J. M. Brown
1949	Ward W. Pigman	J. M. Brown
1950	W. D. Hassid	J. M. Brown
1951	Geo. T. Peckham, Jr.	J. M. Brown

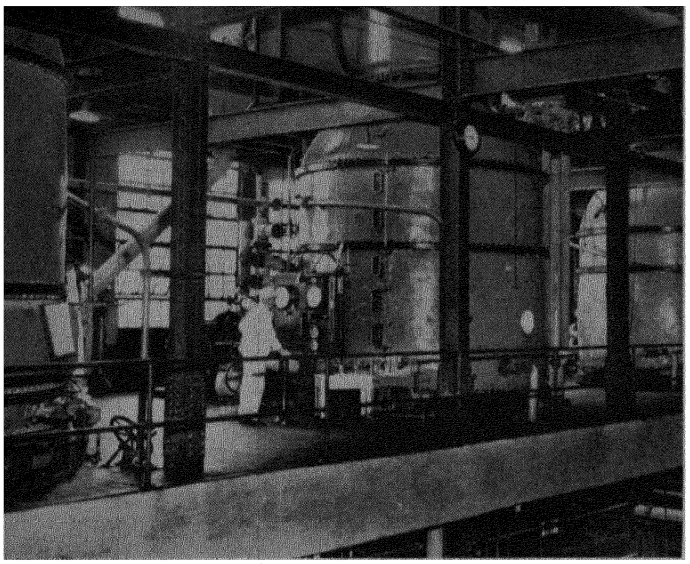
Divisional History

Up to the time the Division of Sugar Chemistry was organized, sugar industry technologists were principally concerned with analytical and engineering developments designed to put the industry under better control, to cut costs, and to produce products of higher quality. In contrast to these improvements in technology, sugar chemistry as a science started slowly in the United States. The impact of Emil Fischer's remarkable work, as well as comparable developments in the early 20th century in England, was not fully felt in this country until the period immediately following World War I. Subsequent events placed increasing emphasis on industrial research, and the fund of academic information already accumulated began to be applied.

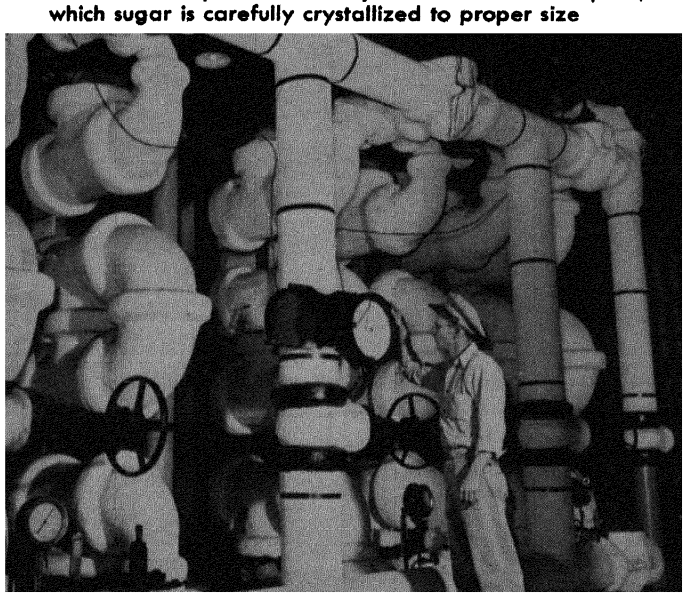
That was the situation in 1919 when C. A. Browne, W. D. Horne, A. H. Bryan, F. J. Bates, and F. G. Wiechmann began discussions and correspondence with other sugar chemists about establishing an organization to cover the field of sugar chemistry and technology. From this exploratory work, it became apparent that the leaders in this proposed organization already were members of the ACS, and therefore an association under the auspices of that society would be advantageous. A plan incorporating this proposal was published in 1919 in the magazine, *Facts about Sugar*. The plan provided that members of the ACS could be included in this group and that persons not members of the ACS could join the section as associate members of the parent society.

This ground work culminated in the first session, which was held at the ACS meeting in St. Louis, April 15, 1920. About 60 members were present. At the time of the Rochester meeting in April 1921, the membership had increased to 160, and there were 34 papers on the program. At the meeting on September 6, 1921, in New York, this group became a self-governing division known as the Division of Sugar Chemistry and Technology, its by-laws accepted by the ACS Council.

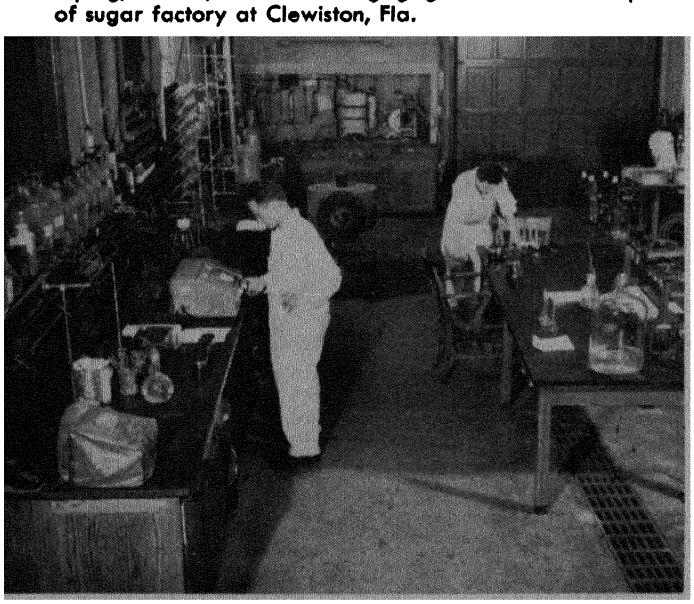
From the beginning, the division attracted sugar chemists and technologists, as well as research workers in the field of carbohydrates. As the membership continued to grow, so did the number and scope of the papers presented at the divisional meetings. Among the most valuable programs have been the symposia often sponsored with other divisions. The first of many such joint sessions was held with the Division of Cellulose Chemistry at New Haven in the spring of 1923, when J. C.



Worker is responsible for operation of vacuum pans, in which sugar is carefully crystallized to proper size



Piping, valves, and recording gages are essential parts of sugar factory at Clewiston, Fla.



Analytical chemists keep close check on manufacturing operations at American Sugar Refining Co.

Irvine spoke on the chemistry of the polysaccharides. In the fall of 1924 at Ithaca, N. Y., the sugar division together with the Division of Cellulose Chemistry heard E. C. C. Baly give an account of his work on the photosynthesis of sugars and J. C. Irvine report on the physical and chemical examination of the sugars prepared by Baly.

As the years went by, an increasing number of papers on carbohydrate chemistry were presented at the meetings. This trend has been more pronounced ever since the 1938 symposium on the nomenclature of sugars, held jointly with the Divisions of Chemical Education and Organic Chemistry, and the program on the chemistry of the sugars, held jointly with the Division of Organic Chemistry. This was followed in 1941 by the celebration of the semicentennial of the publication of the configuration of D-glucose by Emil Fischer. H. O. L. Fischer, his son, served as honorary chairman. In 1942 and again in 1944, joint symposia with the Division of Agricultural and Food Chemistry dealt with the chemical and industrial uses of carbohydrates.

At the spring meeting in 1925, C. S. Hudson presented a resume of his work on the relation between structure and rotatory power in the sugar group before a joint session with the Divisions of Organic and Biological Chemistry. At the Chicago meeting in 1946, the division paid tribute to C. S. Hudson's numerous contributions to sugar chemistry by conducting a special symposium on the achievements of the Hudson group.

An ever-broadening horizon of new discoveries and new applications—growing logically from intensive research in carbohydrates—has been introduced to the sugar industry through the publications and meetings of the ACS. The dispersion of new ideas, resulting in expansion of production, improved efficiency of operations, and the development of new products, is one of the most valuable services which the ACS and the Division of Sugar Chemistry provide for industry. Although originally the emphasis within the division was primarily on cane and beet sugars, now it extends to all sugars. In fact, there is a movement afoot to change the divisional name to the "Division of Carbohydrate Chemistry," as this title more accurately describes the scope of the organization's activities.

From the time of its founding the division has had able leadership and an active program. The continued expansion of the whole field of sugar chemistry throughout the past 30 years has provided a firm basis for further growth in the years to come.

One unifying force in the field of sugar chemistry is the *esprit de corps* that has developed among industrial sugar scientists and their colleagues in research. The ACS and the Sugar Division have been important media for giving them an opportunity to meet in person. This is particularly true of representatives in closely related industries, who frequently have been ardent competitors and warm personal friends.

This tradition has been fostered by such formal organizations as the Sugar Research Foundation, the Corn Industries Research Foundation, and its valuable subsidiary, the Starch Round Table. Such an informal social organization as the Chowder and Marching Society—which meets according to more recent custom after the Sugar Division dinner at the annual meetings—must also be mentioned.

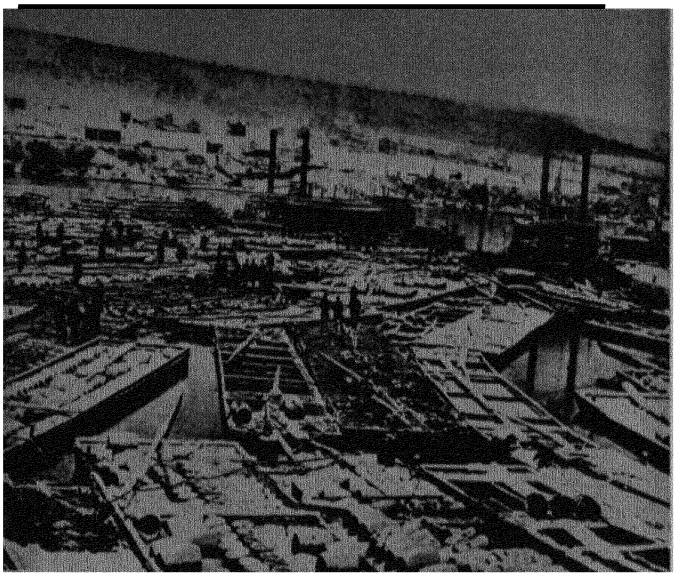
The AMERICAN CHEMICAL SOCIETY has played an important part in fostering the growth of the sugar industry. Certainly it can be expected, on the basis of the experience of the first 75 years of its history, that the Society will continue in this role and that the progress made thus far will be vastly accelerated.

Acknowledgment

The authors acknowledge with gratitude the constructive aid of Olive F. Whitehead and L. A. Wills of the American Sugar Refining Co.; Margaret Liggett; James M. Brown, secretary of the Division of Sugar Chemistry; and the valuable information contained in the many papers on the history of the sugar industry by the late C. A. Browne.



In 1865, wells and offices of the Shoe and Leather Petroleum Co. occupied the side of a Pennsylvania hill

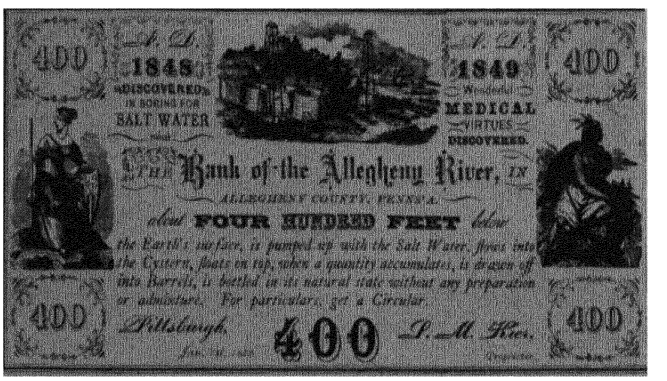


Large numbers of oil barges were anchored helter-skelter in the Allegheny River in the early oil rush days

Petroleum Chemistry

Once a quack medicine, petroleum is now the mainstay of giant enterprises essential to modern technology

GUSTAV EGLOFF *and* **MARY L. ALEXANDER**
Universal Oil Products Co., Chicago, Ill.



Labels on bottles of Kier's Rock Oil announced that petroleum possessed "wonderful medical virtues"



Investors in the Spondulix Petroleum Co. were promised dividends "very often" and copy of "Petroleum Galop"

THE role of chemistry in the petroleum industry began in 1855, 21 years before the birth of the AMERICAN CHEMICAL SOCIETY. In that year, Benjamin Silliman, Jr., professor of chemistry at Yale College, completed his "Report on the Rock Oil, or Petroleum, from Venango Co., Pennsylvania," which was the first scientific analysis of petroleum (*11*). From his studies, Silliman concluded:

> . . . it appears to me that there is much ground for encouragement in the belief that your company have in their possession a raw material from which, by simple and not expensive process, they may manufacture very valuable products.

It was this advice that dispelled doubts as to the value of petroleum and encouraged investment in the venture leading to the drilling of the Drake Well, which was the real beginning

of the petroleum industry. Appropriately, Silliman's report has been called "a chemical classic that touched off an industry."

Although petroleum oil had been known and used for thousands of years, it was the Drake Well in 1859 that showed the way to large quantity production. Heretofore, oil had been obtained in small amounts from hand-dug wells, by skimming pools, and as an unwelcome product from wells drilled for salt and water. Limited quantities were marketed in the United States as a medicinal and for illuminating purposes prior to 1859. Probably the most important and certainly the most colorful of the pre-Drake Well petroleum marketers was Samuel Kier, a druggist of Pittsburgh, who obtained petroleum from the Tarentum salt wells (*3*, *6*). This oil was marketed as a medicinal in half-pint bottles bearing finely engraved labels which resembled a $400 bill. It was claimed to cure everything from gout to blindness.

Although some profits were realized from Kier's Rock Oil, they were entirely too small to satisfy a man of Kier's ambition, and he began experimenting with the possibility of using it as an illuminant to replace kerosene obtained from coal. The first experiments were anything but successful, and Kier, not a man to give up easily, hurried to Philadelphia to consult J. C. Booth, professor of chemistry. Booth suggested that he try distillation. After returning home to work on the distillation problem, he hit upon the idea that if one operation purified the oil to a certain extent, another would further improve it, and he was right. Thus Samuel Kier, before the discovery of the Drake Well, became the first petroleum refiner.

The First Decade

The first decade of the petroleum industry is one of the most sensational chapters in American history (*12*). Farms were turned into oil fields; villages became cities overnight; fortunes were made and lost in a day. Production rose from 2000 barrels in 1859 to 500,000 in 1860 and over 2 million in 1861 (*20*). During this brief period, the price of a barrel of oil fluctuated from $20 to 10 cents.

By 1870, 30 million barrels of oil had been produced. Although Pennsylvania had continued to be the area of highest activity, oil was also found in West Virginia, Ohio, Kentucky, and Kansas in 1860, Colorado in 1862, New York in 1864, California in 1866, and Wyoming in 1867. It is of particular interest that the California discovery was stimulated by the chemist who had played such an important role in the development of the Drake Well (*1*). While on a trip in California in 1864, Benjamin Silliman, Jr., was entranced with the "natural wells" of the Ojai Ranch and wrote to his friend Thomas R. Scott, vice president of the Pennsylvania Railroad, that a profit of $1,365,000 could be made by drilling 10 wells. Scott sent two nephews, Thomas R. Bard and D. C Scott, to the West, and in 1866 they drilled the first California well to produce oil in commercial quantities.

Transportation was one of the most pressing problems of the early days. The only means of transportation to railroads and rivers was by team and wagon, and the teamsters took full advantage of this situation. The high cost of transportation necessitated the development of more economical means, and plans for pipelines began to take shape. A 1000-foot line was completed in 1862, and in 1865 the first "long distance" pipeline, 5 miles in length, was built by Samuel Van Syckel. As might be guessed, the pipelines were built amid much violence and bloodshed, as the teamsters made vigorous efforts to block construction.

The first petroleum refineries were either taken over from or patterned after the "coal oil" plants. The stills were made of cast iron, with a thermometer and "gravity stick" as the only control instruments. The sole activity of the refiner was distillation, and kerosene was the only product in which he was interested. By 1865, there was some activity in making lubricants. Gasoline was a worthless product which created serious hazards. Slight improvements were made in refining during the early years, but no major advances occurred. Kerosene production was increased by about 20% through the discovery that heavier vapors could be condensed and returned to the still for cracking. This discovery was made by an operator who suddenly became ill and returned after four hours to find an abnormally high quantity of kerosene. Most of the earlier improvements resulted from such accidents or from sheer Yankee ingenuity.

Industry Employs Chemists

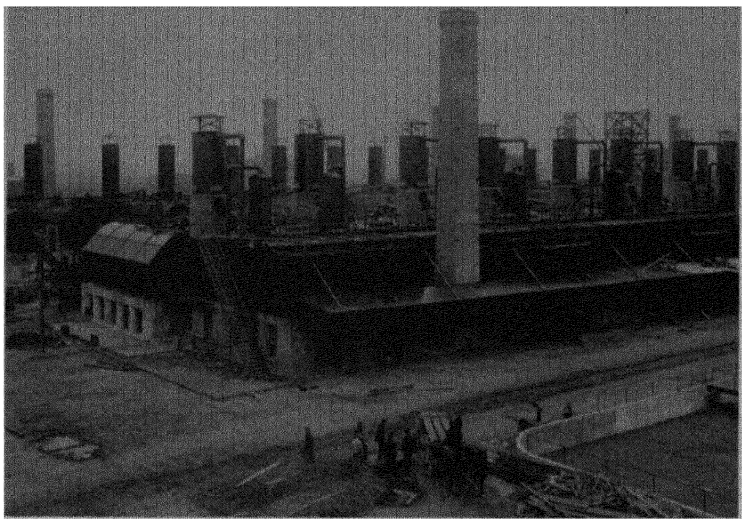
At the end of the first decade, the petroleum industry was a disorderly business. The major product, kerosene, was not uniform. "When a man lighted a lamp he never knew what it would do, smoke or explode" (*4*). The business itself was highly unstable and was a gambling game which resulted in enormous losses and waste. Into this scene came John D. Rockefeller, who sought to stabilize the price and to manufacture uniform products through control of refining and transportation. Working toward these ends, he merged his interests with others to form the Standard Oil Co. in 1870.

Rockefeller called in chemical and mechanical experts for consultation on his refining processes. As a result, advances were made not only in the standardization of products but in the improvement of yields. In the early eighties, Standard employed George Saybolt, probably the first full-time chemist to be hired by the petroleum industry, to work on the standardization of product specifications and test methods.

The real need for chemists in the refining industry became apparent in 1885, when the Lima, Ohio, field was discovered. Everything made from this high-sulfur oil had a skunklike smell. The only use that could be found for it was boiler fuel in industries that were unconcerned with odor. It sold for 14 cents a barrel compared to Pennsylvania crude at $2.25. The answer to the sulfur question was found by chemists. Herman Frasch came to Cleveland and developed a process for eliminating sulfur by adding copper oxide to the oil charged in the refinery. Standard purchased his patents and also employed two chemists, Clarence I. Robinson and William M. Burton, to work on improvements.

Burton, the first Ph.D. chemist in the petroleum industry, worked at the new Standard Oil refinery at Whiting, Ind. (*2*). The first products of the Whiting refinery were discouraging; the kerosene still had the strong smell of Lima crude. Burton set to work in his small laboratory on the second story of a farm house and in due time solved the sulfur problem through improvements in the Frasch process. He expanded his laboratory staff to include George W. Gray in 1896 and Robert E. Humphreys in 1900. The experience with Lima crude had given the petroleum industry a real lesson in the value of research and technology and spurred the industry on to modern refining processes.

Forward-looking petroleum men on the West Coast were also beginning to appreciate the value of science in the oil industry at about the same time (*24*). When the Union Oil Co. was organized in California in 1890, $2500 was appropriated for a laboratory. In 1891, Frederick Salathe, a Swiss chemist who had claimed to have a process which would refine the stubborn California crude into a water-white illuminant, was employed at the unheard-of salary of $10,000 per year. He was succeeded in 1893 by S. F. Peckham, a University of California chemist. At this time, the kerosene produced from California crude could not compete on equal terms with eastern oils, and Peckham had to start on the ground floor. He told the directors: "The trouble with California crude is that no one knows anything about it. We do not know what we are working on and the results of our labor thus far have been sort of thrusts in the dark." Progress was made, however, and the Union Oil refinery succeeded in making good commercial products.



In 1908, this battery of shell stills was operated at the Bayway refinery of Standard Oil of New Jersey

In 1900, Clarence I. Robinson set up the first special research laboratory of the industry at the Standard Oil Co., Bayonne, N. J. Heretofore, research had been carried out within various refinery departments.

Roughly speaking, 1900 marks the end of the "kerosene age" of the petroleum industry. Over 900 million barrels of crude oil had been produced. New production areas continued to be found (*20*). The Lima field had been extended into Indiana and Illinois, and oil had been discovered in Oklahoma and Texas. A network of pipelines carried oil throughout the producing regions and to the seaboards. Many of these pipelines were constructed under opposition from the railroads. This hostility was even more formidable—though less violent—than that of the teamsters. In addition to kerosene, refiners produced fuel oil, lubricants, greases, waxes, candles, and asphalt. Near the end of this era, some gasoline was sold as cleaning fluid, paint thinner, and for use in stoves designed by Standard Oil.

Refining at the turn of the century was mainly a matter of physical separation and chemical treatment of products with sulfuric acid and caustic soda to improve odor and color. Although there was interest in continuous distillation almost from the beginning of the industry, commercial installations did not appear until the first distillation columns were built by the Atlantic Refining Co. in 1885 (*18*). The principal product, kerosene, was produced by simple methods, and there was little need for innovations in the refining processes. The production of lubricants required somewhat greater technical skill. Filtration through bone black to improve color and odor was adopted early. Dewaxing operations were initially carried out by chilling oils with ice and salt. The resulting pasty liquid was placed in a canvas bag, and the oil was pressed through the pores of the canvas. In 1880, this method was replaced by the plate press method which, in addition to improving the oils, made possible the paraffin wax industry. Near the turn of the century, operations were improved by subjecting the crude to a cold settling process and by using fuller's earth for filtration.

The revolution of refining processes from physical separation to chemical conversion was still to come, but the seeds had been planted. Research had been initiated, and the incentive was soon to appear in the form of that revolutionary modern invention, the gasoline buggy.

1900–1920

With the 20th century came many revolutionary changes in the petroleum industry. In a short time, an illuminating oil business became a gasoline industry. Crude production increased from 63,621,000 barrels in 1900 to 442,929,000 barrels in 1920. Some of the largest oil-producing areas were discovered in the Texas Gulf area, Oklahoma, California, and Illinois. Geology was being used increasingly in exploration for oil.

This period also saw the final dissolution of the Standard Oil Trust into 33 independent companies. Despite the sentiment against the old Standard organization, it must be given due credit for its part in turning a chaotic industry into an orderly enterprise and in setting a pattern for thousands of oil companies enjoying successful operation today.

In 1900, the prospects of the oil industry were none too bright. Although there were 8000 automobiles in the United States, their significance was not apparent, and the markets for kerosene as an illuminant were dwindling as a result of the increased use of electricity and manufactured gas for illuminating purposes. By 1910, however, when auto registration had reached 500,000, progressive minded oil men were beginning to realize that the industry would be called upon to produce enormous quantities of gasoline. At that time, gasoline constituted only 13% of the products from crude oil.

Other factors also had an important bearing on the growth and nature of the oil industry. The development of the airplane resulted in another market for gasoline. Both the auto and airplane required special lubricants. Fuel oil demands also increased markedly after 1904, when the U. S. Liquid Fuel Board issued an exhaustive report on the relative efficiencies of coal and fuel oil (*15*). World War I placed even greater demands on the petroleum industry. For the first time in history, a fully mechanized war was being fought, and large quantities of gasoline and fuel oil were necessary to keep the equipment moving.

Increased production of crude oil was not enough to raise gasoline production to meet the growing demands. Greater efficiency in distillation and entirely new processes were necessary. From 1905, there was a gradual change from multiple batch distillation to more selective fractionation (*5, 16, 18*). Progress followed rapidly with the introduction of pipe stills, baffle-plate towers, bubble towers, and heat exchangers.

While the fractionation of greater quantities of crude oil by the methods then in use would increase gasoline production, it would also increase the quantities of kerosene and other products far beyond the demands for them. Some method had to be found for obtaining a higher percentage of gasoline from crude oil. The answer was to come from chemists.

First Cracking Process. About 1909 at Standard of Indiana, W. M. Burton and his laboratory staff, which included R. E. Humphreys and F. M. Rogers, began work on the gasoline problem (*25*). Through their knowledge of chemistry, the Standard men reasoned that high percentages of gasoline could be produced by cracking. After experimentation and careful study of the commercially unsuccessful work by Dewar and Redwood in England, they developed an effective process through use of pressure. In 1911, Burton went before the directors of the parent Standard Oil Co. in New York and requested $800,000 to build six batteries of pressure stills. The answer was emphatic. "No," they said, "You'd blow the whole state of Indiana into Lake Michigan." In a short time, however, the Standard Oil Co. was broken up by court order, and Standard of Indiana became an entirely independent company with a new board of directors, of which Burton was a member. He had better luck in selling his idea to the Indiana board, and the first battery of cracking stills went into operation at Whiting in January 1913. The process was also licensed to other companies, and within a year 240 units more had been authorized.

Shortly thereafter, a number of other cracking processes were developed and many were put into commercial operation. For some time, there was much patent conflict which has since been resolved through licensing policies, so that refiners could make use of the technology best adapted to their particular problems. Some of the liquid phase processes either developed or put into operation during this period were those of Cross, Dubbs, Fleming, Holmes-Manley (Texas Co.), Isom (Sinclair Refining Co.), Jenkins, and the "tube and tank" process (Standard Oil Co., New Jersey). There were also a number of vapor

phase processes, including those developed by Alexander, General Petroleum Corp. (Washburn), Greenstreet, Hall, Parker, Ramage, and Rittman. Although many of these vapor phase methods were put into commercial operation, they were not so successful as the liquid phase processes. The McAfee (Gulf Refining Co.) process is of interest because it was the first example of commercial catalytic cracking.

The first successful continuous method of cracking heavy oils was the Dubbs process, which could be operated for over 20 days without a shutdown, as compared to about two days for the batch-type processes. The Dubbs process introduced the principle of "clean circulation," which almost entirely eliminated coke deposits. In addition, it was the basis for the founding of the Universal Oil Products Co., the first company devoted wholly to research, development, engineering, and service.

Toluene, Too. While the leading product of all of these processes was gasoline, the General Petroleum Corp. had a petroleum cracking process for making toluene, basic material for TNT (*16*). During World War I, toluene installations costing $5 million were built at General Petroleum's Los Angeles refinery and at Standard Oil of California's plant near San Francisco. These two plants produced 3 million pounds of toluene a month.

Prior to 1920, chemical treatment of gasoline was simple. It usually consisted only of washing with caustic soda or sodium plumbite solution, or treating with sulfuric acid followed by an alkaline wash. The latter treatment was used on all cracked gasolines. With the development of cracked gasoline, the necessity of solving the odor and color problems became more apparent. Although odor and color in cracked gasoline actually were not an indication of inferiority, consumers used these properties as their criteria for judging quality.

Need for a Petroleum Division. Although the number of chemists employed in the oil industry was small, there was growing recognition of their importance in many branches of the industry. For example, Standard of Indiana's chemical staff had grown from three in 1900 to 13 in 1920 (*9*). Refiners had learned that crude oils vary widely in their chemical composition and should be processed accordingly. The changing markets of the industry also called for research on new processes. Not only was more gasoline needed but better gasoline. Knowledge of the chemistry of the product showed promise of providing answers to the problems. The same was true of lubricants. The industry was also beginning to appreciate the need for basic research. In 1911, the Gulf Refining Co. established a program of industrial fellowships in petroleum at Mellon Institute.

This state of affairs existed when on January 15, 1918, Ralph R. Matthews wrote to Charles L. Parsons, secretary of the AMERICAN CHEMICAL SOCIETY, suggesting the formation of a new division devoted entirely to petroleum (*14*). Heretofore, all papers dealing with petroleum had been presented before the Division of Industrial and Engineering Chemistry. Although Parsons was in favor of the formation of a petroleum division, he was fearful that an insufficient number of members would be interested and that the petroleum industry would be reluctant to meet for the exchange of technical information. The urgent problems of World War I served to postpone further consideration of the matter until 1920.

1920–1940

Founding of the Petroleum Division. At the spring meeting of the AMERICAN CHEMICAL SOCIETY at St. Louis in 1920, a number of chemists interested in a petroleum division again approached Parsons. He suggested a survey to determine whether a sufficient number of members would support such a division. Following up this suggestion, Matthews wrote to his former professor, F. G. Cottrell, who was then director of the Bureau of Mines, to ask for help from the Petroleum Division of the bureau. The matter was turned over to E. W. Dean at Pittsburgh and N. A. C. Smith at Washington. Dean discussed the matter with W. A. Hamor of Mellon Institute and obtained the wholehearted support of a number of chemists from that institution. At the same time, Smith was working with Parsons to secure a list of representative chemists whose opinions should be asked.

In February 1921, a questionnaire was sent out to determine interest (*11*). Although the usual resistance to any new organization was encountered from a few who were active in other societies interested in petroleum, the general response was excellent. Plans were immediately made to hold an organizational meeting at the Rochester ACS meeting in April 1921. An attractive program was provided under the guidance of W. A. Gruse of Mellon Institute.

T. G. Delbridge of the Atlantic Refining Co. was selected chairman and W. A. Gruse, secretary-treasurer, of the new section. While the members were wrangling over the amount of dues to be assessed, C. F. Mabery of the Case School of Applied Science illustrated his opinion by giving the treasurer $3.00. Almost everyone followed his example, and this amount was then officially approved as the annual dues. Other matters settled at the time included plans for the fall meeting at New York and a decision to furnish each member with abstracts previous to the meetings.

Following the New York meeting, at which 12 papers were presented, a meeting was scheduled for Birmingham in the spring of 1922. At the Birmingham meeting, the ACS Council voted to give the Petroleum Section divisional status, provided acceptable bylaws were submitted at the fall meeting at Pittsburgh (1922). The Council approved the Bylaws submitted at that time and thus the Division of Petroleum Chemistry became a reality. The first divisional officers were: T. G. Delbridge, chairman; D. K. French, vice chairman; W. A. Gruse, secretary-treasurer; W. H. Fulweiler and E. W. Dean, executive committee.

Significance of Early Programs. The titles of the papers at the early meetings of the Petroleum Division indicate some of the important problems of the time (*17*). Among the highlights of the first program was C. F. Mabery's paper on "Petroleum Hydrocarbons That Cannot Be Distilled," one of the first reports on attempts to separate heavy hydrocarbons. Members in attendance recall that the blackboards were covered with molecular formulas illustrating the giant compounds which Mabery discussed. The paper on "Viscosity-Temperature Curves of Fractions of Typical American Crude Oils" by E. W. Dean and F. W. Lane was a forerunner of the classic Dean and Davis viscosity tables. Keen foresight was displayed by Sidney Born in his paper on "Petroleum, a Raw Material for Our Chemical Industries." He called attention to the possibility of using olefins from cracked gases to make alcohols. In addition, he stressed the importance of butadiene, predicting its use as a synthetic rubber.

The status of chemistry in the petroleum industry was effectively summarized in B. T. Brooks's paper, "Some Chemical Considerations of Petroleum Refining" (*8*). He questioned whether, in practice, there was actually such a thing as a chemical technology of petroleum. Besides lauding the philosophy which had inspired the founding of the Petroleum Division, he drew attention to the need for more chemists in the oil industry and for the increased publication of research findings in the petroleum field. He scoffed at the "supposed value of secrecy" and stated that "delay in publication sufficient for patent protection is reasonable but, beyond this, there is no excuse for the burying of scientific information in private office records."

Brooks stressed the importance of doing more work in nonbenzenoid chemistry. He believed that unsaturated hydrocarbons were not well enough understood and that contemporary practices used in removing them resulted in great losses. The

problems of resin and tar formation were also considered. He emphasized the necessity for studying polymerization reactions as a possible source of lubricating oils. Research, he believed, was the answer to the refiner's problem. How very right was his conclusion that "economies . . . will more than cover the sum total of the cost of all petroleum investigations, even should these investigations be undertaken on a very large scale indeed!"

No discussion of the oracles who were present at the initial meeting would be complete without a word on Thomas Midgley, Jr. Actually, the Petroleum Division did not hear until the next year about his discovery of the use of tetraethyllead as an antiknock compound. About the implications of antiknock properties and his predictions of increased mileage through higher compression ratios, Midgley said nothing to the Rochester meeting. However, the distinct aroma of polecat which proclaimed his presence gave an inkling of things to come. On questioning by some of the more courageous members, he revealed that he had been working on diethyl tellurides and selenides in his search for antiknock compounds.

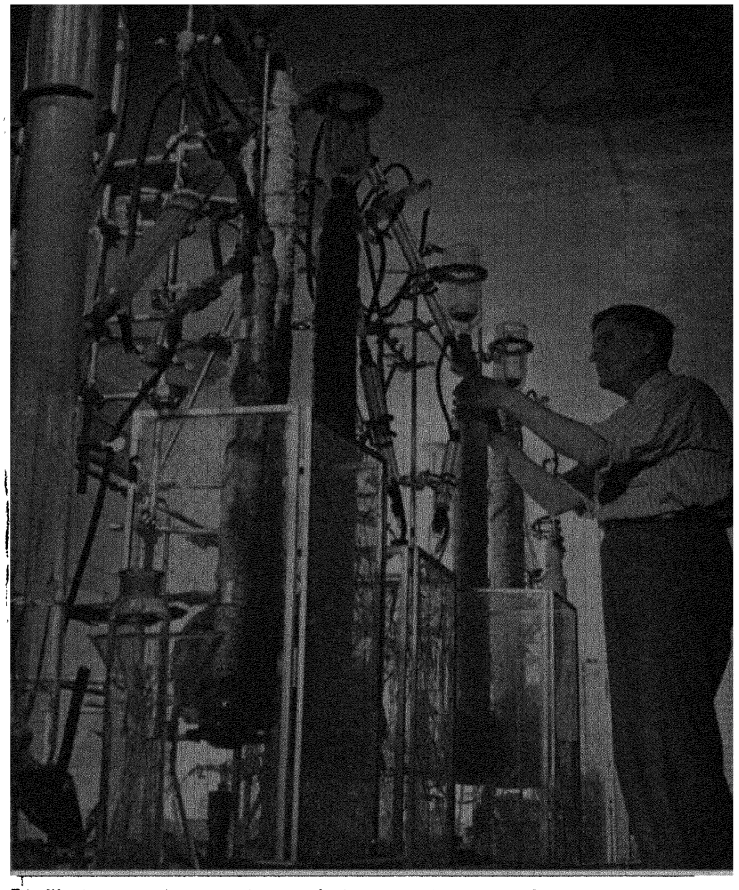
The program at New York in the fall of 1921 attracted attention from distant areas because of the discussion on crude oil emulsions. One chemist came all the way from California to present a paper, and gratified the founding fathers of the division by saying that he had learned a great deal more than he had given.

Outstanding at the Birmingham meeting in the spring of 1922 was a paper on "The Pioneer's Field in Petroleum Research" by Van H. Manning of the American Petroleum Institute. He listed 70 problems which needed investigation, and laid particular emphasis upon the necessity for studies of the physical and chemical constitution of petroleum. The immediate effect of his appeal was the formation of a committee within the Petroleum Division to cooperate with Manning. This paper also had a long-range effect as one of the first in a series of appeals which led to the establishment of the American Petroleum Institute's fundamental research projects at leading universities in 1926. These projects, originally sponsored by grants of $250,000 each from John D. Rockefeller and the Universal Oil Products Co., have been of utmost importance in obtaining basic data in petroleum chemistry.

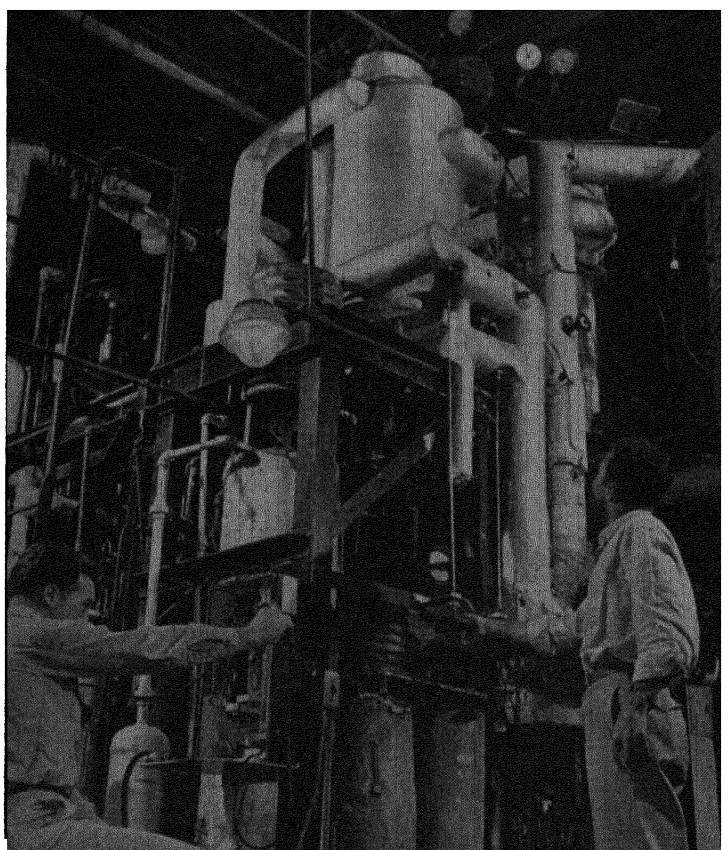
Rapid Expansion and Improvement. The progress of the petroleum industry during the two decades following the birth of the Division of Petroleum Chemistry advanced motor transportation to a new high level. By 1940, crude production had been more than tripled (to 1,328,000,000 barrels) through better production methods and the discovery of vast new fields in Texas, Oklahoma, and California. Separation processes in the refinery advanced greatly through the ever-increasing knowledge of the physical properties of individual hydrocarbons. Analytical studies were greatly facilitated by the introduction of such equipment as the Podbielniak distillation apparatus.

The cracking art was undergoing rapid development throughout this period. Continuous processes, such as the improved Cross, Dubbs, Holmes-Manley, and "tube and tank" processes, gradually superseded the original batch procedures (*7*). Some new vapor phase processes, including the Gyro process of the Pure Oil Co., were also put into operation during this period. With these changes came many new developments in equipment. Operating pressures, which had originally been 75 pounds per square inch, were increased to as high as 1000. Time of operation was lengthened, and it was possible to build increasingly larger units (*9*); the original Burton units charged about 200 barrels per day and ran for only 48 hours without a shutdown, while by 1938, cracking units of 45,000-barrel capacity were in existence and runs were over 100 days.

Catalytic Processes Introduced. The foregoing discussion indicated only the existing thermal processes. Although these constituted almost the entire cracking capacity before 1940,



Distillation equipment is used in investigation of new petroleum process at the California Research Corp.



Houdry catalytic cracking unit supplies pilot plant data required for later design calculations

intensive research on catalytic processes for cracking and other hydrocarbon conversions was going on during the thirties. Catalytic polymerization was installed in 1934 for the conversion of gases from cracking operations into high octane motor gasoline. The first catalytic cracking process was the Houdry fixed-bed. A unit of 200-barrels-per-day capacity was installed by the Socony-Vacuum Oil Co. in 1934, and a large unit was built within a few years by the Sun Oil Co. About 1938, still another catalytic process, called alkylation, made its appearance. This process enabled refiners to make a high octane aviation fuel component from refinery gases. These processes ushered in a new era of refining which was to reach full scale proportions in the next decade.

These technical achievements, along with automotive research, brought about major advancement in gasoline quality. The concept of antiknock properties was introduced about 1922 with the announcement of the use of tetraethyllead as an antiknock compound. The octane scale was devised a few years later. Furthermore, petroleum chemists had become aware of the fact that cracked gasolines had much better antiknock properties. Higher octane motor gasoline was also made available through thermal reforming processes. Stimulated by aviation requirements, methods were sought to make gasoline of still higher octane rating. Through hydrogenation processes, the industry was able to supply limited quantities of 100-octane gasoline (*15*), but the octane number of most of the commercial aviation gasoline did not exceed 87 until alkylation processes were put into operation.

Another notable improvement in gasoline quality has been made possible through the use of antioxidants rather than sulfuric acid in preventing the formation of gum. The sulfuric acid treatment results not only in the removal of some high octane hydrocarbons but also in the formation of undesirable polymers and acid sludges. In contrast, antioxidants eliminate gum formation by preventing oxidation, without the simultaneous removal of hydrocarbons. Moreover, antioxidants do not catalyze the formation of polymers or sludges.

Chemistry in Lubricant Manufacture. Although lubricants are a smaller volume product of petroleum than gasoline, their quality is of equal importance. A number of important advances in the field of lubricants were made during the twenties and thirties. About 1920, the centrifugal separator was introduced in dewaxing operations. Solvent dewaxing began to replace the plate press and centrifuging methods in 1927. The first process used benzene-acetone; a process utilizing propane was installed in 1931 and another using benzene–methyl ethyl ketone appeared in 1934.

Growing recognition of the importance of viscosity came into the picture about 1925, when the industry became highly concerned over the cold-starting problems. By 1930, viscosity index was an established yardstick of the lubricant industry.

Solvent treating of lubricants was initiated in 1929, with phenol as the solvent. A chlorex unit was installed in 1932, a plant for furfural operation in 1933, and the first Duo-Sol (cresylic acid–propane) process in 1934. Propane deasphalting was introduced in 1936. The first synthetic lube oil, which was the polymerization product of cracked waxes, appeared in 1930. Application of high pressure hydrogenation to lubricating oil stocks began in 1932, with resultant improvement in quality.

The use of chemical additives has played an increasingly important role in improving the quality of lubricants. Shortly after 1920, the practice of adding small quantities of oleic acid from vegetable and animal oils to impart oiliness came into use. Particularly noteworthy was the introduction of oxidation inhibitors about 1928. The first use was in "lifetime" turbine oils, and since that time much progress has been made in the development of antioxidants for many types of oils. Pour-point depressors were introduced in 1930. Use of viscosity index improvers began about 1933. The first of these was polyisobutyl-

Battle of Britain. The greater power and maneuverability of planes fueled by 100-octane gasoline enabled British fliers to turn the tide of this battle against the Nazi air armada, which ran on 91-octane fuel. As the war progressed, aviation gasoline exceeded the 100-octane scale and new definitions had to be set up to describe it. Peak production of aviation gasoline reached 550,000 barrels per day.

The largest single factor in this increase of quality and quantity of aviation gasoline was alkylation. A total of 56 alkylation plants were in operation by the end of the war. The rapid commercialization of other catalytic processes was necessary for the production of sufficient raw materials for alkylation. The answer was found in isomerization processes, which were ready for commercial application at that time.

Quantity production of other components of aviation gasoline, such as isopentane and cumene, also required special processes. Production of base stocks was greatly enhanced by the widespread installation and improvement of catalytic cracking procedures. The new Fluid Flow and TCC processes, which were



Phillips Petroleum uses these fractionating columns in the production of liquefied petroleum gas

commercialized in 1942, had the decided advantages of permitting continuous operation and more economical use of catalyst. Fluid Flow units have been operated over 600 continuous days.

Because of the ingenuity of petroleum chemists, enough toluene was available to provide for the utilization of 10 times as much TNT during World War II as was consumed during World War I. In 1939 when war broke out in Europe, the coal tar industry was the sole source of toluene. Alarmed at the limited quantities available from that source, the industry took rapid steps to manufacture a nitration grade toluene from petroleum. The hydroforming process (catalytic reforming in the presence of hydrogen), which had been undergoing development since 1934, was put into operation and proved highly successful. During the first year of operation, the initial plant alone produced twice the previous peak rate of the coal tar industry.

If petroleum chemists had not found ways of making butadiene in enormous quantities, the American stockpile of natural rubber would have been exhausted before World War II had been won. In 1940, synthetic rubbers from petroleum had been developed and were in small quantity production for specialty uses. Foreseeing the disaster that would occur should the Japanese cut off our supplies of natural rubber, work was begun on large scale production of butadiene. Out of this came the dehydrogenation processes for converting butane and butylene into butadiene, and a whole new industry was created in a short period of time. Also of considerable importance was the development of extraction processes for separating pure butadiene.

Production of butadiene from petroleum reached one billion pounds in the postwar year of 1946. This quantity of butadiene permits the production of GR-S rubber in sufficient quantities to make the United States almost entirely independent of foreign supplies.

Although GR-S constitutes the bulk of synthetic rubber production, the oil industry has developed other rubbers which are particularly well suited for certain purposes. Perbunan rubber, which is oil-resistant, self-sealing, and flexible in extreme cold, was of high importance during the war. Butyl rubber, which became a commercial reality in 1941, is far superior to the natural product for tire inner tubes.

Lubricating oil and grease technology also showed many rapid advances during the war. Our troops required machines that would run under the most severe weather conditions. Products were needed for every kind of use—whether in airplanes flying at 60° below zero or in heavy tanks operating in desert heat. An increasing number of chemical additives came into use as well as synthetic lubricants.

because of the increase in compression ratios. The best prewar models had compression ratios of 6.5 to 1, whereas some 1951 models have compression ratios as high as 8.0 to 1. Correspondingly, research octane numbers have risen since the end of the war to an average of 84.9 for regular grade and 91.6 for premium gasoline. Specifications for military aviation gasoline have risen from 100-octane at the beginning of World War II to 115/145 grade at present. Although the cost of producing high octane fuel is greater, the consumer is actually saving money and oil resources are conserved. Since 1925 there has been a continuous increase in the octane number and compression ratios of automobiles which has resulted in better efficiency. Today 50% more mileage is obtained from each gallon of gasoline (*10*). Every increase in the quality of aviation gasoline enables planes to carry greater payloads and operate at higher speeds and with better maneuverability.

The greatest rise in demand for petroleum products has been in the distillate fuels, which include Diesel oil and light heating oil. Production of distillates has almost doubled from 172,800,000



Catalytic cracking unit produces high-octane gasoline at Gulf Oil's Philadelphia, Pa., refinery



At Bishop, Tex., Celanese Corp. of America turns out large variety of chemicals from petroleum

Although many scientific discoveries during the war period were necessarily held secret, the Petroleum Division continued to provide programs on nonsecret subjects. Many features of the catalytic processes which had recently come into widespread use were discussed. Papers on reaction mechanisms and catalyst studies were also presented. A Symposium on Catalysis in the Petroleum Industry was held in 1944. A number of the fundamental studies on hydrocarbons, contributed by those engaged in the API research projects, were presented before the division. "Bench Scale Techniques" were discussed at a symposium in 1944. Because of the crowded condition of transportation facilities and hotels, no national meetings of the Society were held in 1945, but the Petroleum Division contributed a full program of papers as a "Meeting in Print."

Postwar Increase in Demands. Despite many predictions that markets for petroleum products would decrease after the cessation of hostilities, demands were higher than ever before. Crude oil production has increased from 1,328,000,000 barrels in 1940 to an estimated 2 billion plus in 1950. Motor fuel production has increased about 25% since 1945 and over 45% above the prewar year, 1941. The number of motor vehicles has increased about 50% to a total of 48,000,000. Both commercial and private flying are more popular now than ever before.

The over-all result has been an increase not only in the quantity but also in the quality of gasoline. Present-day automobiles require much higher octane gasoline than did the prewar models

barrels in 1941 to 332,800,000 barrels in 1950. The use of Diesel engines by railroads is largely responsible for the growth in the Diesel oil market. The rise in heating oil consumption can be attributed mainly to the widespread installation of oil burners for home heating. As soon as burners were available after the war, many home owners took advantage of oil heating, which requires less manual labor and is cleaner and more easily regulated than coal heating. It is estimated that about 5 million homes are now heated with oil.

One of the most rapidly expanding branches of the oil industry is the liquefied petroleum gas industry. According to the Phillips Petroleum Co., one of the most active in this industry, production is about ten times greater than in 1940. Estimated 1950 production is 3 billion gallons.

No story of the oil industry would be complete without mention of asphalt, which is produced to the extent of over 9 million tons a year. Nowadays, about 90% of the surfacing of all new highways is of asphalt construction.

Broad Expansion Program. To meet the demands for increased quantities and qualities of petroleum products after the war, the petroleum industry has carried out a $12 billion expansion program. Refinery capacity has been brought to 6.7 million barrels per day. Of major importance is the fact that practically all new cracking installations have been catalytic. Compared to thermal cracking, catalytic cracking produces more gasoline and distillate fuel oils for which demand is high, and far less residual oil for which demand is relatively low. It

also permits much greater flexibility, so that gasoline yields can be increased in summer, while the percentage of heating oils can be increased in wintertime.

New installations of auxiliary processes such as polymerization have also been important in producing greater yields of high quality products. Reforming processes for raising the octane number of natural and straight-run gasolines are also of consequence in meeting demands. Recently a new catalytic reforming process called Platforming was put into commercial operation. Another factor which is of high importance in meeting the demands for high quality gasoline is a great increase in facilities for producing tetraethyllead.

With an increase in motor fuel consumption and improvements in automotive engines, there have been corresponding increases in quantities and qualities of lubricating oils. Annual production has gone from about 35 million barrels prewar to 50 million barrels in 1950. Present-day lubricants are tailor-made for specific uses. Synthetic lubricants and greases, such as esters, siloxanes, and phosphates developed during the war, and more recently all-purpose greases, a combination of lithium and ester types, have come into the picture. Increasing use is being made of additives and some new ones have been developed—for example, high level detergents which appeared in 1947.

From the wax fraction removed during the dewaxing operation, the petroleum industry produces over 1300 tons per day of refined waxes which are employed in numerous applications, ranging all the way from the coating of paper milk containers to the production of automobile polishes.

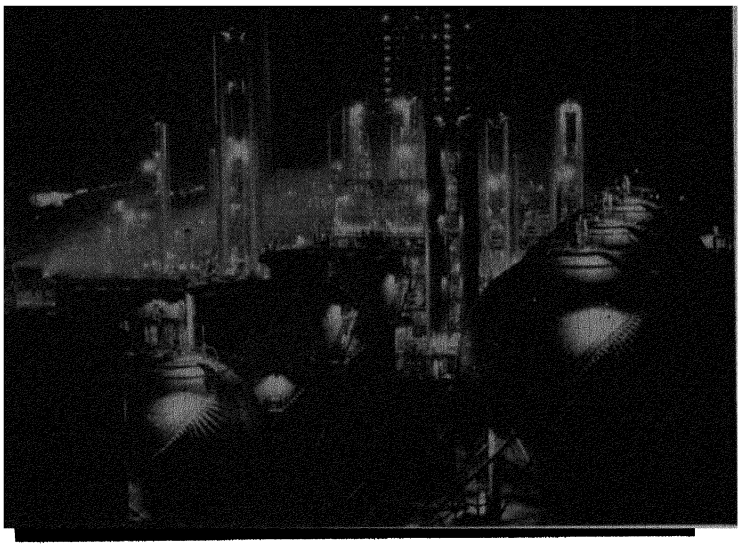
Fantastic Growth of Petroleum Chemicals. For many years, little thought was given to petroleum as a source of chemicals because almost nothing was known of the individual hydrocarbons present. Ethyl alcohol and ether were made from cracked gases in 1896 but the process was not commercially successful. In the early twenties, commercial production of isopropyl alcohol from petroleum gases began but output was small for many years, with only 150,000 pounds produced in 1925. Gradually other chemicals were added to the list, and in the period following World War II petroleum chemicals became an industry in itself. Over $500 million have been invested in plants on the Gulf Coast alone in the past five years. Production in 1950 is expected to be over 5 billion pounds. These products include both materials that are directly recovered from petroleum and natural gas and others that are derived by conversion processes.

Paraffin gases from natural gas and refining operations and olefin gases derived from refining are used as basic materials for high tonnages of oxygenated products such as alcohols, acids, aldehydes, and ketones. Petroleum is the only source of isopropyl alcohol, and about 70% of the ethyl alcohol and methanol is derived therefrom. Some alcohols of higher molecular weight are made from the liquid products of cracking by the oxo process. Ethylene glycol, another high tonnage product, is derived from petroleum gases. A large variety of chlorinated and nitrated products is also made from the gases.

One of the outstanding achievements is the manufacture of glycerol from propylene. This process is also of importance because of the many by-products, which include allyl compounds and the soil fumigant, D-D.

Another major technical advancement is the manufacture of phthalic anhydride by the oxidation of *o*-xylene derived from catalytic cracking or hydroforming. Similarly, terephthalic acid is made from *p*-xylene.

Aromatic hydrocarbons are also being produced in increasing quantities from petroleum. Formerly benzene was produced almost entirely by the coke-oven industry, which is geared to pig iron production. Present demands for benzene exceed the quantities available from that source and increases in supply necessarily come from petroleum. In 1950, about 10 million gallons are being made by modified hydroforming processes and



Night has descended upon the Richmond refinery of Standard Oil Co. of California



Brilliant lights illuminate a section of the Bayway refinery of Standard Oil Co. of New Jersey



Fractionators and Hortonspheres for butadiene storage are located at Humble's Baytown, Tex., refinery

it is expected that the new Platforming process will further augment the benzene supply. These processes can also produce large quantities of other aromatics such as toluene and xylenes.

The petroleum chemicals have a wide variety of uses. The largest volume consumer is the synthetic rubber industry, which has utilized as much as one billion pounds of butadiene per year. The agricultural industry is another important market. It depends on the petroleum industry for large quantities of insecticides, soil fumigants, weed killers, fertilizers, and other products.

The skyrocketing plastics industry uses enormous amounts of a wide variety of petroleum chemicals such as ethylene. There is also a large potential market for petroleum-derived benzene in plastics and resins based on styrene, phenol, and other aromatic substances.

The synthetic detergent industry, which has reached one billion pounds per year, is another large volume consumer. Of the active ingredients used, petroleum chemicals supply about 60%. This market will doubtless continue to expand because of the increasing popularity of detergents for many purposes. Petroleum chemicals have hundreds of other uses, such as in the manufacture of nylon, in textile processing, and in the food industry. These myriad products, however, have only a negligible effect on petroleum supplies. They represent less than 0.5% of the annual petroleum production and less than 10% of the natural gas production.

Research Expansion. The forward-looking attitude of the petroleum industry is to a great extent responsible for its notable achievements. No other industry has shown greater faith in research. Of the total industrial research expenditures in the United States, about 25% or well over $100 million comes from oil companies.

Although the petroleum industry has always been one of the leaders in industrial research, recent expansion has been tremendous. About five times as much is being spent annually on research as was spent in 1940. The number of college-trained employees has been increased greatly. Large new laboratories have been built in many areas of the country since the end of World War II. These new structures offer not only more space but the most modern equipment for carrying on investigations. Many small laboratories have also been built to handle special problems requiring unique facilities.

The number of problems on which the industry is doing research has vastly increased. Studies of motor and aviation gasolines and their behavior are being intensified and include investigations ranging from the theoretical appraisal of hydrocarbon constituents to road and flight tests. Processes for making gasolines are always under study, with the result that improvements are constantly being made. Similar activity in relation to other major products such as fuel oils, Diesel oils, and lubricants is also taking place. The great variety of products which the petroleum industry supplies to agriculture has given rise to special agricultural research units. For instance, the Shell Development Co. operates experimental farms in connection with its agricultural laboratory.

Entirely new factors are constantly arising to act as a challenge to the industry. An example is the jet plane. Much work has been done on fuels for jets and satisfactory ones have been produced, but a number of problems remain unsolved. Out of the research now going on will come tailor-made jet fuels and processes for making them, just as special products and processes were found for high quality aviation gasoline.

Another problem which has recently attracted much attention is synthetic fuels from natural gas, coal, or oil shale. While the oil industry is confident that petroleum supplies are adequate for the foreseeable future, it believes in being prepared for unforeseeable events. Consequently, a number of companies are engaged in research on synthetics, so that they will have the technical knowledge to proceed with commercial development if the need arises. The Bureau of Mines is also actively engaged in research on synthetics, particularly fuels from coal and oil shale.

Great as the achievements in petroleum chemistry have been in the past, they are small compared to future possibilities. The intensive research program of the industry will not only make possible marked improvements and economies in present products but will add hundreds of entirely new products to the list of over 2600 now produced from petroleum.

Officers of the Division of Petroleum Chemistry, 1921–1951

Year	Chairman	Secretary
1921–1922	T. G. Delbridge	W. A. Gruse
1922–1923	T. G. Delbridge	W. A. Gruse
1923–1924	Ralph R. Matthews	W. A. Gruse
		G. A. Burrell
1924–1925	Ralph R. Matthews	G. A. Burrell
1925–1926	Ralph R. Matthews	G. A. Burrell
1926–1927	Ralph R. Matthews	G. A. Burrell
		F. W. Padgett
1927–1928	J. Bennett Hill	C. L. Johnson
1928–1929	J. Bennett Hill	C. L. Johnson
1929–1930	J. Bennett Hill	C. R. Wagner
1930–1931	C. R. Wagner	C. D. Lowry, Jr.
1931–1932	C. R. Wagner	F. L. Koethen
1932–1933	F. W. Sullivan, Jr.	C. R. Wagner
1933–1934	F. W. Sullivan, Jr.	C. R. Wagner
1934–1935	F. W. Hall	C. R. Wagner
1935–1936	F. W. Hall	C. R. Wagner
1936–1937	J. C. Morrell	C. R. Wagner
1937–1938	J. C. Morrell	C. R. Wagner
1938–1939	P. K. Frolich	C. R. Wagner
1939–1940	P. K. Frolich	C. R. Wagner
1940–1941	J. K. Roberts	C. R. Wagner
1941–1942	J. K. Roberts	C. R. Wagner
1942–1943	C. L. Brown	L. M. Henderson
1943–1944	C. L. Brown	L. M. Henderson
1944–1945	S. S. Kurtz, Jr.	C. R. Wagner
1945–1946	S. S. Kurtz, Jr.	C. R. Wagner
1946–1947	Gustav Egloff	C. R. Wagner
1947–1948	Gustav Egloff	C. G. Kirkbride
1948–1949	W. E. Kuhn	C. G. Kirkbride
1949–1950	A. A. O'Kelley	C. G. Kirkbride
1950–1951	B. H. Shoemaker	C. G. Kirkbride

Symposia Featured on Division Programs. The programs of the Petroleum Division since the end of World War II have been particularly well organized and timely. General papers have covered the newer analytical methods, properties of pure hydrocarbons, discussions of various processes, chemical production, catalyst studies, and other subjects. A large number of symposia have been devoted to many of the important subjects of this period. The recent enlivened interest in synthetic fuels prompted the organization of a symposium jointly with the Division of Gas and Fuel Chemistry on "Production of Synthesis Gas." The oil shale aspects of the synthetic fuel question have been discussed in a number of papers on the general programs. At a Symposium on Modern Motor Fuels in 1948, gasolines, Diesel oils, and various processes for making them were treated in the light of recent knowledge and practices. The "Relationship of Fuel Properties to Engine Design and Future High Octane

Fuels" was dealt with more specifically in a later symposium. Interest in the new synthetic lubricants, such as siloxanes, esters, and polyalkylene glycols, stimulated a Symposium on Synthetic Lubricating Oils in 1950.

Although methods for removing sulfur from petroleum and its products have long been known, the petroleum industry is still searching for better methods and has a great interest in putting to economic use every single constituent of a barrel of oil, including the sulfur compounds. At a Symposium on Organic Sulfur Compounds as Related to Petroleum, papers were presented on the sulfur content of crudes and gasolines, properties of sulfur compounds, and methods of removal and recovery.

The rapidly growing petroleum chemicals industry was the basis for two symposia. At the Symposium on the Halogenation of Hydrocarbons and Properties of Products in 1949, both fluorine and chlorine derivatives were subjects of papers presented. In keeping with the widespread interest of the industry in agricultural products, the Petroleum Division cooperated with the Division of Agricultural and Food Chemistry to present a Symposium on Agricultural Applications of Petroleum Products in 1950.

At the Symposium on Use of Isotopes in Petroleum Chemistry, held jointly with the Division of Physical and Inorganic Chemistry in 1950, papers were given on catalyst studies, reaction rate studies, and related subjects. The papers described the industrial uses for isotopes now available as by-products of the atomic bomb project.

Realizing the dependence of petroleum research on scientific literature, the Division of Petroleum Chemistry cooperated with other divisions in presenting symposia on literature techniques and nomenclature. The first of these on "Literature and Patent Surveys and Petroleum Information Services" was held in 1947; the second on "Nomenclature of Hydrocarbons" in 1949.

The expanded research program and broadened interests of the division have also resulted in an increased number of papers. Before 1940, the maximum number of papers at any national meeting was 28, but since that time the average number has been well over 30 and at the spring 1949 meeting 60 papers were presented on programs organized by the division.

Division's Growth Parallels Industrial Expansion. The division has continued to furnish all members with complete preprints of all papers before each national meeting. It has found this service highly valuable for a number of reasons. It gives members who cannot attend the opportunity to keep up to date and those who do attend the opportunity to be prepared for discussion. It also provides for the dissemination of information which may be delayed in publication or never published. Members also receive an annual directory and complimentary copies of the *UOP Bulletin of Abstracts*.

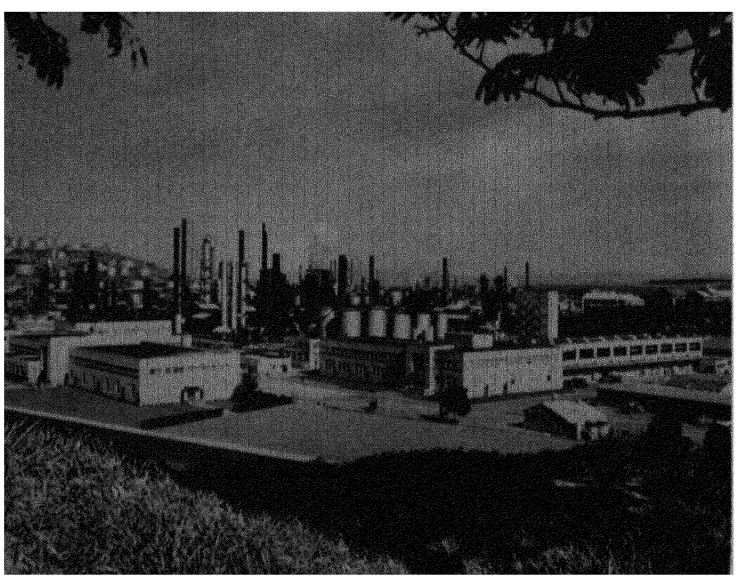
In 1948, the bylaws of the division were revised to provide for an expanded Executive Committee. In place of two members-at-large, the division now elects six area representatives to the committee. Each area is thus assured of having a representative on the division's governing body.

The organization of the division provides for a Committee on Papers, which reviews all manuscripts submitted for the divisional meetings. This committee plays an essential part in maintaining the high quality of the programs. The bylaws also provide for the appointment of such special committees as may be needed. Among those operating at present is a Membership Committee, which is very active. A special committee on nomenclature is studying specific problems in that field and is cooperating with other AMERICAN CHEMICAL SOCIETY committees in an effort to standardize practices. A new Committee on the Improvement of the Petroleum Division has been created to increase interest and participation in the division. The division is making a real effort to improve its services.

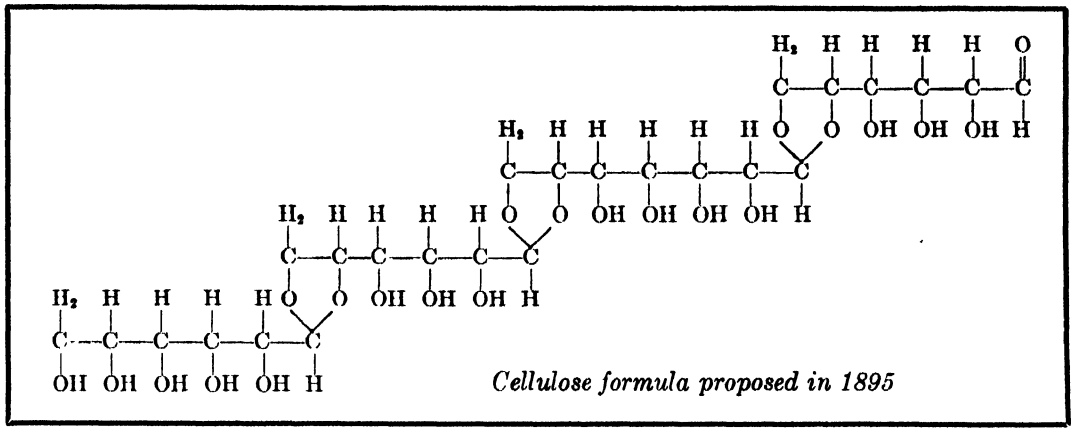
The division is the second largest of the AMERICAN CHEMICAL SOCIETY and has a membership of over 1800. It has almost tripled in size during the past decade. Taking into account the tremendous future expansion of the industry, an even greater increase in divisional membership can well be expected.

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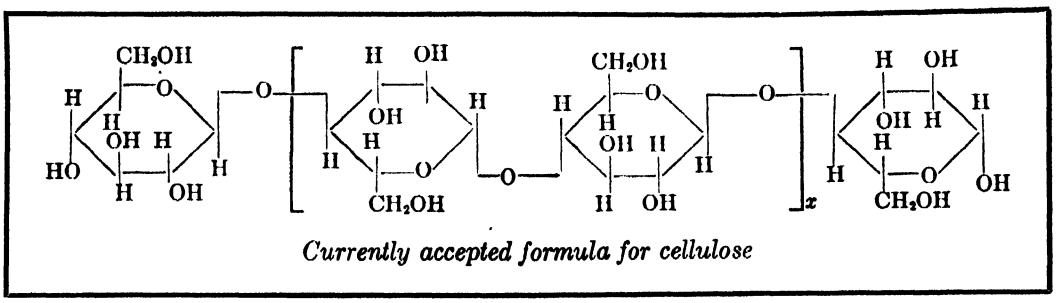
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Panoramic view indicates the breadth of Standard's research laboratories and refinery at Richmond, Calif.



Cellulose formula proposed in 1895



Currently accepted formula for cellulose

Cellulose Chemistry

In the main, the clothes we wear, the books we read, and the homes we inhabit are cellulose

W. O. KENYON
Eastman Kodak Co., Rochester, N. Y.

CELLULOSE in its varied forms has been a natural asset of untold importance in the development of civilization. Prehistoric man used wood for light, warmth, and weapons. We do not know when cellulose, in the form of cotton, was first used as cloth. The Greek historian, Herodotus, described, in 400 B.C., a fleece- or wool-bearing tree seen by travelers in Asia. Undoubtedly, the cotton plant was cultivated much earlier, for remains of cotton fabric have been unearthed in the tombs of the Pharaohs.

Most natural resources are irreplaceable. Cellulose is unique among the great resources in being replaceable on a short term basis as cotton, linen, ramie, and so forth, or on a longer term basis as wood.

Today, the production and utilization of cellulose materials represent one of the great sources of national income. In reality, cellulose is the basis not of one industry but of a complex interrelated group of industries. Cotton is a major agricultural product, the 1949 crop being valued in excess of $2 billion (*13*). But this is only one aspect of its importance. The spinning, weaving, dyeing, and garment trades depend heavily on cotton. The cultivation of flax makes possible the production of beautiful linens. Similarly, a diversified group of industries are based on wood as the raw material. Lumbering, building, and wood fabrication operations provide incomes for millions of people. In addition, pulps from soft and hard woods are the basis for the paper, printing, and publishing businesses.

These vast areas of human activity long preceded organized science. Such activities utilized the physical properties of wood or cellulose fibers and hence were not restrained by any lack of understanding of the chemistry of cellulose. Though this field developed largely on an empirical basis, science and technology were powerful forces in its growth. However, several industries

today owe their very existence to scientific discoveries concerning the basic chemical reactions of cellulose. These include the conversion of cellulose into a xanthate whose solutions produce threads of regenerated cellulose (rayon) or transparent, flexible sheeting. Other chemical operations produce cellulose ethers and esters, which are utilized for plastics, transparent sheeting, fabrics, and lacquers. Prior to the days of metal construction, cellulose ester dopes or lacquers conferred the all-important tautness to fabric-covered wings and bodies of early airplanes. The vast motion picture industry is literally based on transparent cellulose ester films and owes its inception to the advent of such films. The growth of the Division of Cellulose Chemistry of the AMERICAN CHEMICAL SOCIETY was coincident with the modern growth of commercial enterprises based on the chemical properties of cellulose and many of the division members played important roles in these developments.

Despite increasing competition from other natural and synthetic materials, the various forms of cellulose play an ever more important part in daily living. Shortly after birth, we are wrapped in cellulose, we use it in a multitude of ways during life, impress our thoughts on it for posterity, and we are shrouded in it at death. Ironically, cellulose nitrate long ago made possible smokeless powder—a sinew of modern warfare—yet chemical oxidation of cellulose now produces a new surgical gauze to aid in healing the wounds of war.

Cellulose is one of the few natural polymers. Others are starch, rubber, and proteins. Cellulose occurs in a relatively pure state in cotton fibers. It is an important part of the structure of woody tissues of all plants, but here it is closely associated with lignin, pentosans, and other materials. These are difficult to remove completely for the purpose of obtaining a pure cellulose. This problem confused and hampered the early investigators. The purification of cellulose from various plant sources is still an important field of investigation.

Beginnings of Research

The initiation of research in cellulose chemistry is credited to Anselme Payen (*8*, *10*), professor of "Arts et Métiers" in Paris. Payen's investigations of 1837–42 led him to the conclusion that the fibrous constituent of all young plant cells was a carbohydrate composed of glucose residues which had the same chemical composition as starch (44.4% of carbon and 6.2% of hydrogen) yet which could be differentiated from starch by color tests. He named the material *cellulose*. It is remarkable that Payen should have reached these conclusions. His analyses of different cellulose preparations showed deviations from the proper values, and methods for identifying even a simple sugar such as glucose were not well advanced. At this time, organic chemistry was beginning to emerge as a unified branch of science. Liebig had just introduced his analytical methods (1830). Moreover, the decade coincident with Payen's researches (1830–1840) saw the introduction of the compound radical theory of Liebig and Wöhler, which led to the formulation of modern structures of organic compounds.

Payen's description of cellulose as a definite chemical entity did not pass unchallenged. The use of severe chemical treatments to separate cellulose from plant tissues often changed its chemical and physical properties. Milder treatments did not completely remove materials such as lignin, hemicelluloses, and pentosans. These incompletely purified cellulose samples gave sugars other than glucose upon hydrolysis, and the elementary analyses and staining reactions differed from those of Payen's cellulose. Inasmuch as the residual materials varied according to the original plant tissue used, it was argued that each plant produced its own particular type of cellulose. These alleged celluloses were designated according to their plant source—e.g., "bastose" from jute, and so forth. Cellulose of the composition $C_6H_{10}O_5$, containing only combined anhydroglucose units, was considered as an artificial result of chemical treatments carried far enough to produce the desired analytical values and chemical properties.

The various researches on the uniformity of cellulose produced several valuable results. Schulze differentiated cellulose from the associated hemicellulose by recognizing that hemicellulose is more readily hydrolyzed and yields sugars other than glucose. Pectins were distinguished from cellulose, and the term "lignin" was given to the noncarbohydrate portion of the cellulose incrustants. Though recognition of these associated substances should have contributed greatly to an understanding of the variations of properties of the so-called celluloses from different sources, the question of the uniformity of cellulose was not settled until the early 1920's.

During the controversy over the nature of cellulose, many observations were made regarding its chemical reactions. These findings led to important commercial developments. The action of nitric acid on cellulose to produce a partially nitrated product which could be formed into clear, flexible, films was discovered by Braconnot in 1833. The more highly nitrated products (guncottons) were discovered in 1847. At that time, the very significant observation was made that no more than three nitrate groups per anhydroglucose unit could be introduced into the molecule. Treatment of cellulose with hot acetic anhydride yielded cellulose acetate (1870), and the triacetate was recognized as the most highly acylated product.

Investigations of the purification of cellulose had uncovered the solubility of cellulose in cuprammonium solution and its regeneration therefrom and the action of zinc chloride and sulfuric acid to parchmentized paper. Very important contributions to cellulose technology were made in England by John Mercer. His studies of the action of alkali on cellulose produced the improvements in dyeing behavior, luster, and tensile strength which became known technically as "mercerization." These pioneer investigations were extended by others to the production of alkali cellulose used in the preparation of viscose (xanthate), cellulose ethers, and certain higher cellulose esters. Researches of this period concerning the action of various reagents on wood resulted in the sulfite method for producing wood pulp and the establishment of the sulfate pulp and kraft paper industries. These advances in technological and industrial processes were of European origin, except the sulfite process, which was an American discovery.

This, then, was the position of cellulose chemistry and technology at the time the AMERICAN CHEMICAL SOCIETY was founded in 1876. During the ensuing years up to about 1920, great strides were made in the industrial use of cellulose, both in America and Europe.

Artificial Silk

Though Réaumur had suggested in 1754 that an "artificial silk" might be produced from varnishes of gums or resins, the necessary materials or processes were not known which would translate the idea into fact. In France, Count Chardonnet undertook a series of researches which led to the establishment of a plant at Besançon in 1890 to produce the first "artificial silk" (*1*). The process involved spinning nitrocellulose into filaments. The dried nitrate filaments were denitrated by alkali sulfides to regenerate cellulose filaments. This was a dry spinning process—i.e., the cellulose nitrate dope was extruded and the solvents were removed by air drying. In wet spinning, which was introduced later, the filaments were coagulated in water.

In about 1897, the commercial production of artificial silk by another process was undertaken in Germany. Cellulose was not converted to a derivative, but was dissolved in cuprammonium solutions and wet-spun into dilute sulfuric acid coagulating baths. This process was based on the studies of Despeissis (ca. 1890).

The English chemists, Cross and Bevan, published many

studies during the years 1895–1921 on the properties and reactions of cellulose. Those dealing with the action of alkalies on cellulose to produce "soda cellulose" are of special importance.

Soda cellulose reacts with carbon disulfide to produce a water-soluble sodium thiocarbonate (xanthate) derivative. Such solutions can be spun into dilute acids, yielding regenerated cellulose filaments. The invention of this process is credited to Cross, Bevan, and Beadle in 1892 (*1*). The fibers so produced were first called Viscord and, later, viscose.

This new process—which could use various forms of cellulose, including wood pulps, as raw materials in addition to the inexpensive chemicals, sodium hydroxide and carbon disulfide—possessed real economic advantages. Furthermore, the spinning could be done from water rather than from costly organic solvents. These advantages were soon exploited commercially. Although the first plants were set up in Europe, a plant was started in the United States in 1910 and was followed rapidly by others.

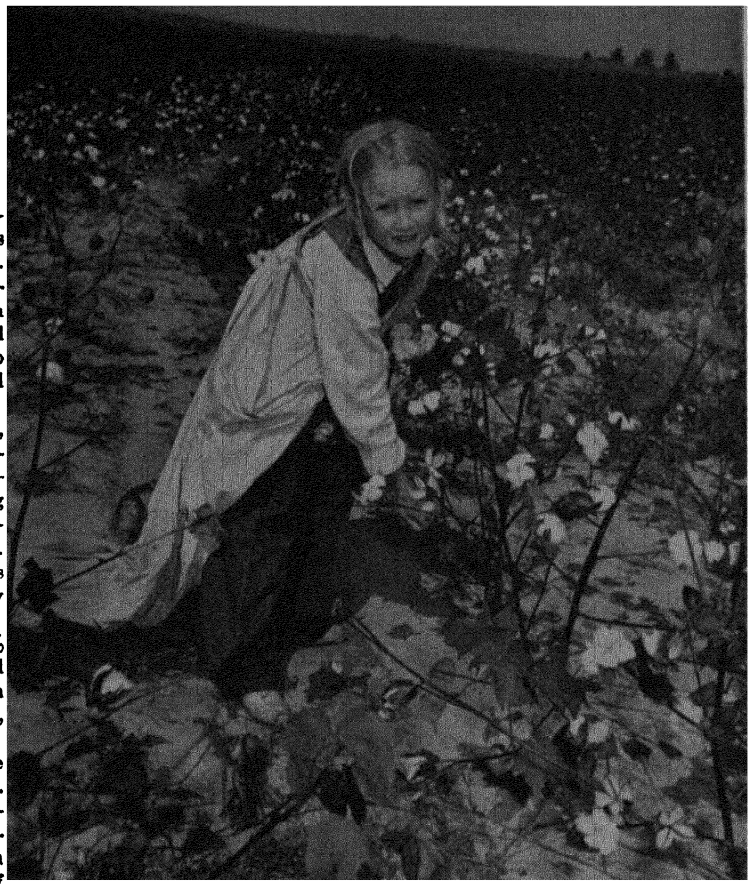
By the early 1920's, the xanthate process produced about 75% of the world output of "artificial silk," while the Chardonnet and cuprammonium processes shared the remaining market. In 1925, the term "rayon" was introduced for this type of fiber, and it has become a household word.

The use of cellulose nitrate for producing regenerated cellulose fibers was only one technical application of this versatile ester. Nitration of cellulose to a high nitrogen content produced guncottons. Esters of lower nitrogen contents provided quick-drying lacquers, while materials of still lower degrees of nitration were combined with camphor, forming plastic compositions of multitudinous uses. The rapid growth of the photographic and motion picture industries during this era demanded increasingly greater amounts of the flexible cellulose nitrate film base. The automotive industry adopted safety glass having nitrate as the central lamella of the sandwich.

Cellulose triacetate, though known for many years, received little commercial attention. It was soluble only in a few relatively costly organic solvents and gave films or fibers of undesirable physical characteristics. In 1904, Miles patented a process involving the hydrolysis of triacetates to esters having lower acetyl contents. These esters, in turn, were soluble in the cheap solvent, acetone. The resulting solutions, or dopes, became widely used in World War I to tauten the canvas coverings of airplanes. The early postwar era saw experiments designed to use these acetates for fibers and to replace the relatively unstable cellulose nitrates as films, sheeting, and plastics. Though some encouraging results were obtained, the major expansion in the cellulose acetate field occurred subsequent to the second decade of the century.

These commercial developments required large tonnages of cellulose as a chemical raw material. After the long cotton fibers are separated for textile use, there remain the very short fibers or linters. Because cotton fibers are essentially cellulose, containing only a very few per cent of waxes and pectin, the purification of linters for chemical use requires relatively simple treatments. On the other hand, wood pulp contains associated materials, such as lignin and hemicelluloses. The removal of these to produce a high grade cellulose on a commercial basis presented a much more formidable problem. This problem was attacked by many investigators. Although during World War I some sulfite pulp was used, further improvements were needed. In fact, such research has continued to the present time.

Many problems concerning the use of cellulose for nonchemical purposes enlisted the attention of increasing numbers of chemists. The postwar era of the early twenties gave to Americans not only greater incomes but increased personal leisure. In turn, the public demanded larger quantities of wood pulp for paper and book stock of ever higher quality. Greater use of color illustrations in periodicals placed heavier emphasis upon whiter printing papers. This requirement necessitated improved purification



Blue-eyed, blonde, 8-year-old child picks snowy handfuls of raw cotton in Alabama field



The invention of the mechanical cotton picker has greatly speeded up the laborious harvesting process

and bleaching processes for the pulp. The heightened competition from rayon spurred the research necessary to improve the quality of textiles from cotton fibers. Work was directed toward improving the methods used for purifying and bleaching the raw cotton, for decreasing shrinkage of cotton goods, decreasing wrinkling, and improving dyeing qualities.

With this brief summary, it will be seen that the period of 1875 to about 1920 was prolific with developments in the technical utilization of cellulose. Cellulose research of this period brought to light many very interesting observations on the behavior of cellulose. Unfortunately, the fundamental knowledge of this period was not able to fit these into a coherent picture and relate them to the structure of cellulose. This was not the fault of the cellulose chemist, for contributory developments were needed in the field of physical chemistry and structural organic chemistry. However, from this sea of empirical observation a few salient points emerged which proved of prime importance in the later elucidation of the cellulose structure.

As indicated earlier, it was long recognized that cellulose could be hydrolyzed to give glucose. Yet, it was not until the classical work of Emil Fischer late in the 19th century that the structure of glucose itself was understood. Cotton cellulose was early shown to have the structure $(C_6H_{10}O_5)_n$, whereas the empirical formula of the glucose is $C_6H_{12}O_6$. Obviously, these two carbohydrates differ in composition by one molecule of water. Recognition of that fact allowed Tollens to propose the above formula for cellulose in 1895.

This formula had the merit of indicating a chain structure with three available hydroxyl groups for all but the terminal unit and correctly indicated the glucose units as being joined through C—O—C links. Although this formula was in error in indicating the position of the links and in its assumption of a cyclic acetal structure, it was much nearer the truth than some structures proposed at a much later date.

The observations of Franchimont (1879–1899) showed that, upon hydrolysis, cellulose yields glucose predominantly, while acetolysis produces an acetylated di- or trisaccharide, later identified as cellobiose octaacetate. Ost had established in 1919 that acetylation of cellulose produced a triester, thus indicating only three available hydroxyl groups per glucose unit, while Denham and Woodhouse produced the trimethyl ether of cellulose analogous to the triacetate. In order to elucidate completely the cellulose structure, it was necessary to have synthesized a variety of glucose derivatives, particularly the methyl ethers, as reference compounds for comparison with the degradation products of cellulose. The necessary background work in this field had been going on in the laboratories of such carbohydrate chemists, as Purdie, Irvine, Denham, and Woodhouse.

DIVISION OF CELLULOSE CHEMISTRY

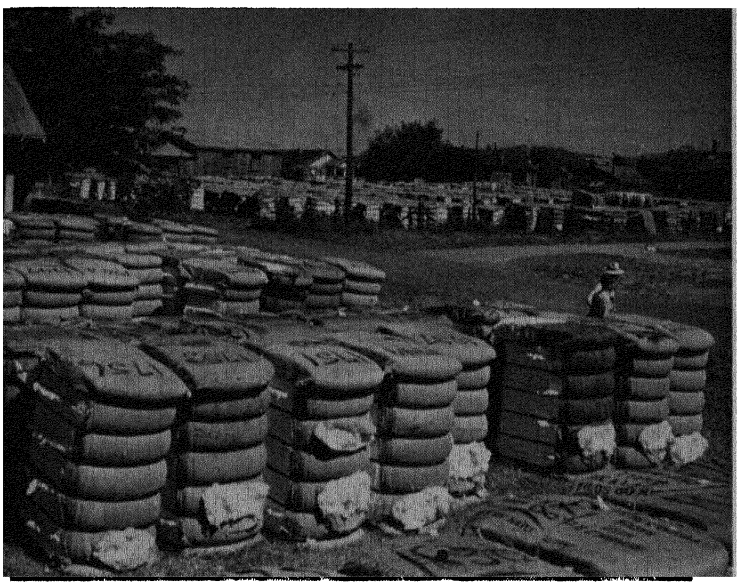
Recognizing the need for adequate scientific knowledge to supplement this extensive technology, a group of chemists representing various interests in cellulose and wood chemistry took the initial steps toward founding a Division of Cellulose Chemistry of the American Chemical Society. Did they sense that the next two decades would witness the rapid establishment of the chemical structure of cellulose and the adoption of many new methods for probing the physical structure of cellulose and wood? Whether they did or not, the growth of the division coincided with the rise of modern cellulose chemistry, and the divisional programs have not only mirrored but have accelerated that advance.

A cellulose symposium was organized under the able guidance of Jasper E. Crane as part of the Division of Industrial and Engineering Chemistry's program at the ACS meeting in St. Louis in April 1920. One objective was to ascertain whether there was sufficient interest among chemists to support a cellulose section. The following quotation from the minutes of that symposium indicates the spirit in which this symposium was conceived and in which the Division of Cellulose Chemistry was later founded:

> The object of such a section would be to promote intercourse and cooperation between the chemists in the various cellulose industries. This group constitutes one of the largest and most important of American industries; all branches of it are intimately concerned in the problems of cellulose, and it seems highly desirable to promote technical activity in this country along these lines. The proposed section would serve as a clearing-house for papers and information on cellulose technology, and should also play an important part in promoting research on the chemistry of cellulose.

Nine papers were presented at this symposium. Emphasis was placed on the determination of cellulose in wood and on the characteristics of cellulose derivatives, such as the nitrate, acetate, and phthalate.

Apparently the first symposium was highly successful, for a second one was held at the Chicago meeting of the ACS in



At a Huntsville, Ala., cotton gin, hundreds of bales wait to be transported to mills and warehouses

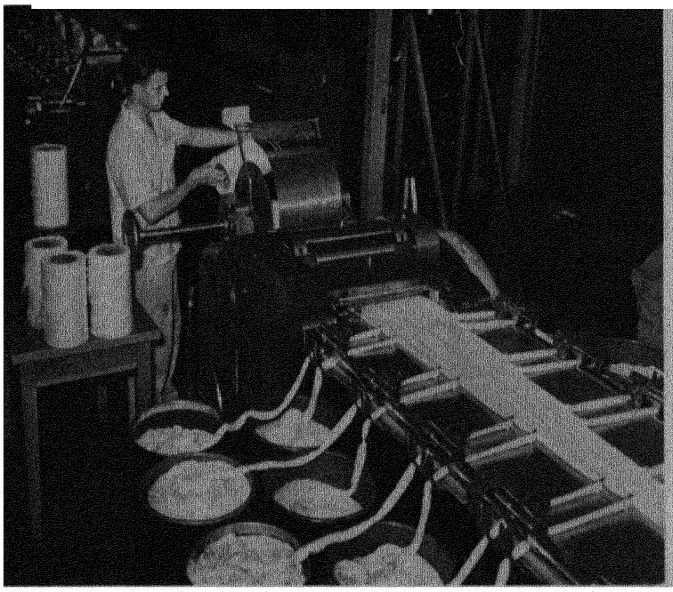
September of that year, again as part of the Division of Industrial and Engineering Chemistry. About 200 chemists attended. A continuing emphasis was placed on the constitution of cellulose and its occurrence in plants, while considerable attention was also directed toward the industrial utilization of cellulose from various sources. The interests of the paper maker in this field were indicated by the discussions of the regeneration of book stock and the recovery of newsprint. Several participants in these symposia later played major roles in the founding of the Division of Cellulose Chemistry, and their scientific contributions in the field of cellulose chemistry won international recognition. At this time, a cellulose section was formed with Harold Hibbert as chairman and G. J. Esselen, Jr., as secretary (7).

The first Cellulose Section was part of the ACS meeting in Rochester, N. Y., in April 1921. The vision and enthusiasm of the founders were well justified, for 20 papers were presented on a wide variety of subjects. Wood distillation, cellulose from corncobs, motor fuel from vegetation (two papers), the tropical regions as a source of cellulose, and the role of the chemist in relation to future liquid fuel supplies were discussed. Three papers were given dealing with cellulose nitrate and two relative to cellulose acetate. One of these latter summarized voluminous data gathered by the Army during World War I concerning the European use of cellulose acetate and cellulose acetate dopes.

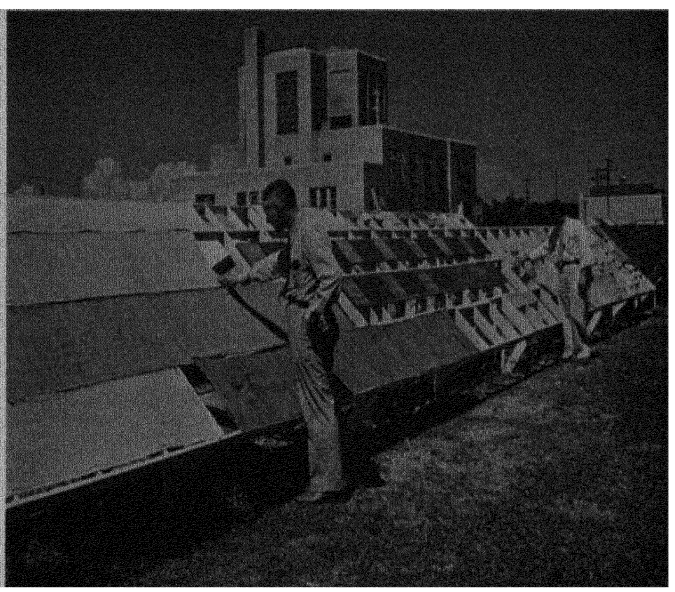
The Cellulose Section went on record as urging that whatever information on this subject could be made available to the public be placed in the Library of Congress or other suitable library. The microstructure of wood, lignin tests, standard cellulose, beater furnish reactions, oxidation of cellulose, action of hydrobromic acid on cellulose, hemicellulose, the chemistry of wood decay, and the bleaching and chemical constitution of pulps from coniferous woods were dealt with. Such subject matter ran the gamut from the fundamentals of cellulose structure through various phases of technological utilization. The techniques of microscopy were carefully considered. One of the charter members still recalls a lengthy discussion as to whether the anhydroglucose unit of cellulose contains three or four free hydroxyl groups. It is particularly significant that the closely related subjects of lignin and hemicellulose structure were discussed, and to this day they have continued to be an important source of papers in the cellulose division. Obviously, the future

Early in 1922, the section petitioned the officers of ACS for the establishment of a Division of Cellulose Chemistry. The Cellulose Section met again in April 1922 and became a chartered division shortly thereafter.

The first meeting of the Division of Cellulose Chemistry was held at Pittsburgh, Pa., in September 1922. The by-laws then adopted were published in the *Journal of the American Chemical Society* in October 1922. The officers were: chairman, G. J. Esselen, Jr.; vice chairman, L. E. Wise; secretary-treasurer, L. F. Hawley; executive committee, Harold Hibbert and J. F. Wait. Events of particular note were two symposia, "The Nature of Wood Cellulose," led by L. E. Wise and E. C. Sherrard, and "The Adsorption of Salts by Cellulose," led by W. D. Bancroft. The former was particularly spirited, and one charter member recalls "that it lasted for at least two hours with Dr. Wise, Dr. Schorger, Dr. Sherrard, Dr. Esselen, and Dr. Sheppard playing prominent parts. This occurred on a particularly hot day, whereupon the participants rolled up their sleeves and indulged in a warm but friendly debate."



Commercial machinery is operated by cotton technologist at Southern Regional Research Laboratory, New Orleans, La.



Experimentally treated fabrics are mounted out-of-doors so that effects of weather and sunlight can be determined

Division of Cellulose Chemistry was to include within its interest many related fields of carbohydrate and plant chemistry. Possibly this complexity of interest has been a potent factor in the growth and effectiveness of the division through the years.

The Rochester program in 1921 brought to light the dearth of standard analytical procedures for studying cellulose. The chairman appointed G. J. Esselen, Jr., to form a committee to frame standards to which all viscosity measurements might be referred. Bjarne Johnsen suggested that the section arrange for the preparation of pure cellulose, which could be made available to investigators in the cellulose field. Use of this standard material in various research programs would facilitate the comparison of results. A committee was appointed to activate this suggestion. These were the first steps of a continuing program which the division has fostered through the years for the purpose of standardizing analytical methods and materials. One of the division's major contributions to cellulose chemistry has been its development of standard methods.

At its April 1922 meeting, the Cellulose Section offered fewer papers than it had the preceding fall. On the other hand, the growth in the diversity of subject matter was more than ever apparent. A symposium entitled "Recent Work on the Constitution of Starch and Cellulose" summarized existing structural knowledge. The adoption of a report by the Standard Cellulose Committee established a method for preparing a standard form of cotton cellulose.

Renaissance of Cellulose Chemistry

The decade of 1920–1930 may be called the renaissance of cellulose chemistry. Only the major developments can be sketched (*5, 9, 12*).

Complete etherification of cellulose was earlier known to introduce a maximum of three ether groups in each anhydroglucose unit. Brilliant experimental work by the English school of carbohydrate chemists showed that the trimethyl ether can be hydrolyzed to a high yield of 2,3,6-trimethylglucose. Thus, the free hydroxyl groups of cellulose correspond to the 2, 3, and 6 hydroxyls of glucose. They further showed that the hydroxyl in position 5 is accounted for by formation of the pyranose ring of the glucose unit. This leaves only the 1 and 4 hydroxyls to be accounted for.

Skraup had shown (1901) that acetolysis of cellulose produced cellobiose octaacetate in which two glucose units were joined. During 1926–1928, cellobiose was shown to have the number 1 hydroxyl of one glucose unit joined to the 4 position of a second glucose unit through an oxygen linkage—i.e., a 4-glucopyranosyl glucose. In retrospect, it would seem that these facts would

have justified immediate acceptance of the modern structure of cellulose as shown above.

Apparently the amylene oxide ring structure and the positions of the three free hydroxyl groups in the anhydroglucose unit were generally accepted. The issue was how the anhydroglucose units combined to form the cellulose molecule. Two opposing schools of thought arose. One argued that the units were chemically combined into a chain more or less like the presently accepted formula shown above. This concept of a linear cellulose structure was opposed by proponents of the second school, who believed that cellulose was formed by aggregation or association of relatively simple carbohydrate units. Vignon in 1899 and later Pictet and his coworkers (1918–1922) suggested that the glucose molecule formed an internal anhydride having the empirical formula $C_6H_{10}O_5$, corresponding to that of cellulose and that this simple anhydride associated to form cellulose. Green and coworkers in the early 1900's followed the same line of thought but gave a somewhat different structural formula for the glucose anhydride. Hess in 1920 propounded the theory that cellulose is formed by association of molecules of pentaglucosidoglucose units. Such units were thought to contain five glucose molecules joined to the five hydroxyl groups of a sixth glucose unit. Residual valence forces were believed to cause association of these pentaglucosidoglucose units into cellulose. Many chemical and physical considerations were brought forward to support this theory, which attracted many adherents. Some of the arguments for this association theory were drawn by analogy from the behavior of solutions of certain colloids, particularly soaps, where the molecules associate into aggregates called micelles.

Today we consider the concept of a long linear molecule as a fundamental part of our knowledge of natural and synthetic polymers. In the 1920's this was a novel and daring concept. Unfortunately, the necessary physical methods were not at hand to prove this linearity.

It can well be imagined that these breath-taking advances in the studies of the chemistry of cellulose and of its structure caused a furor among cellulose chemists. Members of the division followed keenly each successive development and engaged in spirited debates on the merits of the linear polymer theory versus those of the association theory. Harold Hibbert, A. W. Schorger, and H. LeB. Gray proposed structures for cellulose which were based on the linear polymer concept. In 1924 and 1926, the division was particularly honored by the appearance on its programs of Sir James Irvine, whose brilliant researches had made major contributions to elucidation of the chemical structure of cellulose. Perhaps the following statement by L. E. Wise, a charter member of the division, will help to recapture the spirit of these early days (*14*):

[Harold] Hibbert [then at Yale], H. LeB. Gray and [S. E.] Sheppard [of the Eastman Kodak Co.], Bjarne Johnsen [of Hammermill], L. F. Hawley and [E. C.] Sherrard [of the Forest Products Laboratory], A. W. Schorger [of the C. F. Burgess Laboratory], Gustavus Esselen, and I were keenly interested in the founding of the division. There were others, too (like Harold A. Levey of New Orleans and Charles Herty—and still others whom I cannot recall). But I do remember how a number of us—at intervals quite apart from the national meetings of the ACS—met informally at some convenient place (usually at the New York State College of Forestry at Syracuse) and after luncheon at the Faculty Club discussed the latest developments in the chemistry of cellulose and wood. In those days, the concept of long cellulose chains was not generally accepted, and often there were friendly battles involving the interpretation (and misinterpretation) of experimental data. Often our round-table discussions lasted all day. No minutes were ever kept.

A resolution of the structural dilemma was obtained by the acquisition of two new types of evidence. Reference to the structure of cellulose as given above will show that the linear chains should theoretically be terminated by glucose units which contain four free hydroxyls. In 1932, Haworth and Machemer demonstrated that about 0.6% of 2,3,4,6-tetramethylglucose was present in the hydrolysis products of trimethylcellulose. This amount would correspond to a linear chain having possibly 100 to 200 combined glucose units. The second type of evidence came from experiments to determine the structure of the cellulose by means of x-rays.

X-Ray Studies

During the decade of 1920–1930, interest was focused mainly on the chemical investigation of the structure of cellulose. The next decade witnessed a shift of emphasis to the study of cellulose by various physical techniques. As early as 1923, some European investigators had begun to use x-rays to study a wide variety of materials, particularly cellulose fibers. The first paper on a cellulose division program dealing with this new research tool was presented by George L. Clark at the Detroit meeting in September 1927, under the title, "Contribution of X-Ray Science to the Analysis of the Structure of Cellulose." The minutes of that meeting indicate that the subject aroused considerable interest among division members.

That x-ray methods could provide the key to unlock many secrets of cellulose structure was indicated by the work of the American scientists, Sponsler and Dore. In 1926, they published the first detailed suggestion for a molecular configuration which conformed with x-ray diffraction data. They conceived a structure for native cellulose consisting of long chains of anhydroglucose rings arranged parallel to the fiber axis. Unfortunately, these investigators were unable to fit two chain glucoside units into their x-ray unit cell without departing from the accepted 1,4-glucoside linkages and instead substituted an alternate 1,1 and 1,4 sequence.

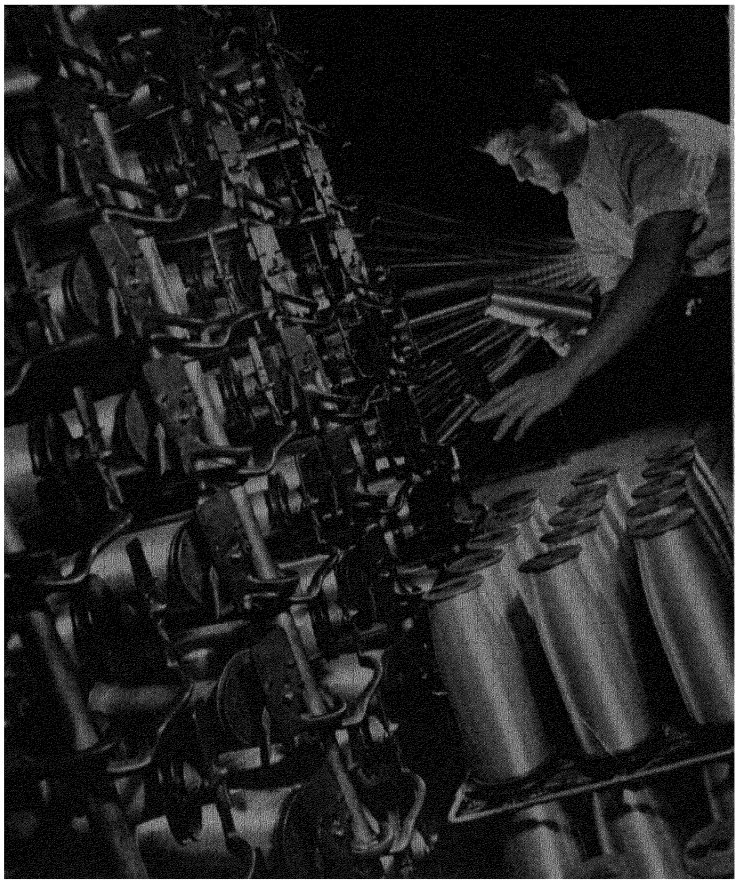
Meyer and Mark in their classical publications of 1928 were able to fit the 1,4-cellobiose structure of Haworth into the unit cell dimensions obtained previously by Polanyi (1921) and to bring the chemical and x-ray data into accord. The model thus deduced by these investigators still stands essentially unchanged.

Sponsler and Dore presented a critique of the use of x-ray methods in determining the structure of cellulose fibers at the division meeting in the spring of 1928. The impact of these new concepts on the course of cellulose chemistry is evidenced by the appearance of at least one paper on x-ray studies of cellulose, lignin, or wood in most of the subsequent division programs.

These x-ray investigations led to further speculation on the arrangement of the cellulose chains which formed the fiber. A theory was developed postulating an oriented aggregation of cellulose molecules into micelles which were arranged like overlapping layers of bricks with their greater dimension along the fiber axis. Between these micelles was an amorphous bonding substance. This micellar theory accounted for the crystalline and amorphous patterns observed by x-rays.

The application of newly developed physical methods soon cast doubt on the micellar theory. Staudinger developed a quantitative relationship between chain length of polymers and the viscosity of their dilute solutions. Viscosity measurements on cellulose indicated chain lengths many times greater than the length of the micelle. Ultracentrifuge measurements of the state of dispersion of cellulose in cuprammonium solvent reported by A. J. Stamm at the spring meeting of 1930 also indicated the presence of very long polymer chains. Ultracentrifuge, viscosity, and osmotic pressure measurements by E. O. Kraemer not only confirmed the long-chain structure of cellulose but indicated a distribution of lengths.

Such data caused a slow metamorphosis from the theory of discrete micelles to the present theory that the long cellulose chains, though roughly parallel, have areas of tightly packed, highly oriented crystalline structure and areas which are loosely packed or amorphous. Thus a single chain may extend through adjacent crystalline and amorphous regions. While this present theory seems to explain adequately the chemical and physical



Cordura rayon, developed by Du Pont chemists, goes into making of cords for automobile tires



Researcher examines cotton fabrics, yarns, and fibers under microscope after they have been chemically treated

properties of regenerated cellulose materials (and many synthetic polymers), it may not be entirely satisfactory when applied to native cellulose fibers. In the latter case, the morphological structure introduces a complicating factor.

Microscopic Structure of Cellulose

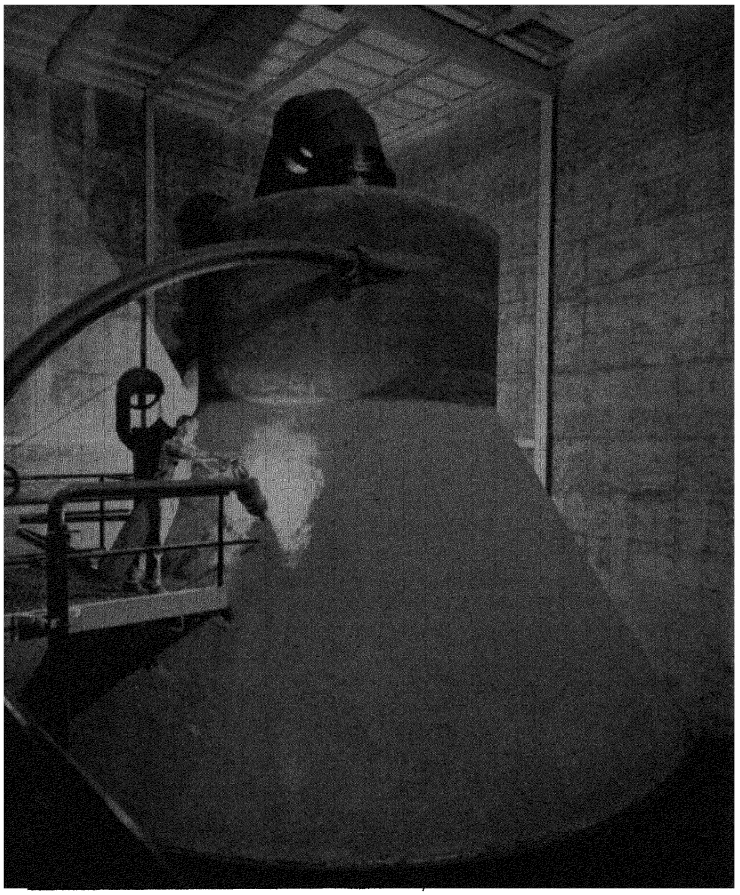
The year 1935 was the approximate mid-point of the division's history, and the spring meeting at New York is still regarded as outstanding. A symposium entitled "Nature of Cellulose and Cellulose Fibers" featured comprehensive summations by authorities in the then current major fields of investigation. But among these are two papers worthy of special mention. Considerable attention had been given recently to the x-ray structure of cellulose—a realm beyond the limits which could be explored by the most powerful microscopes. The paper by H. F. Lewis and O. Smith emphasized the microscopic structure of cellulose in a spectacular fashion. Motion pictures were shown of the swelling of cotton fibers under the influence of chemical agents. With proper conditions, the fiber rapidly swelled at intervals along its length until it resembled a string of beads. Then the fiber structure uncoiled, releasing long layers which had been wound spirally—like a barber pole—along the axis. These separated layers then began to fray, somewhat like the end of a rope, into fibrils. These changes followed each other so rapidly that the fiber in its twistings and uncoiling appeared almost lifelike. Many chemists had been thinking of cellulose as a chemical formula to be converted into chemical derivatives with novel and useful properties. The complex morphology thus demonstrated has continued to interest the cellulose chemists and botanists. Even with the recently added observations of electron microscopy, the structure of cellulose membranes is incompletely known (*4*).

W. K. Farr, in her paper entitled "Formation of Cellulose Membranes," demonstrated by photomicrographs that cellulose membranes from various natural sources, including cotton, appeared to contain small, uniform ellipsoidal particles. These were postulated as building units for the cellulose fibrils which formed the ultimate cell wall. Farr distinguished these from the submicroscopic micelles previously postulated (*3*). In later papers, it was suggested that these cellulose particles are held together in the fiber by a pecticlike material. When the cellulose fiber is disintegrated in cuprammonium solutions, the particles remain suspended while the cementing material dissolves to produce the observed viscosity.

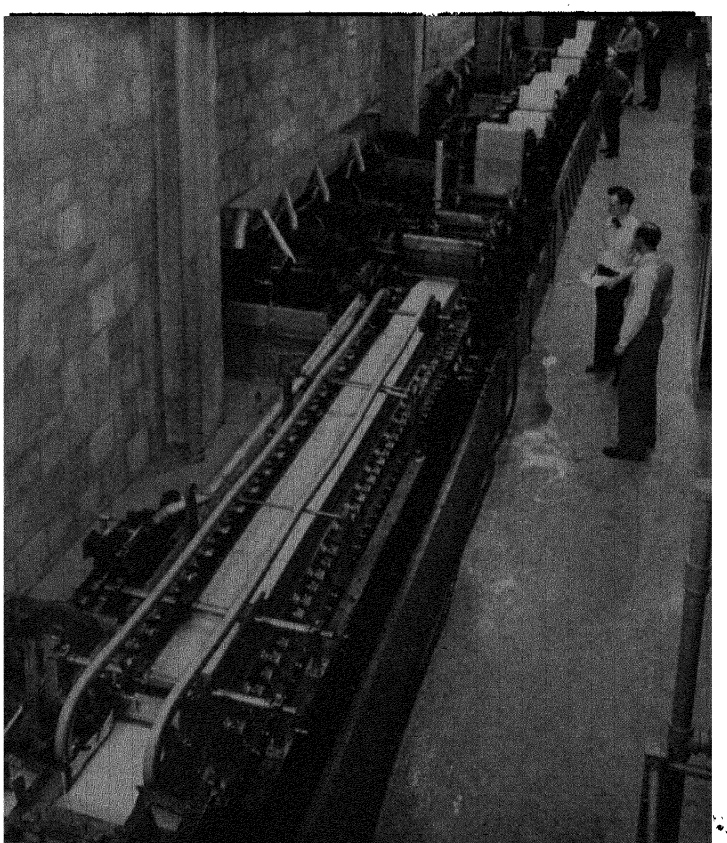
Here was a startlingly new idea. Aside from the botanical and structural significance of these particles, the cellulose chemist had ample reason to believe that cellulose was soluble in cuprammonium solution and that the viscosity observed was due to—and a measure of—the long polymer chains. As may well be imagined, this new idea fostered many chemical, microscopic, and x-ray investigations and drew botanists into the discussion.

The Chapel Hill meeting in April 1937 marked another outstanding division program, not only because it included a large number of diversified papers but also because it climaxed the cellulose particle theory discussion. This theory is not now generally accepted, and a discussion of the experimental evidence is given elsewhere (*6*, *12*).

The period, 1935–1940, saw the appearance or re-emphasis of several new subjects on division programs. Noteworthy were the studies of the formation and properties of cellulose ethers and cellulose acetate, as well as the plastic compositions derived from them. Such papers reflected the growing industrial interest in cellulose derivatives. In the field of fundamental research, the papers by M. L. Wolfrom and his coworkers on mercaptal derivatives of glucose offered a new tool for investigating the hydrolysis structure of simple sugars and cellulose. Investigations reported by C. B. Purves *et al.* introduced new techniques for the structural determination of cellulose derivatives. These



Cooked mass from kraft digester is blown into this tank at pulp mill in Longview, Wash.



Experimental paper machine is operated at the U. S. Forest Products Laboratory, Madison, Wis.

papers were the forerunners of extensive research by both investigators in their respective fields.

Synthetic Polymers

During these five years, a remarkable growth occurred in the field of synthetic polymers. Many of these synthetics, particularly the vinyl types, were much simpler in chemical constitution than cellulose. They could be prepared by simple and controllable polymerization reactions and were free from extraneous materials associated with natural polymers. Because the synthetics are long-chain molecules, they show many physical properties in common with cellulose. These include x-ray patterns, ability to form fibers or sheets, viscosity, osmotic and light-scattering properties, chain length distribution, and so forth.

A natural result was the development of the science of macromolecules. Scientists working in this field drew freely from the accumulated techniques devised during the physicochemical investigations of cellulose and applied them to investigations of macromolecules in general. Moreover, the new general concepts thus developed were applied to specific problems of cellulose chemistry.

This trend became increasingly apparent in the division programs between 1940 and 1945. Papers by H. Mark and coworkers on elastic and plastic behavior of long-chain substances and on the fractionation of polymers, as well as papers by R. Simha on viscosity properties of chain compounds, by S. Coppick and coworkers on the distribution curves of cellulose fractions, by H. M. Spurlin on the characterization of cellulose derivatives by solubility properties, and by W. O. Baker on interchain order and orientation in cellulose esters, opened up new frontiers.

However, the division programs of this era were by no means devoted exclusively to the new macromolecular concepts. Continued investigations were reported in the broad fields of wood and cellulose structure, lignin chemistry, the isolation and characterization of hemicelluloses and pentosans, as well as the effects of chemical treatments upon the properties of cellulose. Several studies were reported on the oxidation of cellulose, including the experimental work of R. F. Nickerson and his colleagues, who applied hydrolytic and oxidative methods to distinguish the amounts of amorphous and crystalline material present. A significant series of papers by Milton Harris and his coworkers on the electrophoretic properties of cellulose and their cation exchange behavior led to the observations of small amounts of pectin substances associated therein. In the course of this work, improved methods were developed for estimating small amounts of uronic acids by carbon dioxide evolution. Papers by several workers indicate increasing interest in improving the physical properties of rayon yarns, particularly to obtain very high tenacity. The rapidly growing technological importance of cellulose derivatives is shown by reports of investigations on the mechanism of the formation of cellulose ethers and the distribution of the ethoxyl groups within the anhydroglucose structure. A comprehensive series of papers by C. J. Malm and C. R. Fordyce and their collaborators described new cellulose derivatives, including the trityl ethers and carbamates, cellulose ester compositions, and in particular new and improved methods for the analysis and characterization of cellulose esters. These papers represent fundamental contributions of importance to both the science and technology of cellulose derivatives.

By 1946 the science of macromolecular chemistry had become of interest to scientists in many fields. At the spring meeting, members from the Divisions of Cellulose, Colloid, Organic, Physical and Inorganic, and Rubber Chemistry joined in a High Polymer Forum. This forum, continued through the years, has explored the physical-chemical aspects of cellulose or its derivatives and has considered these substances in terms of general macromolecular theory. As a result, the later cellulose division programs have shifted their emphasis toward studies of the

technological utilization and chemical properties of wood, cellulose, lignin, and related materials.

Thus far in tracing the history of the division, the accent has been on cellulose. However, many programs featured a large number of papers on related materials, including lignin, pentosans, hemicelluloses, wood structure, and so forth. The division members have made many internationally recognized contributions in these fields. In fact, certain programs of the division have featured a preponderance of papers on these subjects over those on cellulose.

Lignin and Wood

It would be impossible in this history to trace the complete development of the chemistry of substances related to cellulose, particularly lignin. A brief review will be made of certain high points in these fields as they appeared on the programs through the years. A more complete account of the chemical components of wood and particularly of the chemistry of lignin is given elsewhere (*2*, *11*).

There are several factors which have complicated the research on lignin and the arrival at a definite understanding of its chemical structure. It has not been established that the lignin occurring in various types of wood is of the same chemical composition. Furthermore, the apparent chemical composition of the lignin will depend upon the conditions used in isolating it from the other wood components. The isolated products are materials of high molecular weight, which are amorphous and difficult to handle by virtue of their physical and chemical properties. This uncertainty of definite criteria for pure lignin specimens makes it extremely difficult to compare the research results of different investigators. A paper on the first Cellulose Section program was a discussion by E. C. Crocker of the significance of the so-called lignin tests.

A very pertinent observation was contained in a paper by M. Phillips at the fall meeting of 1930, when it was shown that alkali lignin produced a low yield of 3-(3-methoxy-4-hydroxyphenyl) propane upon distillation with zinc dust. This appeared to offer proof that lignin of this type contains a certain proportion of a combined benzene nucleus. The presence of a benzene ring in lignin was later confirmed by the formation of vanillin and acetovanillone by alkaline hydrolysis of lignin sulfonate. Later studies reported by E. E. Harris and his coworkers have shown that the high-temperature hydrogenation of lignin over suitable catalysts produces cyclohexyl propane derivatives which undoubtedly arise by reduction and hydrogenolysis of the benzenoid components present.

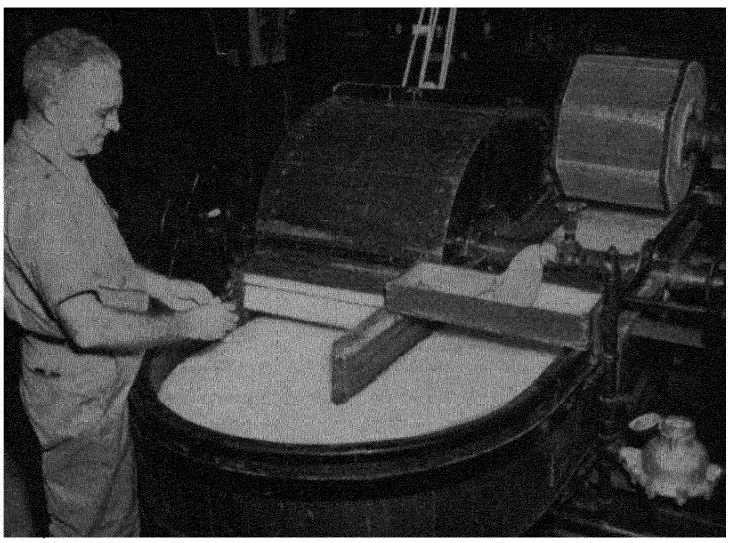
Through the years, certain centers of lignin research came into being, as exemplified by the work of H. Hibbert and his coworkers in Canada, G. J. Ritter and E. E. Harris of the Forest Products Laboratory, and F. E. Brauns, now at the Institute of Paper Chemistry. These workers contributed a wealth of experimental detail on various phases of lignin chemistry. Much of this work was presented on division programs, particularly as symposia in 1933 and 1948. An outstanding discussion of the lignin problem occurred at the Atlantic City meeting in the fall of 1941, where emphasis was placed on the isolation and identification of units which composed the lignin molecule.

There is much to be done in settling the lignin structure. A recent approach has been the investigation by Alfred Russell of the synthesis of lignin by the condensation or polymerization of 2-hydroxy-3-methoxy-5-formyl acetophenone. The product obtained has many physical and chemical characteristics paralleling those of lignin from natural sources. However, there is still considerable discussion and disagreement whether the product so formed does have a structure like the natural lignin. This new approach has nevertheless stimulated further interest in the lignin problem.

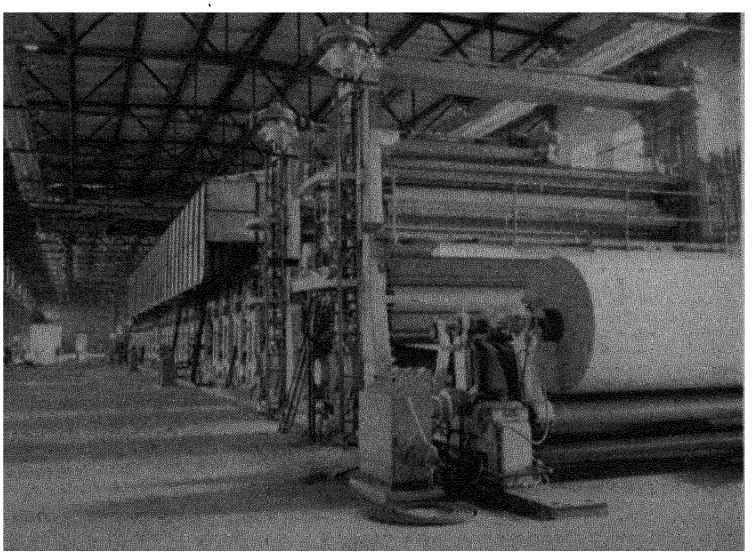
Research on the structure and chemistry of wood has continued



Cellulose sheets are steeped in caustic soda at American Viscose Corp. plant in Marcus Hook, Pa.



In beater, fibers are separated, brushed out, and fibrillated so they will enmesh when made into paper



Enormous papermaking machine in modern plant turns out sheets that are 216 inches wide

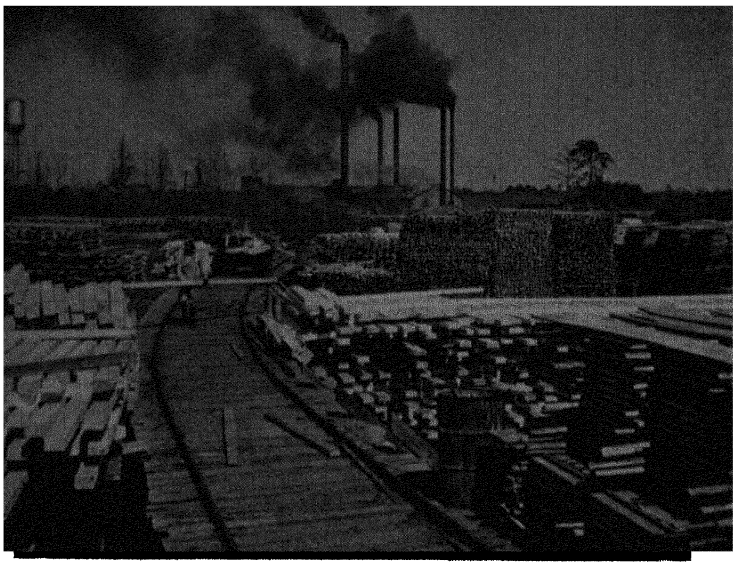
throughout the division's many years. The initial cellulose symposium contained two papers on the determination of cellulose in wood. At this time, the distillation of wood was of considerable technical importance, and many papers were devoted to the chemistry and technology of the process, particularly papers by L. F. Hawley and coworkers. The microstructure of wood early attracted the attention of cellulose chemists, and the first section meeting contained a discussion of this subject. Later years saw an extensive and continuing study. G. J. Ritter and his colleagues have presented a number of papers dealing with various phases of wood structure. The composition and structure of the cell wall of wood, the distribution of lignin in wood, the dissection of wood fibers by chemical means, and the structural unit of wood fibers were particularly emphasized. In 1933, G. J. Ritter and E. F. Kurth introduced the term "holocellulose" to indicate the total carbohydrate fraction of wood freed from lignin and extractives. Subsequent investigations explored the nature of holocellulose from different woods and the hemicelluloses derived from holocellulose. E. C. Sherrard and coworkers specialized in the chemistry and technology of wood treatments, particularly with respect to the chemical pulping of wood, hydrolysis of wood, and extractives obtained by various means. In this connection, it is interesting to note a series of papers by S. I. Aronovsky and R. A. Gortner on the pulping of wood, particularly the technological aspects of various chemical treatments. Of considerable technological importance are the investigations of A. J. Stamm on the chemical treatments of wood, particularly with the objective of decreasing water permeability and swelling. This by no means covers the research which was done on wood and wood products during the period of the Cellulose Division's history, but is intended to summarize the particular phases which received extensive discussion on the division programs.

It would be presumptuous to attempt to evaluate the importance of the many contributions made by Cellulose Division members over the past years. The remarkable increase during the past 30 years in the quality of cellulose products and the number of new products introduced attest to the fact that cellulose chemists have done their work well. This period has seen the evolution of improved processes for producing wood pulp, an increase in the strength and wrinkle resistance of cotton fabrics with decrease of shrinkage during use, more extensive use of regenerated fibers and sheeting, the introduction of high-strength rayon cords for automobile tires, improvements in cellulose derivatives, and the introduction of new ones, as well as the adaptation of composition derived from them for a variety of fabric and plastic uses. Progress in the fields of textiles and cellulose plastics has been periodically reviewed in division symposia. Familiar to all are new methods and improvements in the utilization of wood, particularly as fiberboards, wood laminates including plywood, and the introduction of treatments to decrease the attack of mold and fungus. Vanillin for artificial vanilla extracts and synthetic molding plastics are made from the lignin wastes of wood pulp production.

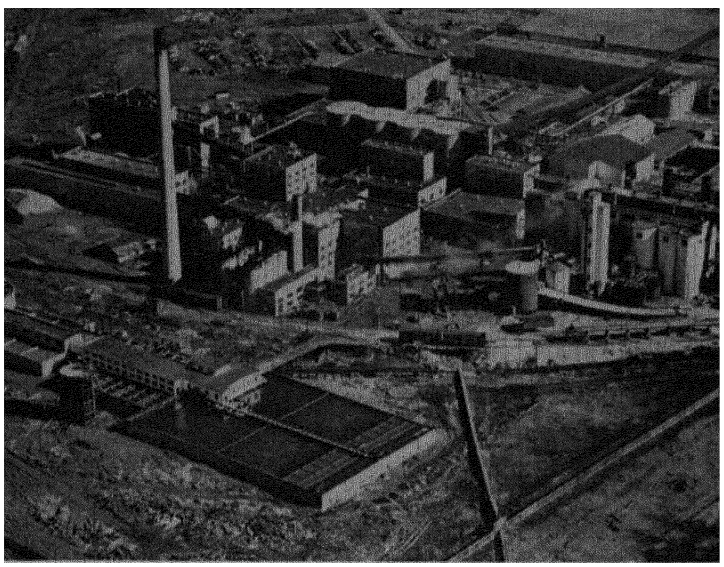
The work of Charles Herty and his colleagues on methods of obtaining high-quality pulp from southern slash pine has been of great economic importance.

Papers by L. F. Henderson beginning in 1928 described the formation of sausage casings from regenerated cellulose. This work led to the large scale production of such casings now widely employed in the meat-packing industry. At one of these early meetings, the division members engaged in direct personal research on such casings suitably stuffed, cooked, and surrounded by fresh rolls. The opinion was unanimous that cellulose chemistry had benefited by contact with the lowly hot dog.

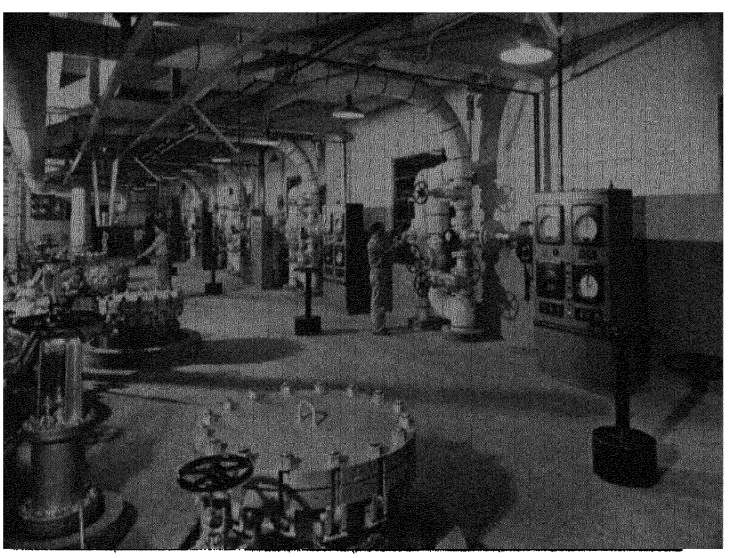
Since the beginning of the use of cellulose pulp for paper and cellulose fibers for textiles, a serious problem has been the loss of physical properties caused by the combined action of light,



Operations are in full swing at sawmill of the W. T. Smith Lumber Co., Chapman, Ala.



Aerial view of Weyerhaeuser Timber Co.'s kraft pulp mill and sulfite recovery plant at Longview, Wash.



Wood chips are fed into the tops of these digesters at the start of the pulpmaking operation



Chemical-grade cotton pulp leaves drying tunnel at Hopewell, Va., plant of Hercules Powder Co.

moisture, and air to produce oxidation resulting in ultimate embrittlement. Many chemical operations for cellulose purification encounter this oxidation problem. Witz showed late in the 19th century that this phenomenon was one of oxidation. Since that time, many chemists have studied the conditions under which cellulose is susceptible to oxidation and have tried to ascertain the oxidative mechanism. A very extensive literature has developed, and the comprehensive work of E. Heuser is outstanding. As a result of these studies, the chemists have learned how to minimize the oxidation reactions that accompany many technical processes employing cellulose. Recent fundamental studies have provided methods for preferential oxidation of certain parts of the glucose unit in cellulose and have identified the products formed. The work of Jackson and Hudson and later of Purves and coworkers on periodate oxidation is particularly important. Others have found that nitrogen dioxide under proper conditions oxidizes cellulose gauze to yield a product now employed in surgery as a packing absorbable by the body and as an aid in the controlling of bleeding.

Officers of the Division of Cellulose Chemistry, 1922–1951

Year	Chairman	Secretary-Treasurer
1922–1924	G. J. Esselen, Jr.	L. F. Hawley
1924–1926	H. LeB. Gray	L. F. Hawley
1926–1927	Bjarne Johnsen	E. C. Sherrard
1927–1928	Louis E. Wise	E. C. Sherrard
1928–1929	J. L. Parsons	C. J. Staud
1929–1930	E. C. Sherrard	C. J. Staud
1930–1931	Fred Olsen	C. J. Staud
1931–1932	Fred Olsen	J. L. Parsons
1932–1933	Harold Hibbert	J. L. Parsons
1933–1934	C. E. Curran	W. O. Kenyon
1934–1935	H. F. Lewis	W. O. Kenyon
1935–1936	G. J. Ritter	W. O. Kenyon
1936–1937	Emil Heuser	W. O. Kenyon
1937–1938	W. F. Henderson	W. O. Kenyon
1938–1939	G. L. Clark	W. O. Kenyon
1939–1940	M. L. Wolfrom	C. R. Fordyce
1940–1941	W. O. Kenyon	C. R. Fordyce
1941–1942	E. E. Harris	C. R. Fordyce
1942–1943	H. M. Spurlin	C. R. Fordyce
1943–1944	E. Berl	C. R. Fordyce
1944–1946	C. B. Purves	J. S. Tinsley
1946–1947	Milton Harris	J. S. Tinsley
1947–1948	C. R. Fordyce	J. S. Tinsley
1948–1949	R. F. Conaway	W. E. Davis
1949–1950	J. S. Tinsley	W. E. Davis
1950–1951	W. A. Sisson	W. E. Davis

The charter members of the division recognized the need for authoritative monographs and textbooks in English on the subjects of cellulose and wood. Discussions of the requirements of a brief critical monograph on the chemistry of cellulose were initiated and led by L. E. Wise. Shortly thereafter, the following volumes were published: "Wood Distillation" by L. F. Hawley (ACS Monograph, 1923); "Textbook of Cellulose Chemistry" by E. Heuser, translated by C. J. West and G. J. Esselen (1924); "The Chemistry of Cellulose and Wood" by A. W. Schorger (1926); and "The Chemistry of Wood" by L. F. Hawley and L. E. Wise (ACS Monograph, 1926). Certain of these have appeared in revised editions, and other members have subsequently produced additional books particularly relevant to newer phases of cellulose chemistry. These books have been of inestimable service to both research workers and students.

Manifestly, it is impossible to mention in this brief history all of the papers given before the Division of Cellulose Chemistry. The author has attempted to select certain ones which are illustrative of the growth of cellulose chemistry in the United States, particularly where such papers represent an extensive series.

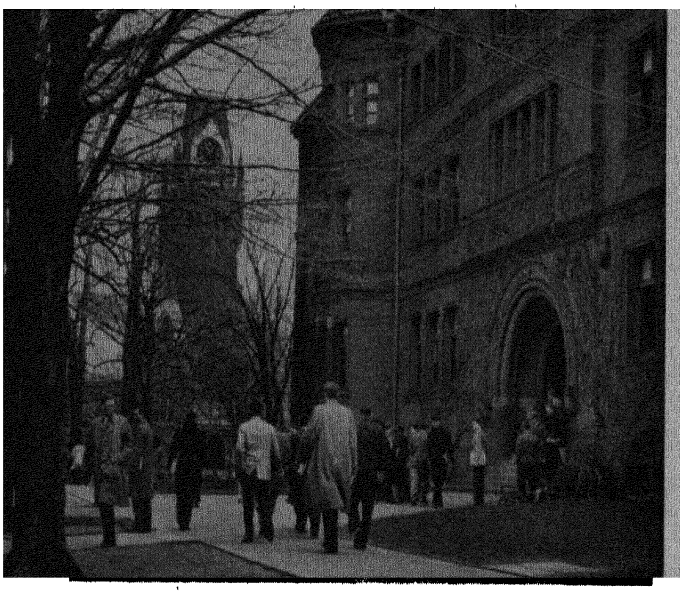
This history would be incomplete without mention of certain unique characteristics of the division. Its relatively small size and the closely related scientific interests of its members have produced an unusual camaraderie and opportunity for extensive personal acquaintanceships. The opinions of the youngest and newest member receive sympathetic attention, while the opinions of the most eminent authority may well be questioned (and often are). Its vociferous polemics are solely a search for truth. May such a spirit long continue!

Acknowledgment

Acknowledgment is made of the great kindness of many division members, and especially of L. F. Hawley, H. F. Lewis, G. J. Ritter, and L. E. Wise, who have supplied much of the early background for this history and have critically read portions of this manuscript. The author appreciates the able assistance of C. C. Unruh in the compiling of the tables, in proofreading, and in suggesting revisions of some of the subject matter included.

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On university campuses, chemistry has become a prominent part of the undergraduate curriculum



Massachusetts Institute of Technology possesses one of the nation's most outstanding schools of chemical engineering

Chemical Education

The future course of the American chemical industry is determined in the classrooms of high schools, colleges, and universities

HARRISON HALE
University of Arkansas, Fayetteville, Ark.

IN *Fortune* for March 1950 (*19*), a feature article entitled "The Chemical Century" bore this heading: "Midway, the chemical industry takes the lead. In ten years, it has more than doubled in plant, nearly tripled in sales, and no end is in sight." The article went on to say: "Chemicals must now be considered the premier industry of the United States. . . . As of now, the chemical industry cannot be matched by any other in growth, earnings, and potential for the future. . . . It is almost wholly an industry founded, built, and run by chemists and engineers, men trained in the sciences."

For the teachers who trained the men for this outstanding industry, the Division of Chemical Education speaks. By no means all these teachers have been members of the division, but all have shared in the fundamental work upon which chemistry in America rests.

It should be remembered that besides training chemists and chemical engineers, teachers of chemistry have given a fundamental scientific background to students in the related fields of medicine, nursing, dentistry, agriculture, and home economics, as well as to many students who elected to study chemistry for its cultural value.

The teacher has also done his full share in the growth and development of the AMERICAN CHEMICAL SOCIETY. When the organization of a chemical society was proposed at the Priestley Centennial at Northumberland, Pa., in 1874, 77 chemists were present. The president, the 13 vice presidents, the secretary, the treasurer, and most of the members of the three committees at that celebration were teachers of chemistry (*8*). The first seven presidents of the AMERICAN CHEMICAL SOCIETY were teachers, as were 12 of the first 13, and eight of the last 13 (1939–1951). Nearly 70% of all presidents have been educators (*21*). At present, about 15% of the Society's total membership are teachers (*11*).

At the celebration of the tenth anniversary of the Divisions of Chemical Education and History of Chemistry in 1931, this statement was made, which is equally true today (*20*):

> The association of chemists in industry with those in education, which this Society throughout all its history has made possible, has been of untold value to both groups. Nothing in America has done more to keep the one group from becoming pedantic or the other from being narrow. That this has been done with an entire absence of group consciousness in any unfortunate sense upon the part of either has been and is a marked achievement of the Society.

The Division of Chemical Education, with its undoubted advantages, would be of questionable value, did it rob us as teachers

of the priceless friendship and association of our fellow chemists who are not teachers. How far we have kept from so unfortunate a condition everyone familiar with the Society knows. In every division at the general meetings and in almost countless local and sectional meetings, the industrial and the educational chemists unite in an attack upon their common problems. For both, this is surely a genuine basis of education, for at these meetings much of the real history of chemistry in America is recorded.

When the AMERICAN CHEMICAL SOCIETY was founded in April 1876, the facilities for teaching chemistry were limited and the number of students was not large. Only 117 colleges and universities were established prior to 1845 and their total enrollment in 1850 was only 11,903 (*26*). Compare these with the figures given by the U. S. Department of Education for 1948–1949, when there were 1750 colleges and universities with 2,408,200 students (*18*).

The lack of recognition given to chemistry 75 years ago was more of a handicap than the deficiency in either the number of colleges or the number of students. Fay states that before 1870 no college accepted science for admission (*17*), while Powers says: "As late as 1875, the provision which had been made for chemistry in most of the colleges was quite meager" (*25*).

In an 1880 Bureau of Education Circular of Information, F. W. Clarke (president of the AMERICAN CHEMICAL SOCIETY in 1901) commented (*15*); "As a rule, the ordinary college course leaves the sciences for the junior and senior years, an arrangement which . . . renders advanced electives in either chemistry or physics out of the question."

In 1878, Charles F. Chandler, speaking of the School of Arts at Columbia University, one of the best institutions, said (*6*) "The sophomore class attends one class a week in chemistry throughout the year. Instruction is given chiefly by lectures. General chemistry is also taught during the senior year three times a week, as an elective, by lectures. No laboratory work is reported."

In a volume recording the celebration of the Twenty-Fifth Anniversary of the AMERICAN CHEMICAL SOCIETY in 1901, the Census Committee summarized the replies received from more than 200 American colleges by saying, in comparing 1876 with 1901: "The accommodations for students and teachers have increased as 1 to 25" (*1*). In this same volume, a special report on organic chemistry by W. A. Noyes, Sr. (ACS President in 1920), stated that there were more than a hundred students engaged in organic research in more than 30 institutions in 1901. In 1876, on the other hand, only three institutions—Massachusetts Institute of Technology and the Universities of Pennsylvania and Virginia—had any provision for laboratory work in organic chemistry. Even so, their facilities allowed for only a total of 11 students (*24*).

The founding of the AMERICAN CHEMICAL SOCIETY preceded a period during which American institutions of higher learning grew most rapidly. That era witnessed a rapid rise in the importance of the land grant colleges, authorized in 1862. These colleges began receiving increasing support from federal and state funds. In these institutions, as well as in technical institutes, the importance and possibilities of science were fully recognized. Quite fortunately, the battle against the strongly entrenched classical viewpoint did not have to be fought.

In 1926, while discussing the status of chemical education in America, Samuel R. Powers concluded (*25*): "The major accomplishments of college education in chemistry have been: (1) the development of industrial and agricultural applications; (2) the development of research; and (3) the general diffusion of the method and attitude of mind of the scientist."

While much was accomplished in each of these three fields prior to 1926, much more has been achieved since then. Industrial and agricultural applications for the products of the chemical industry have increased tremendously. Chemical production figures since the close of World War II tell the story. Research has been fostered as never before, with practical results observable everywhere. Chemistry and kindred sciences have fought off the paralyzing influence of tradition and superstition. Indeed, science has given mankind a rational point of view, the significance of which is obvious, though difficult to measure.

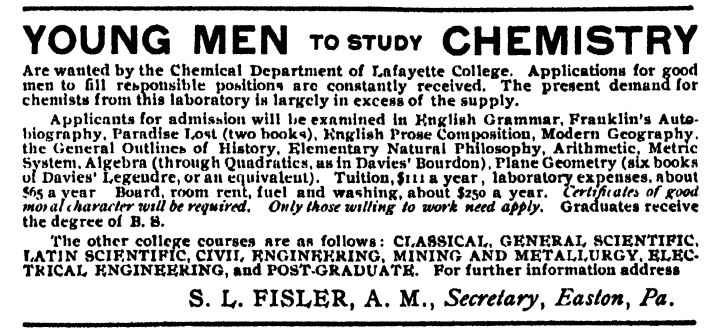
Accrediting College Courses

For many years, in both the AMERICAN CHEMICAL SOCIETY and the American Institute of Chemical Engineers, much work has been done by committees in setting up standards for the accrediting of college courses. Many teachers have devoted a great deal of thought and effort to this time-consuming work, which has been a most important factor in the advancement of chemical education. Both organizations have encouraged student interest and membership. Today, there are more than 200 student affiliate groups of the AMERICAN CHEMICAL SOCIETY (*11*). Student chapters of the American Institute of Chemical Engineers are functioning in approximately 100 colleges of engineering (*3, 12*).

Educational symposia were held long before there was a Section of Chemical Education in the AMERICAN CHEMICAL SOCIETY. Undoubtedly, when two or more early American teachers of chemistry met at ACS meetings, there were conferences on chemical education. Certainly, the value of educational institutions was early recognized. In his presidential address before the AMERICAN CHEMICAL SOCIETY in 1892, G. C. Caldwell made a statement which held true for many years (*5*): "These higher institutions of learning are . . . the fittest places and, indeed, almost the only places for the making of both investigators and investigations."

Conferences on chemical education were not limited to the AMERICAN CHEMICAL SOCIETY. The World's Congress of Chemists met in 1893 in connection with the World's Columbian Exposition in Chicago, immediately following the seventh meeting of the Society, which was the first held in the West. Speaking before this Congress on the subject, "How Chemistry Is Best Taught," Charles F. Mabery of the Case School of Applied Science said (*22*), "The guiding star to successful teaching in chemistry is the personality and enthusiasm of the instructor."

As a result of the work of a committee of six and then of a committee of 50, nearly all of whom were members of the AMERICAN CHEMICAL SOCIETY, the American Institute of Chemical Engineers was organized in Philadelphia, June 22, 1908. In the constitution adopted that day, it was stated that one of the objects of the organization shall be "to cooperate with the educa-



YOUNG MEN TO STUDY CHEMISTRY

Are wanted by the Chemical Department of Lafayette College. Applications for good men to fill responsible positions are constantly received. The present demand for chemists from this laboratory is largely in excess of the supply.

Applicants for admission will be examined in English Grammar, Franklin's Autobiography, Paradise Lost (two books), English Prose Composition, Modern Geography, the General Outlines of History, Elementary Natural Philosophy, Arithmetic, Metric System, Algebra (through Quadratics, as in Davies' Bourdon), Plane Geometry (six books of Davies' Legendre, or an equivalent). Tuition, $111 a year; laboratory expenses, about $65 a year. Board, room rent, fuel and washing, about $250 a year. *Certificates of good moral character will be required. Only those willing to work need apply.* Graduates receive the degree of B. S.

The other college courses are as follows: CLASSICAL, GENERAL SCIENTIFIC, LATIN SCIENTIFIC, CIVIL ENGINEERING, MINING AND METALLURGY, ELECTRICAL ENGINEERING, and POST-GRADUATE. For further information address

S. L. FISLER, A. M., *Secretary, Easton, Pa.*

Advertisement in 1893 issue of *Journal of the American Chemical Society* warned that "only those willing to work need apply" to Lafayette chemical department

tional institutions for the improvement of the education of the men who are to enter this profession" (*4*).

While the Division of Chemical Education was not approved by the Council of the AMERICAN CHEMICAL SOCIETY until the Milwaukee meeting in September 1923, an interest in education had been often expressed before then. From the minutes of the ACS Council meeting in Baltimore, December 1908, we read: "It was voted that the Committee on the Education of Chemists be continued and requested to make arrangements for a meeting of the Educational Section at the next two meetings of the Society, unless a division is organized in the meantime."

So at the 41st meeting in Boston, the Educational Section held sessions on December 26 and 28, 1909, under the chairmanship of Lyman C. Newell. A special feature of the meeting was the discussion of problems relating to secondary school chemistry. About 50 were present.

At the 43rd meeting in Minneapolis on December 29, 1910, the section held a joint session with the Divisions of Industrial Chemists and Chemical Engineers, Fertilizer Chemistry, and Agricultural and Food Chemistry. The chairman, C. F. Burgess, spoke on "The Efficiency of the College Graduate in Chemical Industry." Burgess' talk was followed by a thorough discussion. Again on that same day, the Council voted "that the Committee on the Section of Chemical Education be continued and be given charge of a session of this section for the winter meeting of 1911."

As a result, a joint meeting with the Division of Physical and Inorganic Chemistry was held in Washington, December 27, 1911, with A. A. Noyes as chairman. The meeting in New York in September 1912 coincided with the VIIIth International Congress of Pure and Applied Chemistry. The Section of Chemical Education held no meeting at that time. In fact, the section ceased to exist until the 62nd meeting, conducted in New York in September 1921. This is recognized as the founding meeting of what later became the Division of Chemical Education.

Officers of the Division of Chemical Education, 1923–1951

Year	Chairman	Secretary
1923	Edgar F. Smith	Neil E. Gordon
1924	Neil E. Gordon	Wilhelm Segerblom
1925	W. A. Noyes, Sr.	B. Smith Hopkins
1926	Wilhelm Segerblom	B. Smith Hopkins
1927–1928	B. Smith Hopkins	Ross A. Baker
1929	William McPherson	Ross A. Baker
1930–1931	John N. Swan	Ross A. Baker
1932	Owen L. Shinn	Ross A. Baker
1933	Lyman C. Newell	Norris W. Rakestraw
1934	Ross A. Baker	Norris W. Rakestraw
1935	Robert E. Swain	Norris W. Rakestraw
1936	Harrison Hale	Norris W. Rakestraw
1937	Otto M. Smith	Norris W. Rakestraw
1938	B. Clifford Hendricks	Norris W. Rakestraw
1939	Martin V. McGill	Norris W. Rakestraw
1940	Martin V. McGill	Paul H. Fall
1941	Rufus D. Reed	Paul H. Fall
1942	Frank E. Brown	Paul H. Fall
1943	Arnold J. Currier	Paul H. Fall
1944–1946	Laurence L. Quill	Paul H. Fall
1947	John C. Bailar, Jr.	Paul H. Fall
1948	Edward L. Haenisch	Paul H. Fall
1949	Douglas G. Nicholson	Paul H. Fall
1950	Otis C. Dermer	Paul H. Fall
1951	James A. Campbell	Paul H. Fall

him and were pleased to be a part of an organization which was dear to him and in which he played a helpful part. It is entirely appropriate that at this decennial celebration we give special honor to the memory and service of Dr. Edgar Fahs Smith, the first chairman of the section and a prime mover in the development of the Division of Chemical Education.

The Section of the History of Chemistry, later the division, began at the same time as the Section of Chemical Education, and in it, too, the outstanding figure was Edgar Fahs Smith. Articles from both groups have long appeared in the *Journal of Chemical Education.* So naturally, there has always been a feeling of close fellowship and cooperation between the two groups.

DIVISION OF CHEMICAL EDUCATION

The conversion of the Section of Chemical Education into a division was authorized by the Council at Milwaukee in September 1923. In the fall of the next year, the division appeared on the program of the Ithaca meeting, with Neil E. Gordon as chairman and Wilhelm Segerblom as secretary. The constitution and bylaws of the division were approved by the Council at this meeting. At the Washington meeting in April 1924, it was announced that the following program of the division was well under way (*27*):

1. The correlation of high school and college chemistry
2. The organization of associations of chemistry teachers in the various states
3. The establishment of a *Journal of Chemical Education*

Work on the first of these objectives has been continued for years. There have been numerous committee reports, many

papers, and much discussion. When chemistry teachers within a state were organized, a Senate of Chemical Education was set up, with the chairman of the Committee on Chemical Education as ex-officio chairman of the Senate. Each state was to be represented by a high school teacher, a college or university teacher, and an industrial chemist. A meeting of the Senate was to be held at each meeting of the Society. This Senate was active for a few years, but was later given up because it was difficult to obtain the attendance of all three senators from each state. Subsequently, the work of the Senate was taken over by others within the division.

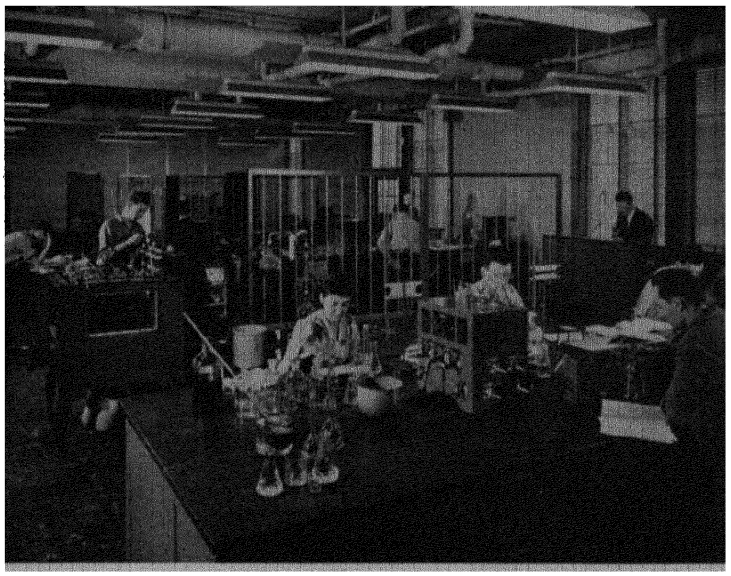
The first issue of the *Journal of Chemical Education* appeared in January 1924, with Neil E. Gordon as editor. Meeting a real need, this journal has been regularly published ever since. Its importance and influence have grown steadily. Many articles of historical interest have been included. The first four numbers of Volume I were published by the Section of Chemical Education, but beginning with Number 5 the Division of Chemical Education has taken responsibility for its publication. Users of the *Education Index* are impressed by the many references to the *Journal of Chemical Education*.

The journal has been fortunate in its editors. Gordon served until December 1932 and was followed by Otto Reinmuth, who was in charge until August 1940. Reinmuth was succeeded by Norris W. Rakestraw, the present editor. In more than a quarter of a century, there have been only three editors. The business affairs of the journal were handled at first by Erle M. Billings, who has given unusually varied and faithful service to the AMERICAN CHEMICAL SOCIETY (*9*). These business matters were taken over by The Chemical Foundation, Inc., in October 1927, with Wm. W. Buffum directing. When this arrangement ceased, Harvey F. Mack became business manager in 1933 and is still in charge. For years, he assumed the financial risk and carried the burdens. Without his help, continued publication of a satisfactory journal would not have been possible. He has been both efficient and generous. Long before his connection with the *Journal of Chemical Education*, he had printed other journals of the Society (*13*). ACS Secretary Alden H. Emery reported the action of the Board of Directors of the AMERICAN CHEMICAL SOCIETY on September 3, 1950 (*14*): "Adopted resolution of appreciation for many contributions of Erle M. Billings to ACS and chemistry. Voted appreciation of Harvey Mack's 50 years of service to chemistry as printer of ACS publications."

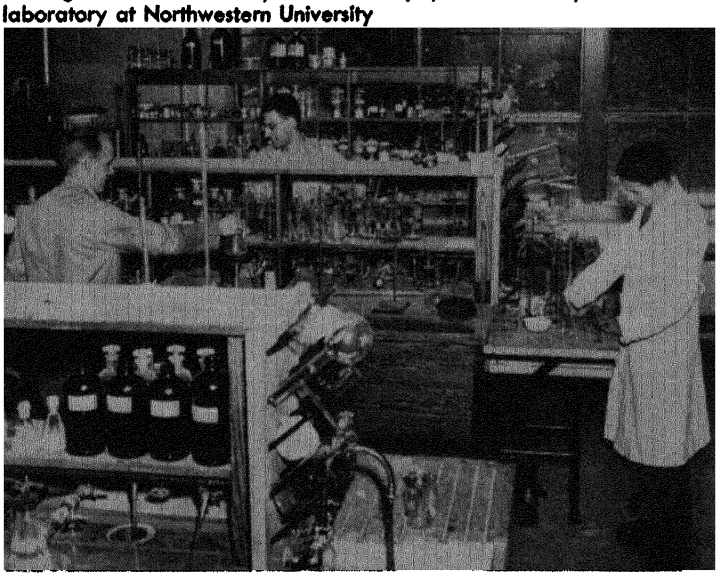
As editors of chemical publications, teachers have done their full share. Outstanding contributions have been made by Charles F. Chandler, Edward Hart, Ira Remsen, W. A. Noyes, Sr., Wilder D. Bancroft, Charles H. Herty, Arthur B. Lamb, Neil E. Gordon, Gerald Wendt, Otto Reinmuth, Norris W. Rakestraw, W. A. Noyes, Jr., Harold C. Urey, and Ralph L. Shriner. These last four are still active. Five of these editors have been presidents of the AMERICAN CHEMICAL SOCIETY. In some cases, one man has served as editor of more than one journal. For example, W. A. Noyes, Sr., edited the *Journal of the American Chemical Society*, *Chemical Abstracts*, and *Chemical Reviews*. In addition, he served as editor of Scientific Monographs from its beginning in 1919 until 1941. Benjamin Silliman, the elder, first professor of chemistry at Yale, was the founder in 1818 of the *American Journal of Science and Art*, the first truly scientific journal in the United States. This journal is still being published.

Divisional Membership

Of the 8762 teachers who were members of the AMERICAN CHEMICAL SOCIETY in 1949, only 658 (7.5%) were members of the Division of Chemical Education. This is a poor showing, contrasted with the over-all percentage. For the Society as a whole, 29% of all members belong to one or more divisions. In 1949, membership in the Division of Chemical Education increased 138% over 1948. This is encouraging. But there is



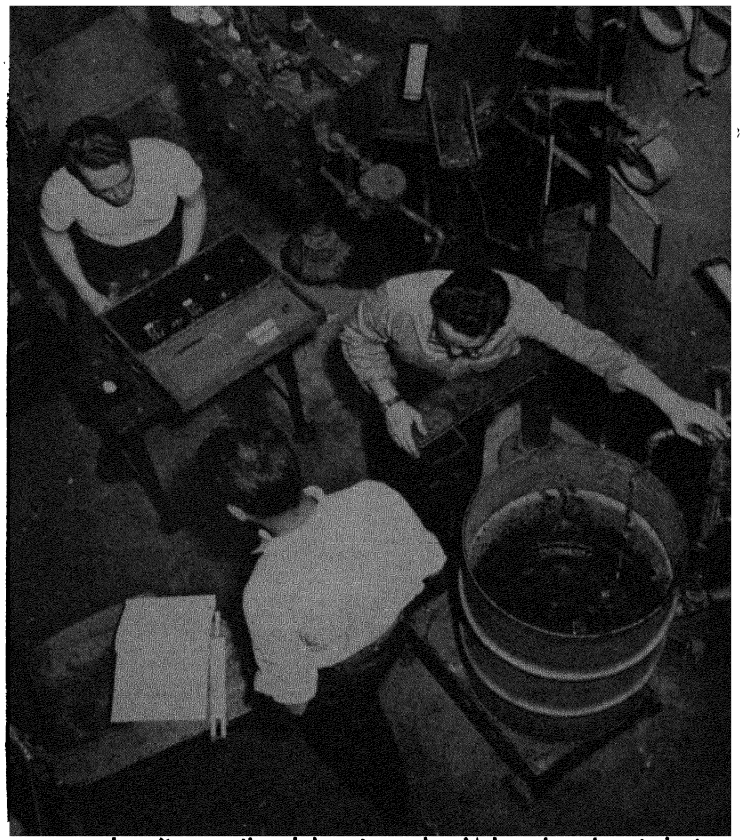
Undergraduates are busily at work in physical chemistry laboratory at Northwestern University



Graduate students conduct original research in 6-man laboratory at University of Rochester



Industry carries on job of chemical education, as here at Pennsylvania Salt Manufacturing Co.



In unit operations laboratory, chemical engineering students study workings of double-effect evaporator

still a long way to go, for the teacher who is not a member of the division misses much (*10*).

Members of the division were active in the promotion and direction of the Patricia Garvan Prize Essay Contests. Mr. and Mrs. Francis P. Garvan established these contests in September 1923 in memory of their daughter (*23*). These competitions were held over a period of eight years, during which time half a million dollars were spent and many prizes awarded to students in high schools, normal schools, and colleges. They gave to the youth of the country an intelligent appreciation of the vital part played by chemistry in numerous phases of American life.

Approved by the ACS Board of Directors on June 8, 1950, an annual award in chemical education will be given to the outstanding chemistry teacher of the year. This award in recognition of the fundamental importance of the teaching of chemistry will be financed by the nation's scientific apparatus makers.

From the beginning, the programs of the section and then of the division have been attractive and of value. Previewing the 113th ACS meeting in 1948, *Chemical and Engineering News* commented (*7*): "The Division of Chemical Education . . . has gained a reputation for its diverse, extensive, and interesting programs."

Certainly, a glance at the divisional programs from the very first confirms this statement. It is difficult to think of a phase of chemical education which has not been discussed. The best methods for correlating high school and college chemistry curricula, so often considered from the earliest years, have naturally been followed by discussions on courses in general, analytical, physical, and organic chemistry, and how each of these can best be presented to different groups of students.

Subjects for symposia, of which more than 60 have been held in 30 years, have covered a wide range of topics and have been undertaken with other divisions and many special groups. There were seven symposia in one meeting in Atlantic City. Courses in chemistry for premedical students, for chemists and chemical engineers, and for the nonmajor students; lecture demonstrations; design and construction of chemical laboratories; reaction kinetics; chemical thermodynamics; theories and teaching of acids and bases; standardized tests; chemical nomenclature; technical journalism; professional and economic status; training and opportunity for women in chemistry; relation of cotton to chemistry; plastics; what industry wants of its chemists; and many other subjects have been discussed.

The influence of these symposia has been widespread. They obviously have affected the content of textbooks and the method by which chemistry is presented. Many teachers have received a broader outlook, a clearer understanding of the importance of their work, and a fresh inspiration. Prominent industrialists who have accepted places on the program to tell what is expected of graduates in chemistry and chemical engineering have received from the resulting discussions a better understanding of the problems involved.

More recently, symposia have dealt with such subjects as chemical literature, literature and patent surveys, petroleum information service, and technical library techniques. These symposia were the basis for this statement in *Chemical and Engineering News* (*8*): "For several years, a group of members has organized for each national meeting a comprehensive symposium on some phase of the use of chemical literature. The sessions, held under the auspices of the Division of Chemical Education, have been well attended. In late 1947, a petition was filed for the creation of a Division of Chemical Literature, and on September 5, 1948, the Council acted favorably."

The chairmen of the Division of Chemical Education have come from 25 institutions, including high schools, academies, teachers' colleges, and state and nonstate colleges and universities. The Section and the Division of Chemical Education have been fortunate in the ability, enthusiasm, and devotion of its officers and members. Their influence is reflected in the program of the most recent meeting held in Chicago in September 1950. There, for four days of general session and symposia, problems of chemical education were presented and discussed. The symposia centered around the teaching of chemistry to nonmajor students, organic chemistry for chemistry majors, standardized tests, and educational activities of local sections (*16*).

And so the Division of Chemical Education in its thirtieth year—well officered and with a journal of widening influence—is in a better position than ever to assist in solving the countless problems which must be met and mastered if men and women are to be trained for the continued advance of chemistry in America.

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In last century, soft coal burners were advertised with all the ballyhoo currently reserved for fluid-drive automobiles, television sets, dishwashing machines, and toothpaste

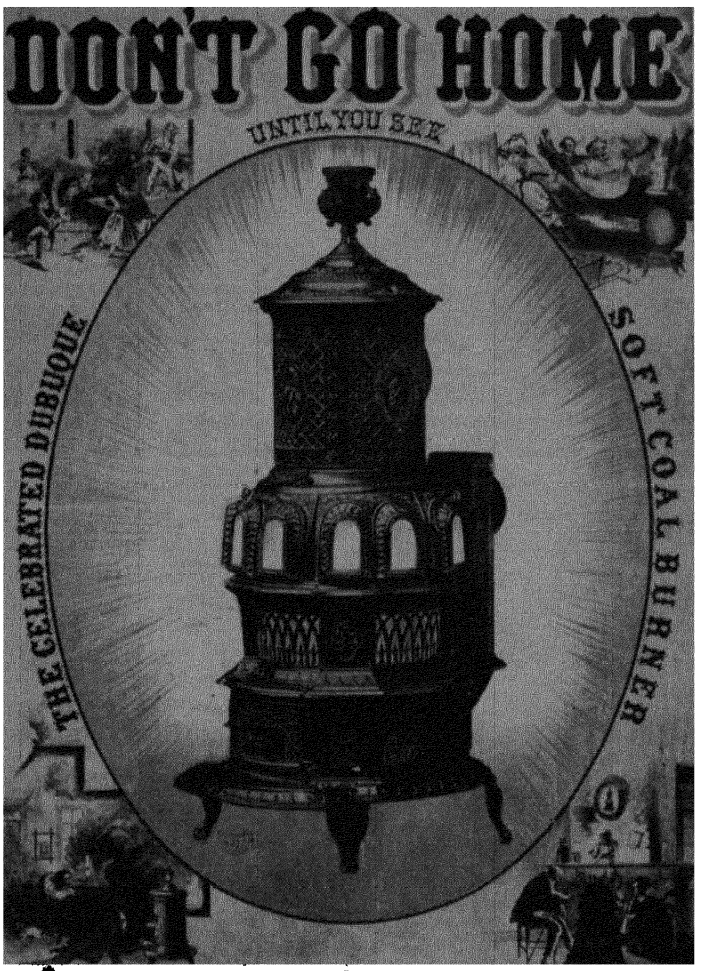
Gas and Fuel Chemistry

Long dependent upon natural fuels, chemists more and more are turning their attention to synthetics

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Illinois State Geological Survey, Urbana, Ill.



WHEN the AMERICAN CHEMICAL SOCIETY was founded in 1876, anthracite, bituminous coal, and wood were the principal fuels used in the United States. Natural gas was employed locally for street lighting and domestic purposes, petroleum had replaced cannel coal as a source of "coal oil," gas lighting was well established in cities, and both beehive coke and anthracite outranked charcoal in the smelting of iron ore.

During the previous century, Joseph Priestley in 1774 demonstrated that a burning candle generates as much "fixed air" as it uses "dephlogisticated air." Benjamin Franklin in 1785 described a stove employing the downdraft principle. Count Rumford proposed a crude calorimeter, while in 1826 Marcus Bull designed a small insulated room which contained a stove for determining the comparative heating value of various fuels.

About the middle of the 19th century, three events presaged the development of the petroleum industry. These were Samuel W. Kier's production of an illuminating oil by the distillation of petroleum; a remarkably complete distillation analysis and chemical study of a sample of oil by Benjamin Silliman, Jr., of Yale College; and the drilling of the first oil well by Colonel E. L. Drake at Titusville, Pa. The new petroleum industry promptly captured the illuminating-oil market previously developed by the retorting of cannel coal in the United States and made heavy inroads into the shale-oil-retorting industry of Great Britain. Indeed, kerosene from petroleum was long known as "coal oil" by the general public.

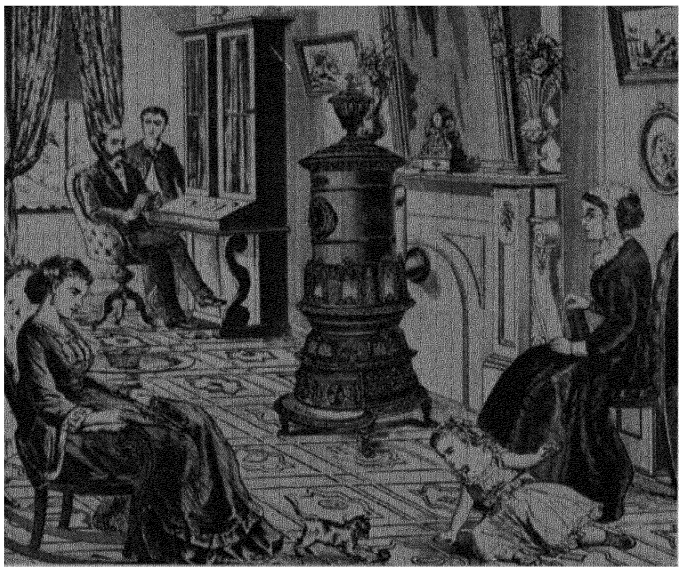
A remarkable volume, entitled "A Report to the Navy Department of the United States on American Coals Applicable to Steam Navigation, and to Other Purposes," was published in 1844 by Walter R. Johnson. A book of 606 pages, this report gave in detail the data on complete evaporative tests conducted on 43 samples, three of which were shipments from England, Scotland, and Nova Scotia, and one of which was American wood. The data were set forth in 200 tables. In one table, the results were presented in the form of a ratio of fixed carbon to volatile matter. This ratio was shown to have a constant relation to the evaporative power of the fuels tested. This appears to have been the origin of the "fuel-ratio" concept.

One can obtain some appreciation of the value of this monumental study from a comment written by S. W. Parr [*Ind. Eng. Chem.*, 18, 95 (1926)]: "One cannot go through the pages of this report without marvelling at the indefatigable energy that must have characterized the author; the skill with which he developed a technique along lines having no established precedent to follow, and the wisdom with which he arranged and interpreted his results." Not until the establishment of the fuel testing program by the U. S. Geological Survey at the St. Louis World's Fair in 1904 was a comparable investigation in the field of combustion to appear.

From the earliest days of coal mining, differences among various coals were recognized. These were based on physical appearance rather than on inherent chemical compositions. Immediately after the publication of Johnson's work, H. D. Rogers attempted a classification of coals based on proximate analysis into anthracite, semianthracite, semibituminous, bituminous, hydrogenous, and gas coals. This was the situation as it existed in 1875.

Proximate and ultimate analyses of coals were made, though not with the precision of present-day techniques. J. B. Britton stated unequivocally in 1876 that "the method of determining water by merely finding the loss which coal sustains by drying... is fallacious."

In so far as gaseous fuels are concerned, coal was distilled to



Family enjoys the warmth and elegance of coal stove, a miracle of 19th-century ingenuity



In front of blazing fireplace, suitor delicately pops the question—when in walks Pop

produce gas for lighting, the objective being to obtain as large a proportion of illuminants as possible. Water gas had been introduced several years earlier by T. S. C. Lowe, and petroleum products were already used for the candle-power enrichment of gas. Since gas was employed mainly for lighting, photometric tests of candlepower were of greater importance than tests of heating value. In 1875, Charles F. Chandler (a charter member and past president of the Society) presented a very complete lecture on gas manufacture to the American Gas Light Association. He listed over 100 components of gas, ammonia liquor, and tar.

Gas analysis generally followed the eudiometric and explosion practices of H. Bunte, W. Hempel, and Cl. Winkler. However, the German Orsat apparatus described by T. Egleston in 1874 was to set the pattern for later developments along these lines. It was not until publication in 1894 of a brilliant thesis by F. C. Phillips of Western University of Pennsylvania (now University of Pittsburgh) upon the "Phenomena of Oxidation and Chemical Properties of Gases" that the presence of unsaturated hydrocarbons, carbon monoxide, and hydrogen in natural gas was questioned.

The First 30 Years

In the autocatalytic progress of fuel chemistry, the period from 1875 to 1904 may be considered one of incubation, during which time a few pioneers laid the groundwork for progress which came much later. In 1877 Persifor Frazer, Jr., of the Pennsylvania Second Geological Survey presented what is generally considered to be the first scientific classification of coal devised in America; the system was based upon the so-called "fuel ratio."

Coal analyses included both proximate and ultimate. Heating values were determined in bomb calorimeters imported from Europe. Because of the wide variety of available procedures for proximate analysis, there developed a growing recognition that standardization was needed. In 1895 a committee of the American Chemical Society, consisting of W. F. Hillebrand, C. B. Dudley, and W. A. Noyes, was appointed to study the problem. In 1899 this group presented to the Society recommendations for proximate analysis, including the Eschka method for sulfur.

In 1895, in a report of the Storrs (Conn.) Experiment Station, W. O. Atwater and C. D. Woods described the first American-made bomb calorimeter. A platinum or gold-plated copper lining was used in a simple steel bomb.

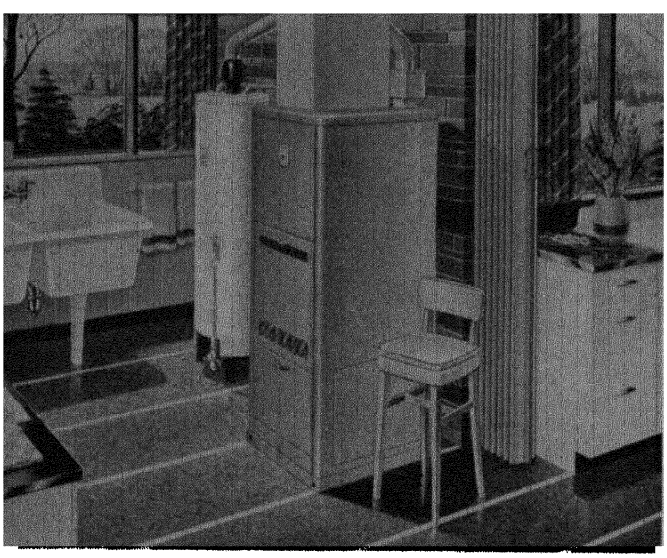
In 1897, N. W. Lord and Frank Haas published the proximate analyses and calorific values (determined in a Mahler bomb calorimeter) of a number of Ohio coals. They showed that the carbonaceous material (moisture-, ash-, and sulfur-free) was remarkably uniform in heating value. In 1900, S. W. Parr initiated a life of fruitful contributions to fuel chemistry (and to the Society) by devising a new coal calorimeter that employed sodium peroxide.

The use of natural gas spread to steel mills, glass works, and other industrial establishments, and the coal industry was beginning to notice the competition from both oil and gas.

The manufacture of coke grew rapidly from 1880 onward. In 1892 a by-product coke plant was built in Syracuse, N. Y., by the Semet-Solvay Co. for the production of ammonia, and in 1895 the first by-product ovens (Otto-Hoffman) for making blast-furnace coke were built in Johnstown, Pa., for the Cambria iron works.

John Fulton played an important role in the development of the industry. In 1875 he noted how both the cellular structure and the strength of coke affected blast furnace operation. His treatise on coke, published in 1895, remains a valuable contribution to the literature.

Gas manufacture from coal continued to grow, but as electricity began to capture the lighting market, the industry gradually changed to domestic fuel production. Heating value became more important than candlepower. Gas producers and water-gas generators multiplied in number, attempts were made at oil-gas generation, and the practice of carburetion of water gas



Modern self-operating heating unit uses natural, manufactured, mixed, or liquefied petroleum gas

spread rapidly. The work of J. K. Clement, L. H. Adams, and C. N. Haskins on equilibria and reaction kinetics, published in Bulletin 7 of the United States Bureau of Mines (1911), was the first serious attempt to study the chemistry of the process.

In 1904, under the direction of J. A. Holmes, M. R. Campbell, and E. W. Parker, a coal testing plant was established by the U. S. Geological Survey at the Louisiana Purchase Exposition in St. Louis, Mo. This station was equipped to make full scale tests of coal in boiler furnaces, gas producers, beehive coke ovens, briquetting machines, and coal-washing plants. Car-load samples of representative coals from various parts of the United States were sent to the plant, and face samples of the coal beds were taken for analysis. Professional Paper 48 of the U. S. Geological Survey, published in 1906, gave the first comprehensive information on the composition and utilization properties of American coals.

The Coal Testing Plant continued operations until 1907, when it was merged with Coal-Mine Accidents Investigations, at Pittsburgh, Pa., to constitute the Technologic Branch of the U. S. Geological Survey. In 1910 Congress authorized the creation of the Bureau of Mines, to which the Technologic Branch was transferred. This support of the Federal Government was a tremendous stimulus to public interest in fuels. N. W. Lord and E. E. Somermeier directed the chemical investigations at the testing plant and found, on application of the ACS standard methods to a wide range of coals and lignite, that certain additional precautions were necessary if correct results in the proximate analysis of coal were to be obtained. This led to important improvements in sampling and analytical methods.

Coal Sampling, Analysis, and Testing

In 1911 a joint committee of the American Chemical Society and the American Society for Testing Materials, consisting of W. A. Noyes, chairman, Perry Barker, H. C. Dickenson, A. C. Fieldner, Frank Haas, W. F. Hillebrand, S. W. Parr, S. S. Vorhees, and A. H. White, was appointed to revise existing methods. Their reports were published in the *Journal of Industrial and Engineering Chemistry* in June 1913 and January 1917. Procedures were given for sampling, proximate and ultimate analyses, and the determination of sulfur and phosphorus. The calorific value of coal was found by use of an oxygen bomb calorimeter. The American Society for Testing Materials adopted these as standard methods on the recommendation of its Committee E-4, of which Parr was chairman. From time to time these procedures have been revised by ASTM Committee D-5 on coal and coke.

Parr's most useful invention, from the standpoint of the coal analyst, was his calorimeter bomb of noncorrosive Illium alloy, which eliminated the need for platinum, gold, or enamel linings and all their attendant annoyances. However, he made other contributions through his investigation of the spontaneous weathering and combustion of coal in storage, the effect of sulfur compounds, an accelerated weathering test, and, with A. R. Powell, a direct method for determining the forms of sulfur in coal.

As the use of coal became more widespread, needs developed for other tests. A. C. Fieldner and associates studied the effect of oxidizing and reducing conditions on the fusibility of coal ash and its relationship to clinker formation. This work served as the basis of the present standard method for determining the softening temperature of coal ash.

In an effort to determine in the laboratory the behavior of coals in coke ovens, a number of laboratory tests were devised for measuring volume changes and pressures developed on carbonization. Associated with this work were V. J. Altieri, R. E. Brewer, W. T. Brown, J. D. Davis, A. W. Gauger, C. C. Russell, and others. None of these tests has as yet reached general acceptance as a standard method. The 12-inch, movable-wall, slot-type test oven designed by Russell for measuring expansion pressure is used by some coke-plant operators to evaluate coals and coal blends and to avoid the use of high expanding mixtures that might damage oven walls.

During this same period, many attempts were made to devise tests for measuring the agglutinating or plastic properties of coking coal when heated through its softening temperature in the absence of air. S. W. Parr and his students measured the resistance to flow encountered by nitrogen passing through a column of granular coal that had been heated to the softening temperature. S. M. Marshall, B. M. Bird, W. A. Selvig, and others sought to standardize some of the older methods for measuring the agglutinating power of coal when mixed with varying percentages of inert material (such as sand or silicon carbide). In 1931, J. D. Davis designed a plastometer which measured the temperature range of stickiness and the resistance to rotation of a horizontal cylinder containing a stirrer and a charge of coal. In 1939 R. E. Brewer and J. E. Triff modified the German Gieseler apparatus, by means of which the softening and solidification temperatures and changes in fluidity or consistency of the coking mass can be determined. None of these techniques has proved entirely satisfactory, although some research workers use one or another of these methods in their studies of various coal blends used in coke making.

In the *Journal of Industrial and Engineering Chemistry* in 1909, E. G. Bailey reported a method of improving the accuracy of coal sampling. He showed that the most important factors in sampling are the size and number of impurities in proportion to the weight of the sample (the "size-weight" ratio).

The study by J. B. Morrow and C. P. Proctor [*Trans. Am. Inst. Mech. Engrs.*, 119, 227–76 (1936)] led to a revised ASTM standard procedure for sampling coal based on the ash content and the number of increments.

Origin, Petrography, and Classification of Coal

David White of the U. S. Geological Survey and Reinhardt Thiessen of the U. S. Bureau of Mines were American pioneers in the study of the origin and petrography of coal. Thiessen perfected a new technique for grinding thin, virtually transparent test sections. Throwing new light on the constitution and origin of coal, he proved that the glossy bright bands, which he called anthraxylon, consisted of coalified stems and branches of wood rather than a residual structureless jelly, as many had believed. He also showed that the duller bands, which he called attritus, were made up of a mixture of anthraxylon fragments, leaf cuticles, spores, resin particles, and other particulate matter. Later, H. G. Turner devised a procedure for etching surfaces of anthracite by flame. His microscopic studies revealed the relationship between anthracite and bituminous coals.

The names vitrain, durain, clarain, and fusain, introduced by British investigators, and anthraxylon and attritus, introduced by Thiessen, soon became familiar to coal chemists. However, the determination of these components remained in the domain of the microscopist until 1936, when Hsiao, Fuchs, and Gauger reported a chemical method for the quantitative determination of fusain. The determining factor in this test was the difference in the rate at which the components reacted with nitric acid.

The classification system of Persifor Frazer, Jr. (1877), was based on eastern coals and was unsatisfactory for the lower-rank western coals. Other investigators, including G. H. Ashley, M. R. Campbell, O. C. Ralston, and S. W. Parr, carried this original classification still further. While the systems they suggested became widely known and helped to provide broad, general designations for various ranks of coal, it became apparent that a standard, uniform system was needed. Consequently, in 1927, a Sectional Committee on Classification of Coal, sponsored by the American Society for Testing Materials, was established under the rules of the American Standards Association.

In the standard specifications for classification of coals by rank, recommended by this committee and adopted by the ASTM and ASA in 1936, the coals are divided into four broad classes, designated as anthracitic, bituminous, subbituminous, and lignitic. Each of these classes is further divided into named groups, depending on the fixed-carbon content or calorific value. These specifications have stood without revision since 1938.

The Chemical Nature of Coal

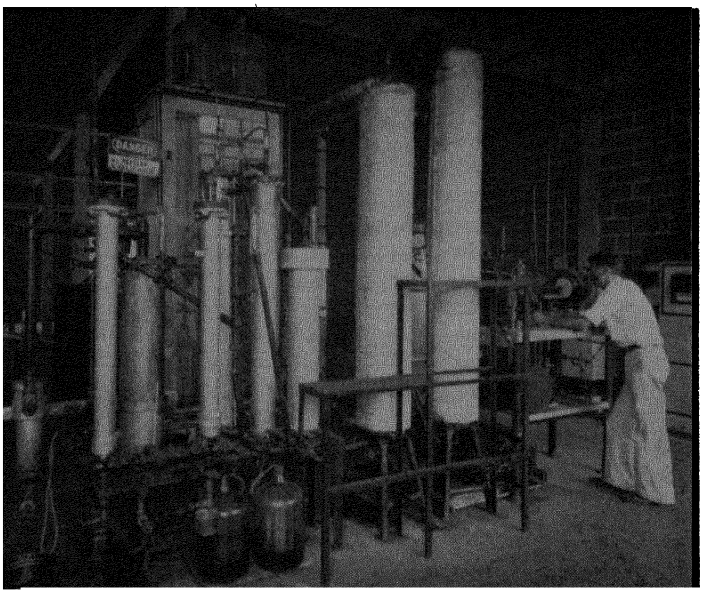
As recently as a dozen years ago, a popular handbook of chemistry made the statement that carbon occurs "...free as diamond and graphite, and in an impure form as coal..." The picture which has emerged from years of chemical research is not that coal is an impure form of elemental carbon but that it is a mixture of complex compounds of carbon in which six-membered carbon rings form an increasingly important part as the rank of the coal increases. The increase in rank is also accompanied by an increase in "fixed carbon" (the coke residue left on destructive distillation) and a progressive decrease in moisture content. Varying quantities of mineral matter are found in physical mixture in coals.

The study of the moisture content and its relationship to the nature of coal had its beginning in the analytical determination of the moisture by weight loss methods. Dissatisfied with this type of procedure, E. Stansfield and K. C. Gilbart developed their equilibration method, as the outgrowth of work started in 1907. Since that time, experiments by these authors and by H. C. Porter, O. C. Ralston, Edward Mack, G. A. Hulett, A. W. Gauger, I. Lavine, O. W. Rees, F. H. Reed, and G. W. Land in this country, and by many investigators abroad showed that the moisture in coals has a lower vapor pressure than does free water at the same temperature. From this has grown the concept of micropores in the coal material. At the same time, interest has developed in the study of pore sizes and the measurement of surface areas by gas-adsorption methods.

Ash determinations and ash analyses (recently employing spectroscopic methods for the detection and estimation of trace elements) have been a part of the coal chemist's work for many years. However, it has never been considered that these methods gave a true picture of the minerals that were originally present in the coals. Early in the century, S. W. Parr at the University of Illinois developed an empirical method for calculating the amount of mineral matter from ash and sulfur data. Later work at Pennsylvania State College, the Illinois State Geological Survey, and the Bureau of Mines showed that over 90% of the mineral matter in many Pennsylvania and Illinois coals consists of kaolinite, pyrite, and calcite, with smaller amounts of other minerals also present.

Little attention was given to the problem of elucidating the chemical nature of the organic portions of coal until early in the present century. Probably the first work on the degradation of coal centered around thermal decomposition. However, it soon became apparent that pyrolytic changes were so far reaching that a study of the products, useful as they may be commercially, had little or no value in deducing the constitution of coal. Attempts to decrease the severity of pyrolysis were made by H. C. Porter and G. B. Taylor of the Bureau of Mines in 1914, when they undertook distillations at pressures as low as 0.5 mm. Twenty years later, H. H. Lowry and H. C. Howard of the Coal Research Laboratory of the Carnegie Institute of Technology applied the technique of molecular distillation. Even under these conditions, it was evident that extensive decomposition must be induced if an appreciable amount of distillate is to be formed. The application of solvent extraction, using various solvents under a wide variety of conditions, may be viewed as a milder form of pyrolysis, yet these procedures have failed to produce results of the desired significance in coal-constitution studies.

The application of oxidative degradation methods to the

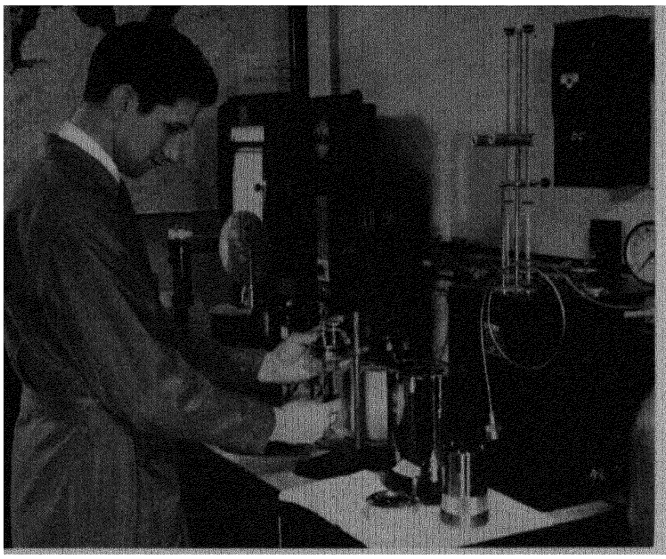


Studying coking properties of coals, researcher recovers tar, ammonia, light oil, and other by-products

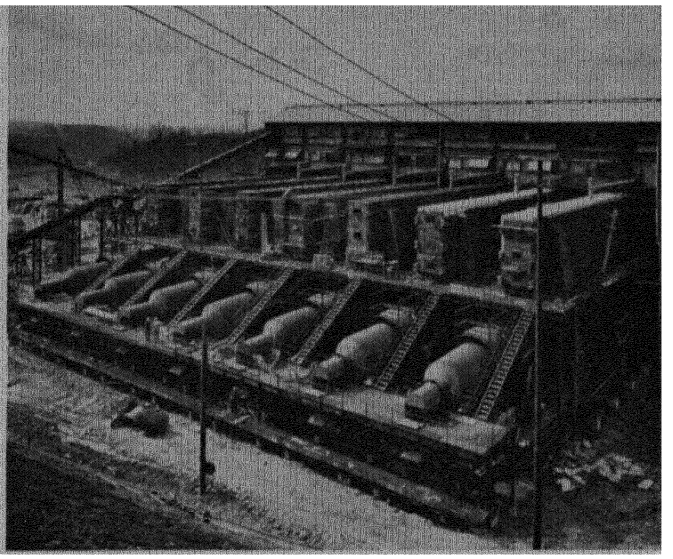
investigation of chemical structures in coal was shown to be of value about 30 years ago, when Franz Fischer and his coworkers in Germany announced the isolation of benzene carboxylic acids from coal oxidized by air under pressure. During the middle and late 1920's, W. Francis and R. V. Wheeler, and W. A. Bone and his coworkers in England extended the oxidation work, especially with alkaline permanganate. By isolating and identifying various aromatic polycarboxylic acids, they obtained the first really significant evidence of the benzenoid nature of the main portion of coal matter. They further demonstrated that an increase in rank is accompanied by an increase in the size or extent of the condensed cyclic structure.

Within the past decade and a half, oxidation studies have been carried on at various laboratories in the United States. The group at Pennsylvania State College has worked on the formation and investigation of the nature of the "humic acids" obtained by mild oxidation of bituminous coals. At the Illinois State Geological Survey, it was shown that the initial atmospheric oxidation of coals proceeds with the formation of an intermediate having peroxidic properties. A study of the oxidation of methylated coals revealed the existence of phenolic structures in coals of ranks up through the high-volatile bituminous. The reaction between oxygen and an alkaline suspension of bituminous coal at elevated temperatures and pressures in the Carnegie Institute of Technology pilot plant resulted in good yields of a mixture of aromatic polycarboxylic acids. The nature and possible uses of these materials are now being investigated. Derivatives of some of these acids have been shown to contain a furan type of oxygen heterocyclic structure.

Early observations on the elementary composition of coal and the low ratio of hydrogen to carbon (as compared with petroleum) suggested that coal might be converted to oil by reaction with hydrogen. The experiments of F. Bergius about 35 years ago showed the commercial possibilities of the process. Although much of the coal hydrogenation work that has been done since that time has had liquid fuel production as its goal, some fundamental information has been gained. In the United States, hydrogenation of coal in the laboratories of the Bureau of Mines has demonstrated the existence of two main types of oxygen linkage in coal and has produced additional evidence that the condensed cyclic structures form larger units in coals of higher ranks. Hydrogenolysis of pure organic compounds at Pennsylvania State College and a comparison of these findings with results obtained with compounds isolated from coals have thrown a great deal



At Midwest Research Institute, chemist employs Parr calorimeter to determine the heating value of coals



Disco low-temperature carbonization plant is located a short distance from Pittsburgh, Pa.

of light on the nature of carbon and nitrogen linkages in the coal substance.

Combustion

Immediately upon establishment of the Bureau of Mines, Henry Kreisinger and others conducted basic investigations on the nature of combustion in fuel beds and in the combustion space of boiler furnaces. This work led to a great improvement in the efficiency of fuel utilization. These investigators established the fact that the primary air for combustion is consumed rapidly, until, at a distance of 3 or 4 inches above the grate, the oxygen content of the gas is virtually zero. They not only found that rate of burning is governed by the amount and velocity of primary air but that the temperature of the fuel bed is increased with the rate of burning; and that the size of the combustion space over the fuel bed is affected by the quantity and quality of volatile matter, amount of excess air, rate of combustion, and other factors. At a Milwaukee power plant in 1921, this group of investigators cooperated with industry in conducting the first comprehensive tests on the burning of pulverized coal. Subsequent to this pioneering work, much fundamental knowledge on combustion in fuel beds has been gained from the experiments of P. Nicholls and others in the Bureau of Mines, as well as from the studies of the Battelle Memorial Institute, equipment manufacturers, and others. All these investigations have been useful in advancing the design of furnaces.

Pioneering researches by the Bureau of Mines and later by Haslam and associates at the Massachusetts Institute of Technology have led to a fuller understanding of producer gas processes. With the tremendous growth of the natural gas industry, interest in gas producers waned. However, renewed interest in this subject has recently been stimulated by the production of industrial peak-load gas and by the use of oxygen in the manufacture of synthesis gas—a field in which C. C. Wright and L. L. Newman have made important contributions.

The physical chemistry of the system carbon-hydrogen-oxygen has been the subject of much study because of its importance in the utilization of fuels. It has been considered in two systems. The first is a homogeneous system containing oxygen or air and one or more of the following: hydrogen, carbon monoxide, and hydrocarbons; the second is a heterogeneous system, containing oxygen or air and a heterogeneous solid.

In general, the present view on gaseous combustion is that a chain reaction is involved, initiated by dissociation of either one or both of the reactants under the activation of a third body. If one subjects a hydrocarbon and oxygen to heat, there is at first a prolonged induction period, followed by a reaction at a measurable and auto accelerating rate that may even attain explosive violence. If a small amount of an aldehyde is added to the mixture, the induction period is almost entirely eliminated. Furthermore, an aldehyde, if not originally present, appears early in the reaction. One possible explanation of aldehyde formation is surface oxidation to peroxide, followed by decomposition to aldehyde and water. Bernard Lewis and Guenther von Elbe of the Bureau of Mines have been active in this field of research. F. D. Rossini, while at the Bureau of Standards, assembled the most complete thermodynamic data on these reactions.

The gradual elucidation of the phenomena of flames and explosives is well recorded in three combustion symposia held under the auspices of the AMERICAN CHEMICAL SOCIETY. These symposia attracted the nation's leading combustion experts. The first symposium was held in Baltimore, Md., in 1925; the second, in Swampscott, Mass., in 1928; and the third in Rochester, N. Y., in 1937. To this series we must add a symposium held in 1948 in Madison, Wis., which was not officially sponsored by the Society but was attended by so many members that it was in fact, if not in name, a Society meeting. At these symposia, the results of flame, explosion, and ordinary gaseous combustion studies were reported.

Much less progress has been made in developing the physical chemistry which is involved in the combustion of carbonaceous solids. We know much about the thermodynamics of the reactions but little about their mechanism. An early theory suggested by Armstrong in 1905 and developed by Rhead and Wheeler in England assumed that the first product of the combustion of carbon is a loosely formed complex, regarded as an unstable compound C_xO_y. This compound was subsequently decomposed into carbon monoxide and carbon dioxide. This theory took into account the fact that both carbon monoxide and carbon dioxide were found in the reaction products, but actually gave no clear picture of the mechanism. The work of American, as well as foreign, investigators in the last quarter century has indicated that the rate of combustion may be governed by the diffusion of the reactant and resultant gases to and from the burning surface. This surface is surrounded by a stagnant film of uniform thickness. Neither carbon monoxide nor carbon dioxide alone is the primary product but some ratio of the two. However, this view does not explain all the known facts.

Gas Investigations

Early methods of gas analysis depended upon the measurement of volume changes which resulted when the individual compo-

nents of the mixture were removed by absorption or by other means. Before the U. S. Bureau of Mines was established, the Hempel and Orsat apparatus dominated the art. Fortunately, G. A. Burrell, head of the gas laboratory of the Bureau of Mines, undertook an investigation of the explosion hazards of methane in mine air and the dangers of asphyxiation from oxygen-deficient and carbon monoxide–containing atmospheres. In the course of this work, he and his associates published many papers on improved methods of gas analysis, new gas detectors, the flammable limits of combustible gases, and protection against carbon monoxide and other poisonous gases. When the United States entered World War I, Burrell and his group formed the nucleus of the Bureau of Mines War Gases Investigations staff which later became the Research Division of the Chemical Warfare Service. Burrell also pioneered in research on natural gas and with his associates was instrumental in the early development of processes for recovering natural gasoline from natural gas. His group made some of the first complete analyses of natural and city gases by liquefaction at low temperatures and by subsequent fractional distillation. A further advance in low temperature analysis was made by Podbielniak, whose automatic and semiautomatic devices have proved very useful.

After the war, the Bureau of Mines led in the adaptation of military gas masks to wide industrial use and in the early 1920's conducted pioneering studies that determined the method of ventilation of the Holland vehicular tunnel under the Hudson River between New York and New Jersey. The bureau developed a very sensitive recording apparatus for determining the carbon monoxide in tunnel atmospheres. In this device, the temperature of a catalytic surface is measured by sensitive multiple thermocouples.

Shortly before World War I, the National Bureau of Standards established a section of gas investigations. R. S. McBride, E. R. Weaver, Martin Shepherd, R. S. Jessup, and others made important contributions to the establishment of calorific and purity standards and to the standardization of analytical methods and tests. Of special value have been studies of methods for determining the specific gravity of gases, the development of the gas balance by J. D. Edwards, the thermal conductivity method for the analysis of gases by Weaver and Palmer, tests for hydrogen sulfide, and studies on combustion in gas-burning appliances.

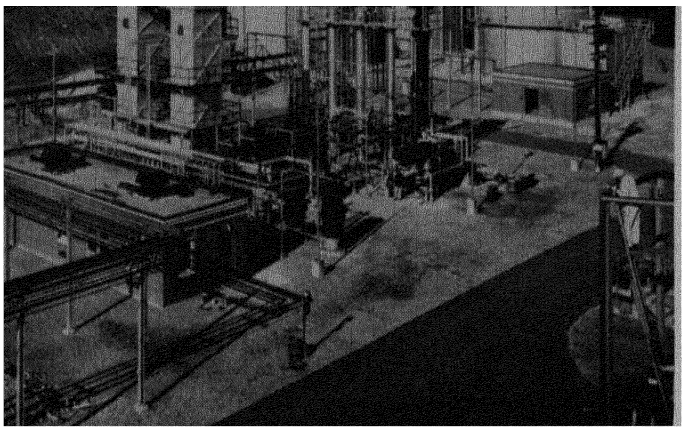
Work by the Bureau of Standards and by G. W. Jones and W. P. Yant of the Bureau of Mines in 1920 and 1925 on hazards from carbon monoxide in improperly designed gas stoves led to the establishment of the American Gas Association Testing Laboratory for the approval of gas appliances on the basis of efficiency and safety.

In 1934 a growing need for the standardization of methods for testing and analyzing gaseous fuels became apparent. As a result, Committee D-3 on Gaseous Fuels was established by the American Society for Testing Materials in 1935, under the chairmanship of A. C. Fieldner. In 1940 A. W. Gauger became chairman. This committee studied the various aspects of the problem with great care and stimulated considerable research into various phases of gas analysis, particularly at the National Bureau of Standards and at Pennsylvania State College. The contributions of Martin Shepherd on complete analysis, R. S. Jessup on calorimetry, H. S. Bean on measurement, and F. A. Smith, J. H. Eiseman, and E. C. Creitz on the determination of specific gravity are particularly noteworthy.

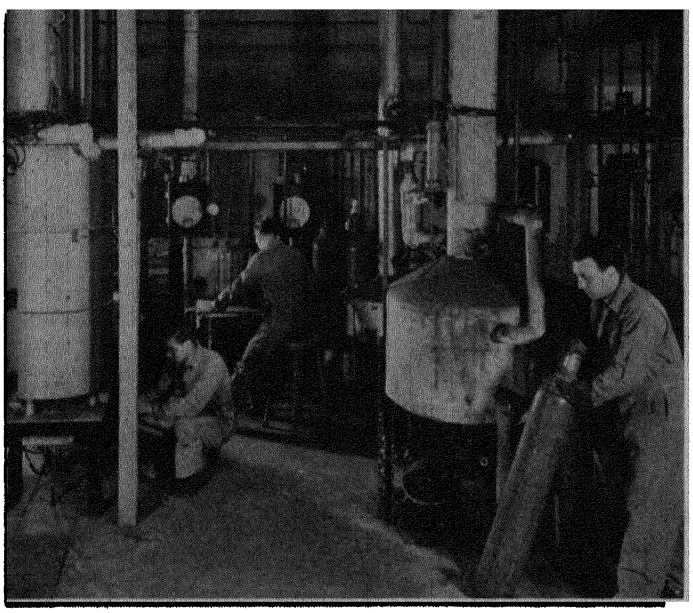
In the field of gas analysis, there is a trend toward use of physical techniques, such as the mass spectroscope, infrared absorption, and thermal conductivity, particularly where large numbers of analyses are required for control purposes.

Coking and Gas Making

At the turn of the century, most coal gas was made in horizontal retorts. By-product coke ovens were just beginning to supplement beehive ovens in the manufacture of coke. The first intermittent vertical gas-making retorts were installed at Manchester, N. H., in 1908, while the first continuous units were introduced at Aurora, Ill., in 1909. Following World War I, by-product ovens began to be used on an increasing scale in the production of base-load gas for municipal supply and in the manufacture of coke for domestic fuel.



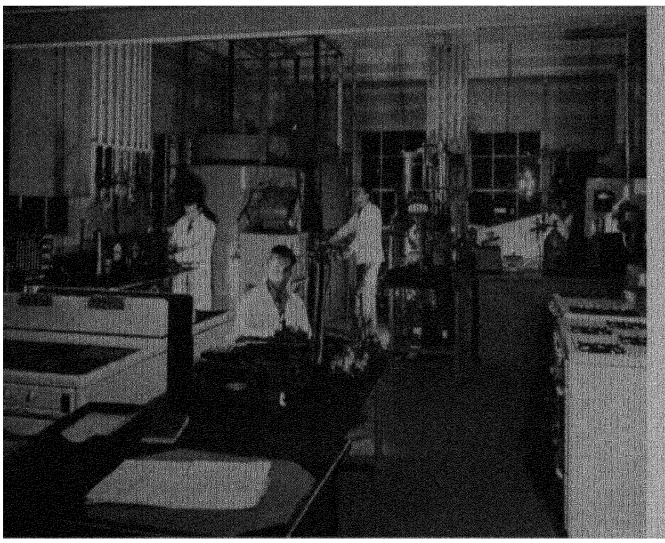
Hydrogen and synthesis gas are produced from natural gas at Bureau of Mines plant in Bruceton, Pa.



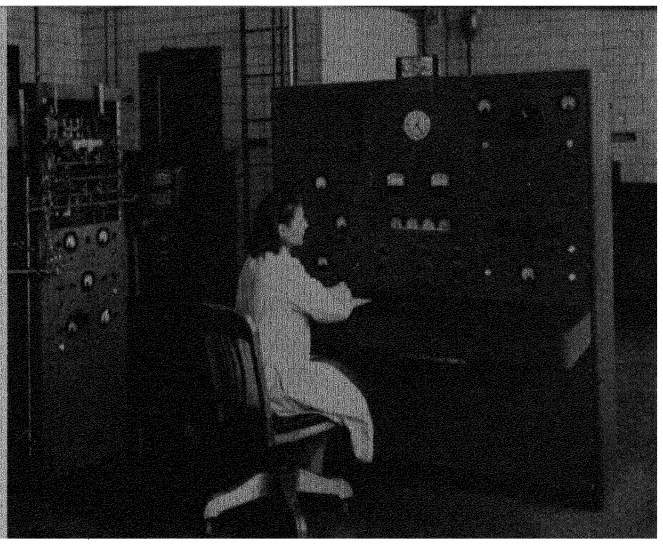
Hydrogen is produced in these experimental units at Bureau of Mines coal hydrogenation plant

In the public utility gas industry, the use of carbureted water gas continued to grow in importance throughout the early part of the twentieth century, until the long-distance pipeline transmission of natural gas began to displace gas from coal. Until 1917, coke and anthracite in geographically favorable areas were the usual generator fuels. Heavy war demands for coke in the steel industry then led to trials with bituminous coals. Investigations by W. W. Odell of the Bureau of Mines and W. A. Dunkley of the Illinois State Geological Survey, working with the gas industry, showed that these coals could be used at lower costs than coke, provided appropriate operating conditions were maintained in the fuel bed.

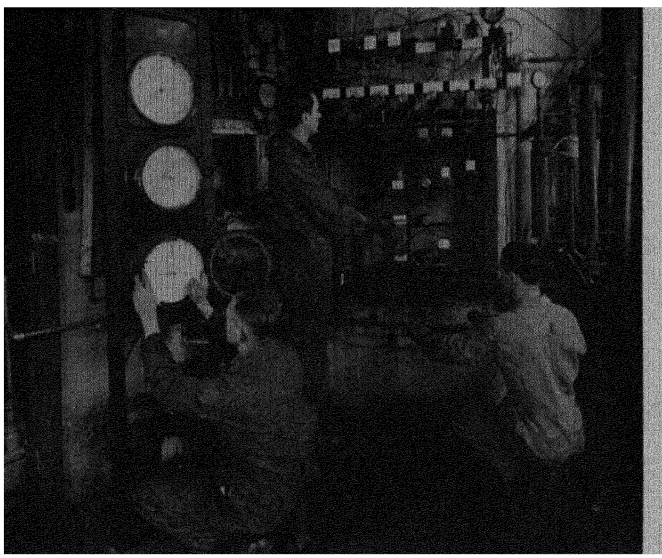
Interest spread to the use of eastern coals, and it was found that the somewhat splinty bituminous coals of eastern Kentucky and southern West Virginia could also be used if charged in uniform sizes, free from fines. The industrial development by the United



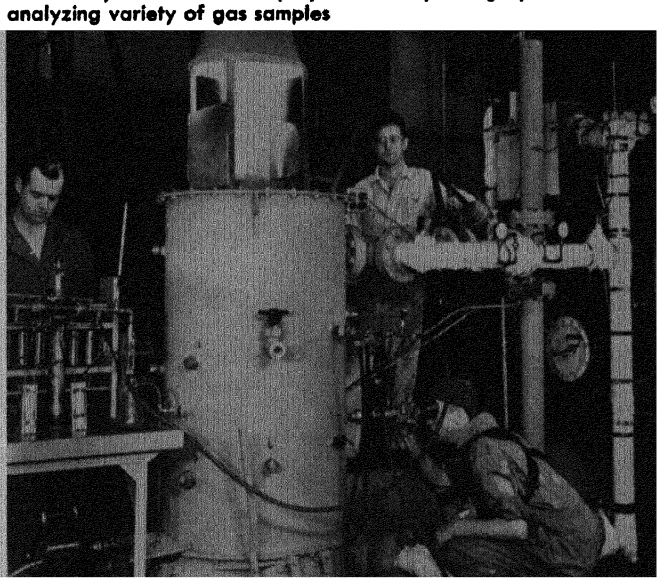
In American Gas Association laboratory, extensive research is conducted on the burning of gaseous fuels



Laboratory technician employs mass spectrograph in analyzing variety of gas samples



Government research workers regulate the flow of hydrogen and coal paste to neighboring converter



In project sponsored by American Gas Association, water gas generator was built at Battelle Institute

Gas Improvement Co. and others of favorable operating methods and equipment, such as the Pier process, the blow run, the back run, and other special cycles of operation, led to considerable use of bituminous coal in the years following the war. W. H. Fulweiler presented an excellent review of this subject at the First International Conference on Bituminous Coal at the Carnegie Institute of Technology in 1926.

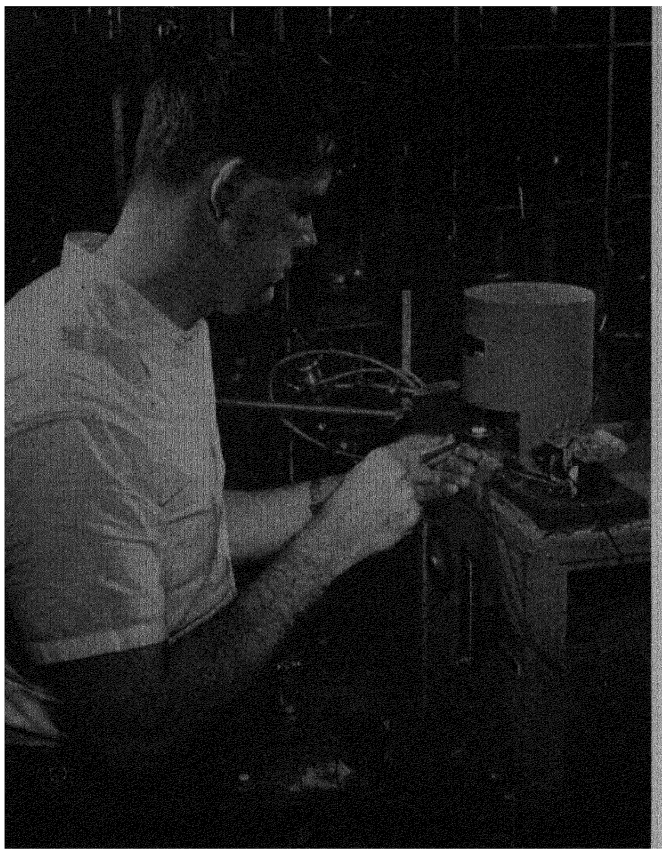
The first Koppers oven was built by the Illinois Steel Co. at Joliet, Ill., in 1908, but the installation of by-product ovens proceeded slowly up to 1915. Then the outbreak of World War I brought an accelerated demand for coke, sorely needed by the expanding steel industry. The need for benzene, toluene, and other coke oven by-products used in the production of explosives, dyes, and organic chemicals formerly imported from Germany, required the sizable expansion of coke-producing capacity.

In 1915, the Mellons took over the H. Koppers Co. and established a multiple research fellowship at the Mellon Institute of Industrial Research, with F. W. Sperr, Jr., at its head. Within a few years, this fellowship had provided important contributions to gas and fuel chemistry, including improvements in the recovery of benzene and toluene from gas; the development of processes for the liquid purification of gas and the recovery of elementary sulfur from it; and the removal of naphthalene and gum-forming constituents from gas.

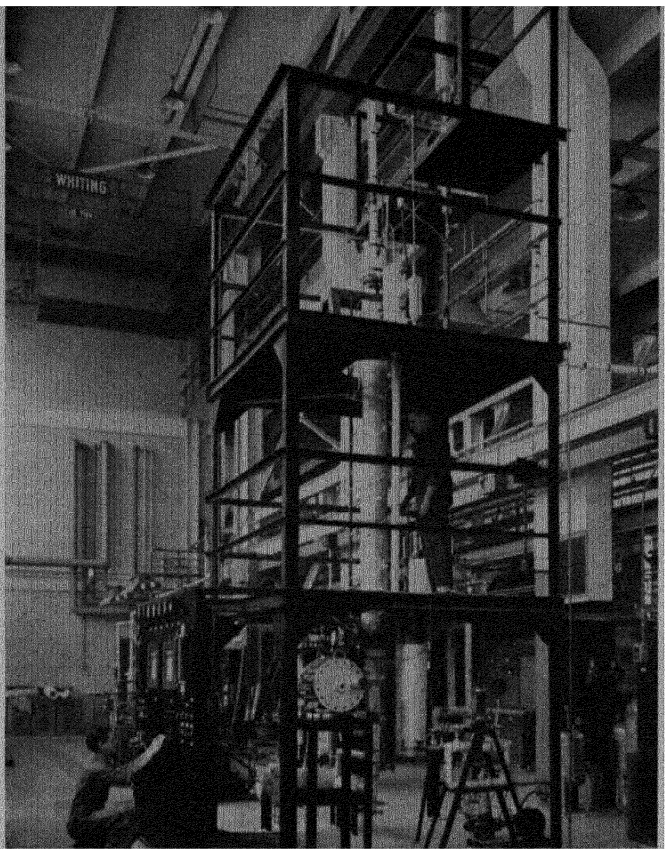
A high rate of by-product oven construction during and after World War I increased the proportion of by-product coke to 97.4% of the total coke production in 1935. Many of the new plants were installed for the production of base-load city gas. In 1927 the Bureau of Mines, in cooperation with the American Gas Association, developed the BM-AGA test for determining the coke-, gas-, and by-product-making properties of American coals. This work, under the leadership of A. C. Fieldner and J. D. Davis, has provided a valuable fund of information on which gas and coke plants can draw in selecting coals.

Attacking the problem of utilizing high-oxygen coals in making metallurgical coke during World War II, F. H. Reed and his associates at the Illinois State Geological Survey constructed an electrically heated, slot-type oven of 500-pound coal capacity, capable of duplicating the performance of commercial ovens. In cooperation with several coke oven operators in the Chicago and St. Louis areas, these investigators showed that it was possible to make satisfactory metallurgical coke from blends containing 30 to 40% of high-rank eastern coals and 60 to 70% of coal from the nearby Illinois coal fields. This discovery led to appreciable savings in transportation.

H. W. Jackman of the Illinois State Geological Survey, working with N. Isenberg at the Inland Steel Co., carried out a series of blending tests with eastern coking coals. In 1945, they published



At Mellon Institute, radioactive tracers are used in investigation of synthetic liquid fuels production



Gas synthesis by Fischer-Tropsch process is studied in government pilot plant at Bruceton, Pa.

data on the variation of expansion pressure with the composition of the blends and gave the results of full scale blast furnace tests with certain of the cokes.

S. W. Parr was the pioneering American investigator of the low-temperature carbonization of coal. Beginning with a paper on "Anthracising Bituminous Coals" early in the century, he and a succession of students showed that a firm and easily ignitable coke could be made from the carbonization of high-oxygen Illinois coals at temperatures below 750° C., coincident with the recovery of material quantities of tar of high tar-acid content. In the early twenties, S. W. Parr and T. E. Layng developed a two-stage carbonization process in which the coal was preheated in a rotary dryer just short of the temperature where plasticity begins. The material was then charged hot into a retort, in which it was heated to still higher temperatures. This technique resulted in more efficient heat transfer through the range of endothermic reactions, particularly because advantage was taken of the heat contributed by exothermic reactions during the primary decomposition in the coke oven.

Although never put into commercial operation, a two-stage, low-temperature process patented by C. B. Wisner in 1924, in which the agglomerating properties of the coal are reduced by controlled air oxidation and preheating below the plastic stage, was developed to a commercial stage early in the 1930's by C. E. Lesher of the Pittsburgh Coal Carbonization Co. The original plant, placed in production some 15 years ago, has recently been replaced by a considerably enlarged installation for the production of smokeless domestic fuel in the form of balls of semicoke. A Lurgi-process plant has operated for a number of years at Dickenson, N. D. Using lignites from the North Dakota area, the plant produces a char that is briquetted for use as a domestic fuel.

Education

In the educational field, the activities of a number of men are worthy of mention. Pioneering among these are N. W. Lord of the Ohio State University, S. W. Parr of the University of Illinois, and A. H. White of the University of Michigan.

Although Lord was a metallurgist, his interest in fuels and his realization of their importance caused him to take a leading part in the development of methods for evaluating them. He trained many of his students along these lines.

The investigations conducted by Parr on analysis and calorimetry and on various phases of the applied chemistry of fuels constitute only a part of his contribution to this field, for many of his students of the first third of the century are prominent today in fuel technology.

When the Michigan Gas Association established a fellowship in gas engineering at the University of Michigan in 1900, A. H. White was a young instructor in the department of chemical engineering. During the subsequent 50 years, he provided inspiring leadership for a large number of students, many of whom are active today in the development of fuel technology. In addition, his laboratories made important contributions to the chemical enginering of gas manufacture, including the purification of gas and the recovery of chemical by-products.

Other educators who deserve mention are H. A. Curtis of Yale University, who worked on low-temperature carbonization; J. J. Morgan of Columbia, who studied low-temperature carbonization by-products; R. T. Haslam at the Massachusetts Institute of Technology, who organized a course in gas and fuel engineering in 1922 and who, together with his students, reported for several years the results of research studies on the mechanism of fuel combustion in furnaces and on the manufacture of producer gas and water gas; W. J. Huff, who accepted the professorship of gas engineering at Johns Hopkins in 1924; E. S. Pettyjohn, who has charge of the work at the Institute of Gas Technology in Chicago; and A. W. Gauger and C. C. Wright of the Department of Fuel Technology at Pennsylvania State College, where a department of fuel technology for undergraduate and graduate instruction and research was established in 1932.

Synthetic Liquid Fuels

Twenty-five years ago, Charles E. Munroe included in his history of industrial chemistry in the United States during the half century of the Society the following prophetic sentence: "The

consumption of our petroleum is advancing so rapidly that other sources of liquid fuel must soon be sought." Even as these words were written, the groundwork for the synthesis of liquid fuels from carbon monoxide and hydrogen was being laid, and a pilot plant for direct hydrogenation of coal was in operation in Germany. Although America's petroleum industry is still supplying liquid fuels, recent years have seen much progress in the development of the information that will be needed when synthetic fuels must supplement the nation's dwindling petroleum resources.

In the United States, the first laboratory investigation of synthetic liquid fuels was conducted by D. F. Smith, C. O. Hawk, and P. Golden of the Bureau of Mines in 1928–30. In studying the mechanism of the Fischer-Tropsch synthesis, these chemists found that ethylene reacts with carbon monoxide and hydrogen over a cobalt-copper-manganese catalyst to form higher hydrocarbons and organic oxygen compounds. This work was the basis of what is now the commercially valuable oxo process.

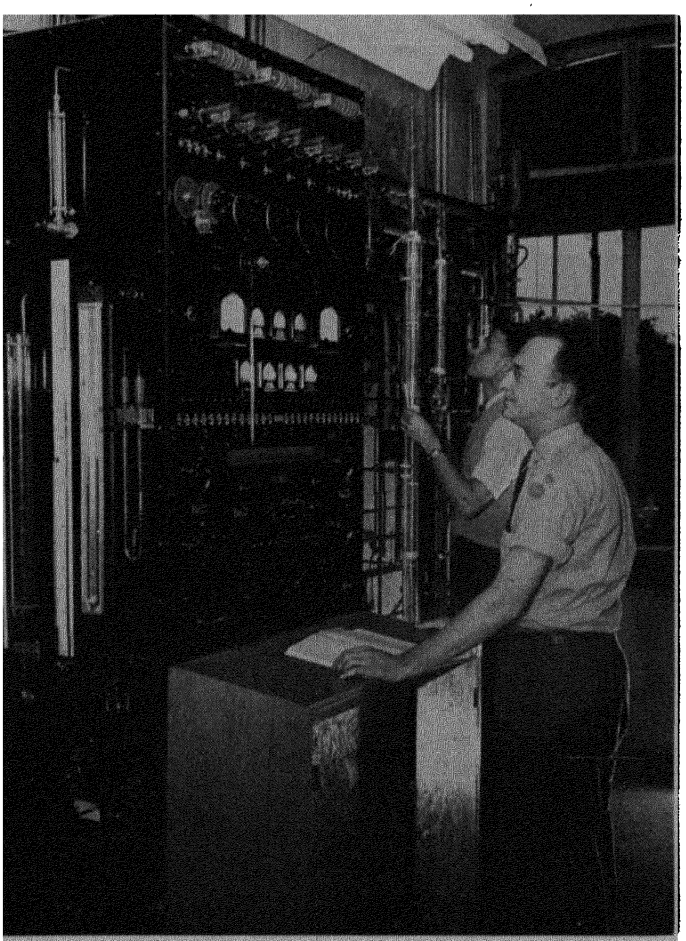
In 1936, under the direction of H. H. Storch, the U. S. Bureau of Mines at Pittsburgh initiated its experimental program of testing American coals in the direct hydrogenation process. In 1944 passage of the Synthetic Liquid Fuels Act by Congress authorized the Bureau of Mines to undertake an extensive research and development program and to construct demonstration plants for the production of liquid fuels from coal, oil shale, and other materials. Research and development work on oil from coal was started at Bruceton, near Pittsburgh, Pa. The production of synthesis gas was undertaken at Morgantown, W. Va., while at Laramie, Wyo., a plant was built for the production of oil from shale. The Missouri Ordnance Works at Louisiana, Mo., was taken over and converted to a coal-to-oil demonstration plant, and an oil-shale mine and demonstration plant were constructed at Rifle, Colo.

Both the Bergius–I. G. direct-hydrogenation and the Fischer-Tropsch gas synthesis processes were taken up in the Bureau of Mines investigations and also by industrial organizations and other research workers.

Interest in the Fischer-Tropsch process was very much in evidence at the New York meeting of the AMERICAN CHEMICAL SOCIETY in September 1947, when the Divisions of Gas and Fuel Chemistry and Petroleum Chemistry jointly sponsored a Symposium on the Production of Synthesis Gas.

The conversion of natural gas to liquid hydrocarbon fuels by controlled oxidation of the gas with oxygen to yield synthesis gas for the Fischer-Tropsch method has been accomplished by commercial interests at Brownsville, Tex. Experimental work directed toward the possible production of synthesis or power gas by the underground gasification of coal has been undertaken by the U. S. Bureau of Mines, cooperating with the Alabama Power Co., and by the Missouri School of Mines, working with the Sinclair Coal Co. in Missouri.

During 1925 to 1929, the U. S. Bureau of Mines operated an experimental oil-shale mine and retorting plant near Rulison, Colo., and a laboratory-scale refinery at Boulder. The passage of the Synthetic Liquid Fuels Act in 1944 made possible the resumption of oil-shale work, and a research and development laboratory was erected on the University of Wyoming campus at Laramie. In addition, a demonstration oil-shale mine and retorting plant were established at Anvil Points, near Rifle, Colo. Pioneering mechanical mining methods have been developed



Distillation of light oil and coal tar fractions is regulated at amply instrumented control panel

which have lowered the costs of mining the shale to far below any previous estimates. Retorting methods are now well on the way to commercial development both by the Bureau of Mines and by the petroleum industry.

DIVISION OF GAS AND FUEL CHEMISTRY

In 1922, chemists interested in gas and fuel testing and research felt the need of a division in the AMERICAN CHEMICAL SOCIETY in which papers pertaining to this field could be given and discussed to better advantage than in the more heterogeneous Division of Industrial and Engineering Chemistry. This group was led by S. W. Parr of the University of Illinois, dean of American coal chemists; R. T. Haslam of the Massachusetts Institute of Technology, where a course in gas and fuel engineering had been established; F. W. Sperr, Jr., chief chemist of the Koppers Co.; W. H. Fulweiler, chemical engineer of the United Gas Improvement Co.; R. S. McBride, consulting engineer of Washington, D. C.; and A. C. Fieldner, then superintendent of the Pittsburgh Experiment Station of the U. S. Bureau of Mines.

Permission was obtained to hold a trial sectional session at the October 1922 meeting in Pittsburgh, Pa. Over 100 persons attended. Under the leadership of R. T. Haslam, a symposium on combustion was held jointly with the Division of Industrial and Engineering Chemistry. In addition, 16 other papers were presented. Other well attended sectional meetings were held at the spring and fall meetings of the Society in 1923, 1924, and 1925. At the spring meeting of 1925, the Council of the AMERICAN CHEMICAL SOCIETY approved the petition of the Gas and Fuel Section to become the Division of Gas and Fuel Chemistry. The first divisional officers elected to hold office, for the fall meeting in 1925 and for both meetings in 1926, were S. W. Parr, chairman; S. S. Morgan, vice chairman; O. O. Malleis, secretary-treasurer; A. C. Fieldner and W. H. Fulweiler, members of the Executive Committee. The first meeting of the new division was held jointly with the Division of Petroleum Chemistry at Los Angeles in August 1925. Parr served as chairman.

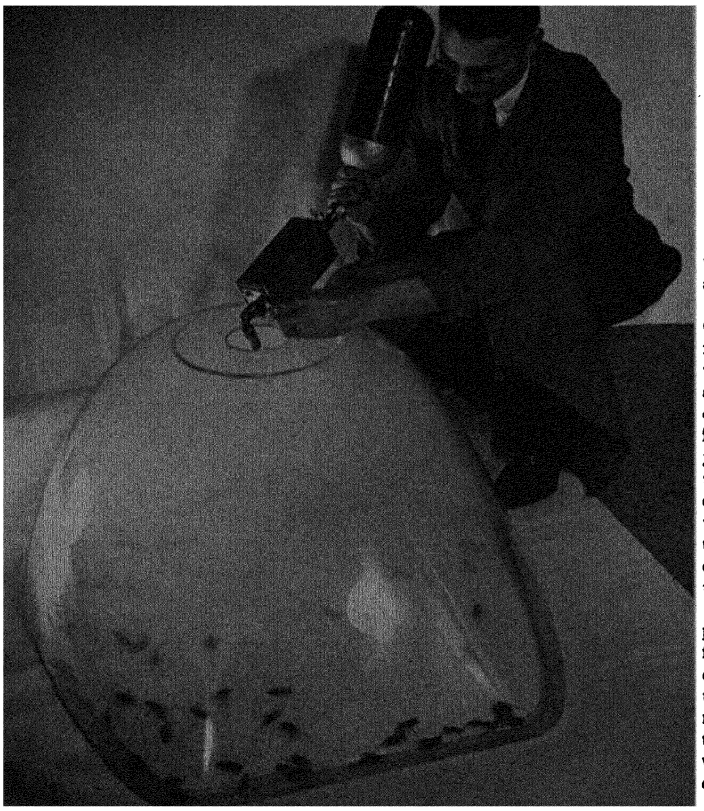
The first full year of operation of the Division of Gas and Fuel Chemistry—1926—was marked by two interesting programs of 12 and 15 papers each at Tulsa, Okla., in April, and at Philadelphia in September. The maximum attendance at the sessions ranged from 50 to 80. An eight-paper Symposium on the Processing of Coal was held at Philadelphia; six of these papers related to low-temperature carbonization. The other papers at the two sessions covered a broad field of solid and gaseous fuels chemistry, including a number of fundamental papers on gaseous explosions, flame propagation and radiation, gas flow through packed columns, heat of carbonization of coal, constitution of coal, origin of carbon disulfide in the carbonization of coal, and the reactions in the fuel bed of the gas producer.

Forty-six meetings of the division were held from August 1925 to September 1950, inclusive. These included 14 divisional symposia or round-table discussions and 13 joint symposia with other divisions. The attendance at sessions varied from 40 to 100 at divisional sessions and from 60 to 300 at joint symposia. The papers presented continued to cover a broad field, with papers on the properties and carbonization of coal in the lead. Recently, papers relating to synthetic liquid fuels have taken first place.

The Division of Gas and Fuel Chemistry has lived up to the promise shown by the early sectional meetings held in 1922 to 1925—a time of rising interest in new developments in the processing of coal, of combustion, and of fuel technology in general. Since authorization of the division by the Council of the AMERICAN CHEMICAL SOCIETY in September 1925, the divisional meetings and symposia with other divisions have reflected chemical progress in fuels, not only in the United States but throughout the world. Many fundamental scientific papers have been given by members of the staffs of universities, technical schools, research institutes, state and federal laboratories, and industrial organizations. The discussions stimulated by these meetings have had an important part in promoting progress in fuel research. The division has an excellent record, and its members look forwar i to more

Officers of the Division of Gas and Fuel Chemistry, 1925–1951

Year	Chairman	Secretary
1925	S. W. Parr	O. O. Malleis
1926	S. W. Parr	O. O. Malleis
1927	G. G. Brown	O. O. Malleis
1928	A. C. Fieldner	O. O. Malleis
1929	S. P. Burke	O. O. Malleis
1930	H. C. Porter	O. O. Malleis
1931	G. St. J. Perrott	O. O. Malleis
1932	J. D. Davis	O. O. Malleis
1933	A. W. Gaug	
1934	H. J. Rose	
1935	W. J. Huff	
1936	O. O. Malle	
1937	A. R. Powe	
1938	H. H. Lowr	
1939	F. H. Reed	
1940	H. H. Storc	
1941	H. C. How	
1942–1943	O. W. Rees	
1944	Gilbert Thi	
1945–1947	S. S. Tomki	
1948	C. C. Wrigl	
1949	G. R. Yohe	
1950	R. E. Brew	
1951	A. A. Ornin	



Example of important use of colloid chemistry is this type of aerosol bomb employed in insect control

Colloid Chemistry

Here the smallness of particles and the greatness of science are strikingly highlighted

W. O. MILLIGAN
The Rice Institute, Houston, Tex.

J. W. WILLIAMS
University of Wisconsin, Madison, Wis.

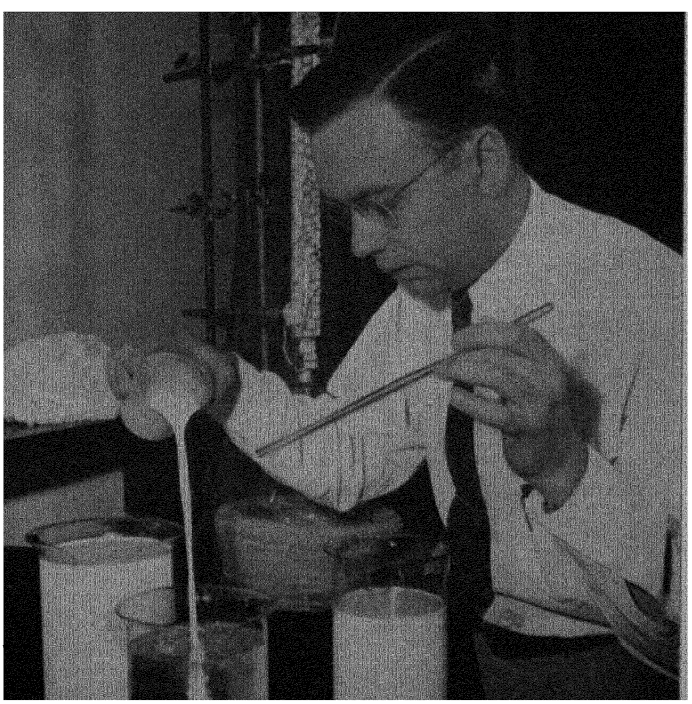
E. J. MILLER
Michigan State College, East Lansing, Mich.

MATERIALS in a finely divided form, consisting of small particles or large molecules, have been known and used by man since prehistoric times. Numerous early investigators prepared and examined substances now known to be colloidal—for example, the well-known purple of Cassius was first reported in 1663. Scientific studies of the chemical and physical properties of such systems were first definitively formulated by Thomas Graham only 90 years ago. In 1861 Graham observed that certain substances such as glue and gum arabic diffused very slowly through membranes, whereas substances such as salt and sugar diffused much more rapidly. Graham designated the former as colloids (Greek: gluelike) and the latter as crystalloids. Today it is recognized that no necessary relationship exists between chemical constitution and the colloidal state of matter, inasmuch as, in general, any chemical compound may be rendered colloidal. Nothing can be further from the truth than the myth which has developed, primarily in the introductory pages of many elementary textbooks on colloid chemistry, that colloidal materials are amorphous, whereas noncolloidal materials are crystalline.

The rapid development of colloid chemistry since the time of Graham has followed two courses. For almost half a century, many investigators in the field of colloid chemistry were content to prepare colloidal solutions or gels, note their stability and color, and pass on to the preparation of other colloids. This first qualitative period was no doubt necessary to build up a mass of information during the early stages of development of the subject, but it gradually yielded to the quantitative period. During this second period, quantitative data were sought, controlled experiments were made, and extensive precision measurements were taken. At first, attempts were made to correlate with the usual laws of physical chemistry what some naive investigators designated as the "peculiar colloidal laws or principles" regulating the conduct of colloidal particles.

As soon as it became evident that there was no set of laws peculiar to colloids, colloid chemistry expanded rapidly within the framework of physical knowledge, permuting many old ideas and creating more new ones. This quantitative era of colloid chemistry is still young and flourishing, but the progress made thus far may be attributed to the success of the newer methods of investigating fundamental properties of colloid particles, methods which have been employed in the study of colloidal systems or developed within the field of colloid chemistry.

The ultramicroscope, by making colloidal particles visible to the aided eye, inaugurated the quantitative period of colloid chemistry. X-ray and electron diffraction examination of col-



Department of Agriculture researcher uses coagulation technique in recovering lactoprene from its emulsion

loidal particles demonstrated clearly that colloids may be either crystalline or noncrystalline, and enabled a clear distinction to be made between primary particle size or crystal size and secondary particle size or degree of aggregation. The ultracentrifuge and the electron microscope are two modern instruments of unbounded possibilities for colloid chemistry.

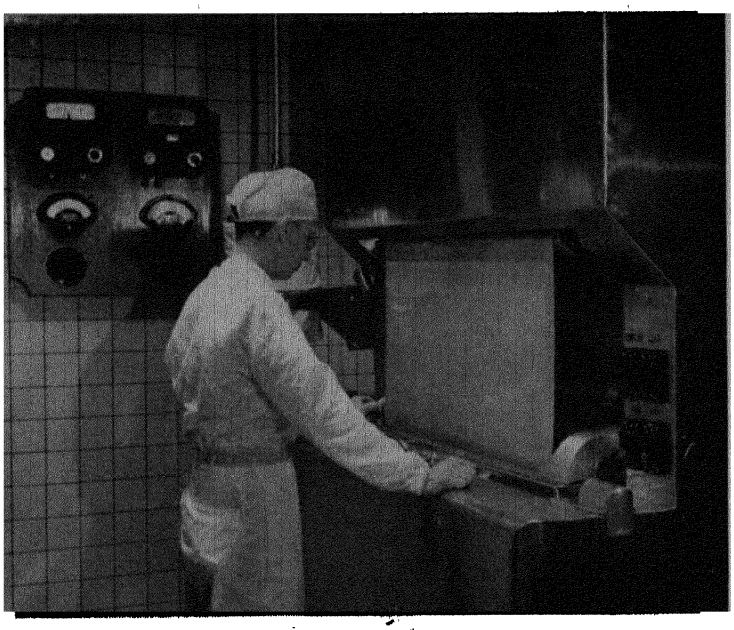
The development of precision methods and advanced techniques has also contributed to the advancement of colloid chemistry—for example, the electrical measurement of membrane potentials, electrophoresis, the modern method of light scattering, and measurements of such physical properties as magnetic susceptibility, dielectric constant, and rheological properties have added to the store of fundamental knowledge. This basic information has made possible many advances, providing a more thorough understanding of the state of adsorbed materials and the factors contributing to the stability of sols.

Inorganic colloid chemistry has expanded widely in recent decades not only because of advances in instrumentation and techniques, but also because of the extensive applications of colloidal properties. The large surface area and the necessarily high adsorptive capacities of many inorganic colloidal systems have been especially useful, particularly in the field of pigments, in heterogeneous catalysis, and in separations based on adsorption. This latter field includes the use of ion exchange resins and chromatographic analysis. The successful development of these specific branches of inorganic colloid chemistry has been made possible, or at least has occurred simultaneously with, the development of instruments and techniques. The bulk structure of colloidal particles (determined from x-ray and electron diffraction studies and by the electron microscope) and the surface structure of colloidal particles (deduced from adsorption isotherms, adsorption isobars, and measurements of surface area and pore size) are only two examples of the knowledge of properties made possible by these advances.

In particular, great strides have been made in understanding surface properties, especially in their application to catalysis. In fact, colloid chemistry may be entitled to considerable credit in aiding the current transformation of the art of catalysis to the science of catalysis.

Officers of the Division of Colloid Chemistry, 1927–1951

Year	Chairman	Secretary-Treasurer
1927–1928	H. B. Weiser	F. E. Bartell
1929–1930	F. E. Bartell	R. A. Gortner
1931	R. A. Gortner	E. O. Kraemer
1932	E. O. Kraemer	E. J. Miller
1933	E. J. Miller	W. G. France
1934	W. G. France	A. J. Stamm
1935	A. J. Stamm	S. S. Kistler
1936	S. S. Kistler	Richard Bradfield
1937	Richard Bradfield	L. H. Reyerson
1938	J. W. Williams	E. A. Hauser
1939	L. H. Reyerson	A. M. Buswell
1940	E. A. Hauser	Fred Olsen
1941	A. M. Buswell	W. O. Milligan
1942	Fred Olsen	J. W. McBain
1943	W. O. Milligan	C. E. Cunningham
1944	J. W. McBain	C. E. Marshall
1945–1946	G. E. Cunningham	R. D. Vold
1947	C. E. Marshall	W. O. Milligan
1948	R. D. Vold	W. O. Milligan
1949	D. S. le Beau	W. O. Milligan
1950	S. Ross	W. O. Milligan
1951	M. W. Tamele	W. O. Milligan



Film base receives a coating of photographic emulsion at plant of Eastman Kodak Co.

Colloid Chemistry of Biochemical and Organic Materials

In contrast to the earlier views of the colloidal state, one now speaks of a colloidal state of aggregation. The new point of view was not fully developed until about 1910.

Present-day classification is based upon the thermodynamic stability of the colloidal system. Natural colloids, usually of organic nature, are called intrinsic colloids (including molecular colloids and micellar colloids). They form thermodynamically stable systems. The other colloids, extrinsic or accidental, represent, in general, the dispersions or ordinary insoluble materials obtained by processes involving subdivision and are most often inorganic in character.

The new classification is the result of logical development. In the early years of this century, the ultramicroscope had become a favorite instrument in the study of extrinsic colloids, but now it has given way to the electron microscope. With this new instrument all colloidal particles down to viruses and certain polysaccharides are now made visible. Size, shape, and size distribution studies have proved to be of great value.

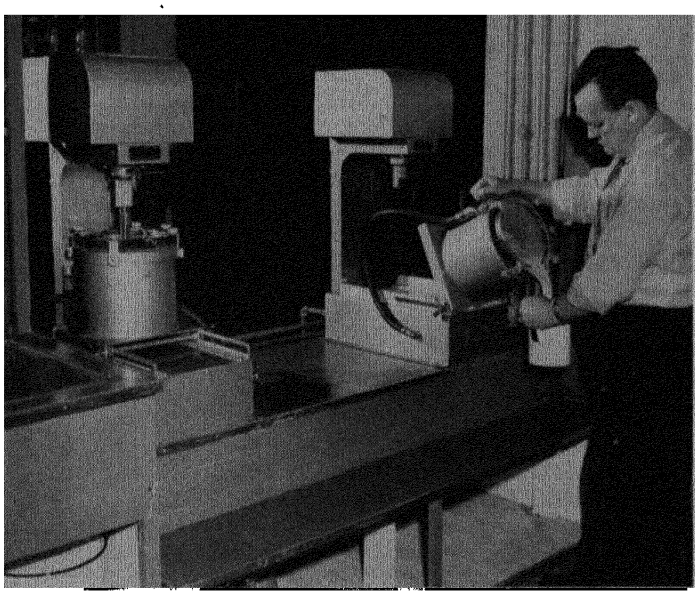
In the case of organic macromolecules (including proteins, soaps, dyes, polymers) not visible in the electron microscope, the ultracentrifuge has become a standard tool for study and description. With it absolute measurements of molecular weight and weight frequency are made in such systems, with considerable aid from viscometry, osmotic pressure, diffusion, and x-ray data. In a sense the chemistry of the intrinsic colloids may be termed polymer chemistry. It encompasses the wide field of natural products such as rubber, proteins, cellulose, and other polysaccharides, together with a large group of synthetic substances formed by established chemical processes. Certain general principles have been recognized to be of common applicability to all these macromolecules, and it is primarily with these fundamental ideas that many present-day colloid chemists are engaged.

Through the study of the physical chemistry of the proteins, research in colloid chemistry has become closely allied to biochemistry and medicine. In many instances the relation between the chemistry and reactivity of the protein molecule and its highly specialized biological function or functions has been revealed. Thus, in blood plasma the albumin is largely responsible for the fluid balance between blood and tissues; apparently it is the albumin molecules which transport such substances as the sulfa

drugs and antibiotics (through protein-ion interactions) in the blood stream. Substances responsible for immunity to disease, the clotting of blood, and the contraction of muscle are proteins. The enzymes, or biological catalysts, are probably proteinaceous in character. They are involved in digestion, in respiration, in the control of cell growth, and in many other ways. An important class is the flavo-proteins or "yellow enzymes" which occur in the kidney, liver, heart, milk, and yeast. A great number of the diseases, both of man and of plants, have been shown to be caused by the viruses, a class of nucleoproteins.

These proteins and many others of biological interest have been studied intensively by colloid chemists during the 75-year span of the AMERICAN CHEMICAL SOCIETY, but more particularly during the past 25 years.

Polymerization of organic molecules offers the possibility of constructing high polymer molecules of accurately known structure. The average molecular weights of the condensation polymers have been found to be subject to control at will by variation of the degree of condensation. By using the same molecular kinetic methods found so effective in the study of proteins, scientists have determined precisely their average molecular weights and weight distributions. In many ways these polymers have become preferred subjects for fundamental investigation.



Laboratory attritor is employed in preparation of experimental latex dispersion at American Anode, Inc.

Actually, the scientific study of the polymers is a relatively new field. Bakelite, Glyptal, celluloid, rayon, nylon, and many other substances have been produced as articles of commerce for some time, but in order to improve some of these plastics and fibers it became necessary to carry out fundamental investigations with them. Many striking properties were discovered. The behavior of the polymers was at once complicated because these substances consist of many repeating units which combine to give aggregates with extremely high molecular weights. The polymer chemists have learned how to include the consequences of this type of structure in the theoretical treatment of their thermodynamics, and early "anomalies" are now understood.

Now, the basic problems underlying the formation and the structure of synthetic polymers are clear, and the subject has passed beyond the empirical stage. With the theoretical and technological advances of the past two decades, one now may predict, for example, that cotton and wool will be replaced in commerce by synthetic fibers.

One might go on to develop the history of the physical and colloidal chemistry of detergents (including the soaps), dyes, silicate and silicones, but it would be most incomplete. By way of prediction, one can expect that future developments in these fields will be comparable to those which have been made and are taking place with the proteins and high polymers. As far as detergents are concerned, one still finds widely divergent views concerning the structure of the basic units, the so-called micelles. The object of many present-day researches is to determine the size and shape of detergents in solution. What has been learned by the protein chemist and the polymer chemist is certain to be of aid in this extension of information.

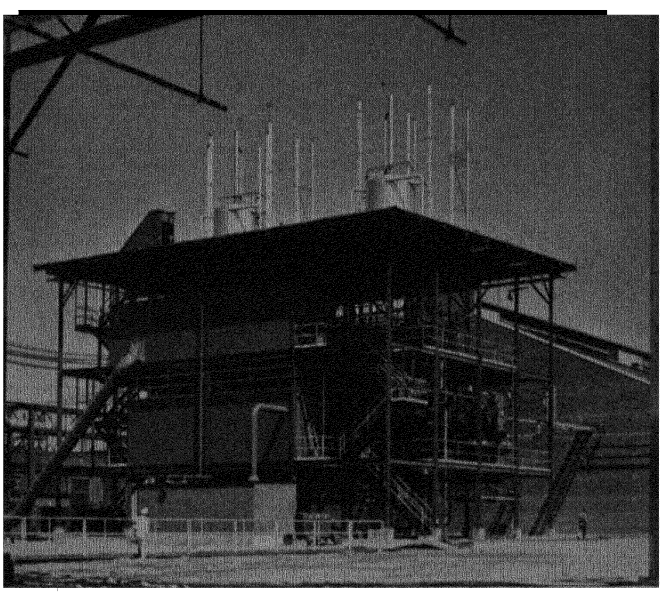
In the past some chemists believed that the fundamental laws of physics and chemistry were abrogated in colloidal systems and that a new science had to be built up for the description of colloids. Today some treatises on the subject bear the title "Colloid Science." In 1951, however, one must believe that as more exact information is made available, the study of colloids will find its rightful place—namely, as one aspect of the broad field of chemistry.

Division of Colloid Chemistry

The Division of Colloid Chemistry of the AMERICAN CHEMICAL SOCIETY officially became a division by vote of the Council at the Golden Jubilee Meeting in Philadelphia on September 6, 1926. Actually the formation of the division was an outgrowth of the National Symposium on Colloid Chemistry first held three years previously at the University of Wisconsin.

The spontaneous success of the first colloid symposium revealed the need for such symposia. University scientists began to realize that the subject of colloid chemistry merited more than the usual few paragraphs or pages in the standard texts of elementary physical chemistry. They pioneered boldly, not only in the writing of textbooks on colloid chemistry but also in the presentation of formal courses in the subject at their universities. Industrial research directors and their staffs became aware that further progress in their industries awaited the development of new and fundamental concepts in colloid chemistry.

A comprehensive list of names of those who were most active in the early programs and symposia of the division is far beyond the scope of this brief history. Their names are recorded for posterity in the literature of our scientific journals, books, and symposia monographs. It is imperative, however, that mention be made of those who organized the first colloid symposium—J. H. Mathews of the University of Wisconsin and Harry N. Holmes, chairman of the National Research Council Committee on the Chemis-



Dow plant at Midland, Mich., produces latex coating materials for paper, textile, and paint industries

try of Colloids, together with members of that committee. The committee also included Jerome Alexander, consulting chemist, New York, N. Y.; F. E. Bartell, University of Michigan; E. C. Bingham, Lafayette College; R. A. Gortner, University of Minnesota; J. H. Mathews, S. E. Sheppard, Eastman Kodak Co.; E. B. Spear, consulting chemist, Pittsburgh, Pa.; H. B. Weiser, Rice Institute; J. A. Wilson, A. F. Gallun Sons Co., Milwaukee, Wis.; and W. D. Bancroft, Cornell University. All the members of the committee presented papers and took an active part in the discussion. Among the many prominent chemists who participated were The Svedberg, E. F. Burton, J. H. Hildebrand, Elmer O. Kraemer, A. W. Thomas, Jacques Loeb, Martin H. Fischer, Richard Bradfield, R. H. Bogue, Robert E. Wilson, H. S. Taylor, and Louis Kahlenberg. To them, colloid chemistry in America owes much.

The first program of the Division of Colloid Chemistry was held at the 74th meeting of the AMERICAN CHEMICAL SOCIETY in Detroit in September 1927. Seven papers were presented. The division concentrated on arranging an outstanding national symposium program each spring, which usually required about 3 full days for its presentation. The divisional programs were subordinate to this main activitity. This situation prevailed until the Century of Progress Meeting at the World's Fair in Chicago in the fall of 1933. The program was then expanded to 23 papers, 9 of which were devoted to "A Century of Progress of Colloid Chemistry." This program attracted an audience of nearly 500 persons. The remainder of the papers dealt with subjects in the fields of therapeutics, biochemistry, photography, cellulose, synthetic resins, water and waste treatment, soils, vitamins, paints, and rubber. The program thus had grown to full stature.

How great the interest and activity in colloid chemistry have become in the 23 years since the first meeting can best be realized by reviewing briefly the programs of the division for 1950. At the divided spring meeting in Houston, Tex., 36 papers were presented. Ten of these comprised a Symposium on Adsorption of Gases, another 12 dealt with specificity of adsorption, and the remaining 14 pertained to miscellaneous aspects of colloid chemistry. The Division of Colloid Chemistry also participated with a number of other divisions in a High Polymer Forum at the divided spring meeting in Detroit, Mich.

At the fall meeting of the AMERICAN CHEMICAL SOCIETY in Chicago, a program of unprecedented magnitude was conducted. Fifty-eight papers were scheduled, requiring an all-day session for every day of the meeting. The papers were grouped under the headings: (1) Applications of Ion Exchange, (2) Foams, (3) Surface Roughness, and (4) General. This impressive record of activities for the single year of 1950 is eloquent proof of the tremendous strides the Division of Colloid Chemistry has taken in the years since the first colloid symposium and the first divisional meeting. The current year's program also attests to the vigor with which the present officers are conducting the affairs of the division.

Some idea of the role the division has played in the development of the widely dispersed interests and applications of colloid chemistry in the world of chemistry today may be obtained by enumerating the titles of a few special symposia that have been presented either by the division alone or in conjunction with other divisions.

1931 Physical and Colloidal Chemistry of Cellulose and Cellulose Derivatives
1932 Adsorption
1935 Starch
1936 Synthetic Resins and Plastics
1937 Physical and Colloid Chemistry of Photography
1938 Surface Active Agents
1944 Detergents
1946 High Polymer Forum
1947 Colloid Chemistry of Catalysts
1947 Ion Exchange Separations
1948 Teaching of Colloid Chemistry
1949 Properties and Structure of Natural and Synthetic Fibers

After reading this condensed list of symposium topics, one cannot fail to appreciate the importance of colloid chemistry to chemistry in most, if not all, branches. One glance at the roster of today's largest industries points to the vast developments that have taken place since their research directors and members of their research staffs first met at the meetings and symposia of the Division of Colloid Chemistry to present papers and discuss their mutual problems only a short 25 years ago. Witness, for example, today's huge photographic emulsion and film industry, rubber, cellulose and synthetic fiber, smokeless powder, ceramics, paint, emulsion polymerization, and a long list of other industries. Then recall their status when the names of their research representatives appeared on the early programs of the Division of Colloid Chemistry and the National Colloid Symposia. The phenomenal developments defy description and even concrete data and statistics fail to give an adequate conception of the vastness of the changes that have taken place. The influence the Division of Colloid Chemistry and the National Colloid Symposia have exerted on these developments has been very great.

One factor undoubtedly contributed greatly to the progress and development of colloid chemistry in American science and industry. The committee in charge of plans for the First National Colloid Symposium initiated the policy of inviting an outstanding colloid chemist from Europe to be the division's foreign guest of honor. For many years these outstanding scientists added greatly to the stature of the symposia. They brought with them a wealth of information concerning their various fields of specialization in colloid chemistry. In many cases they remained in the United States to teach and conduct seminars for a summer session or a year in the universities where the symposia had been held. In some cases they eventually returned to make their permanent home here and thus continued to enrich colloid chemistry in America. Among the many invited guests were The Svedberg, Herbert Freundlich, James McBain, William H. Bragg, Emil Hatschek, Arne Tiselius, Wolfgang Ostwald, Leonor Michaelis, H. R. Kruyt, W. B. Hardy, F. G. Donnan, P. Koets, and J. D. Bernal.

The history of the Division of Colloid Chemistry would be incomplete without mention of those persons who planned and molded the destiny of the division. It was their task to perceive the trends and incipient developments in colloid chemistry in university, college, and industrial laboratories and to arrange programs around those growing interests so that greater progress would be possible. Their names appear in the table on a preceding page.

While in all cases the officers of the division have contributed greatly to the programs of the division and the National Colloid Symposia, others have likewise contributed frequently with outstanding papers and active participation in the programs and discussions. To them, much credit is due for the success of the division. To mention only a few at random; W. D. Bancroft, W. D. Harkins, Irving Langmuir, Harry Holmes, Thomas Midgley, Jr., S. E. Sheppard, G. S. Whitby, E. F. Burton, E. C. Bingham, J. H. Hildebrand, A. W. Thomas, Neil Gordon, H. B. Bull, D. R. Briggs, and H. A. Neville—some of them Past Presidents of the AMERICAN CHEMICAL SOCIETY and Nobel Prize winners. The division was fortunate in having such men on its roster, and, therefore, it is understandable that the membership in the division increased from a few dozen in 1927 to 875 by 1950.

It has been a privilege to witness the genesis and growth of the Division of Colloid Chemistry, to take part in its programs, and to observe the roles the members have played in the development not only of colloid chemistry but of huge industries as well. This development leaves one with a deep sense that here is a splendid, concrete example of how men and industries grow under the American way of life.

What new wonders the history of the next 25 years of colloid chemistry and industry will reveal—to equal, if not exceed, the tremendous advances of the past 25 years—is impossible to forecast in detail, but it is certain that much promise lies ahead.

the two sections worked and have continued to work together very closely.

At Birmingham in April 1922, the Section of the History of Chemistry held its first formal meeting. Smith made a plea that the members devote themselves to research on the development of chemistry in their own localities. This was a subject on which both he and Browne felt deeply, and there is little doubt but that both intended that the major work of the section should be a study of the history of American chemistry. This desire on the part of the founders has always been respected, and an important portion of each meeting has usually been given to this subject. The division has never become provincial, however. Much work of great significance has always been reported on the general history and philosophy of chemistry.

The Council of the AMERICAN CHEMICAL SOCIETY at Birmingham voted that, after that meeting, all sections before receiving divisional status would be required to go through a probationary period of three years to justify their formation and prove their ability to continue in active work (*8*). The newly formed section had little difficulty in demonstrating its fitness. Even at Birmingham, 11 papers had been presented, and over a hundred chemists had attended the meeting. In the following year, the spring meeting at New Haven coincided with the dedication of the new Sterling Chemical Laboratory of Yale, and the section arranged an extensive exhibit of historical material relating to chemistry at Yale. Smith gave one of the major addresses of the meeting on the subject "History of Chemistry in America with Special Reference to Yale."

The pattern for future meetings was now set. Following the example of Smith and Browne, members of the section brought books, manuscripts, medallions, and other illustrative material to each meeting. The informal discussions were as important as the formal papers. At first, the latter were given by a rather small group, much the same at each meeting, but it soon became evident that there was actually a wider interest in history than had originally been suspected. Now that there was an opportunity for presentation of papers in this field, an increasing number of men began to offer titles, and the names which appeared on the programs became more varied.

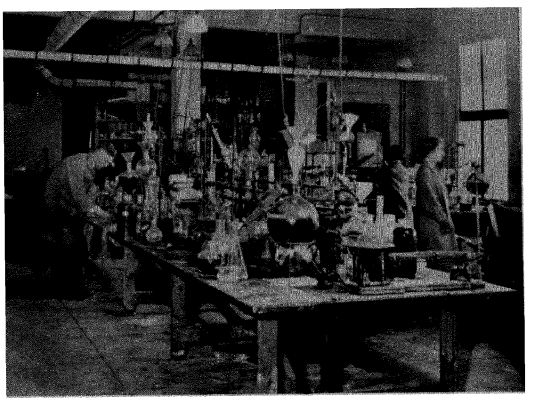
For a long time, Smith had wished to publish a journal in the history of chemistry. Now he felt the time had come. He was not too optimistic about its possible circulation, however. He, therefore, attempted to raise a subsidy to support the projected publication. While he was thus engaged, the Section of Chemical Education laid plans to publish the *Journal of Chemical Education*. This offered a means for printing historical papers, and so Smith laid aside his plans for a special historical journal. The first number of the *Journal of Chemical Education* appeared in 1924, and ever since it has been the official organ of the Section and Division of the History of Chemistry, as well as of the Division of Chemical Education. Once more, as in the days of the *American Chemist*, purely historical papers pertaining to chemistry could be published in America. The editors of the journal have always been interested in historical subjects, and most of the significant historical papers presented at meetings of the AMERICAN CHEMICAL SOCIETY have subsequently appeared in its pages.

The opportunity to hear or present papers on historical topics stimulated those interested to new activity. As a result, the section had little trouble in proving its right to become a division. The report of the Council meeting at Detroit in September 1927 stated: "The Section of the History of Chemistry, having held successfully the six meetings prescribed by the Council, petitioned that it be made a division of the Society, and this request was granted and the bylaws submitted approved."

The meetings of the division have been flexible and have often been adapted to a special location or occasion. Among its outstanding symposia have been those on the history of the American chemical industry at New York in 1935 on the occasion of the tercentenary of American chemical industry; symposia on the



Edgar Fahs Smith Collection at University of Pennsylvania specializes in chemical history



In 1920, laboratory of major chemical company was a disordered array of glassware, burners, and electrical wiring



In this modern research laboratory, new chapters are being added to the fast-growing history of chemistry

and devoted the rest of his life to research in the history and bibliography of chemistry. He built up the finest library on the history of chemistry which then existed in America. The outstanding result of his studies was his "Select Bibliography of Chemistry, 1492–1892," with supplements which carried it on to 1903. His interests were wide and he published many shorter papers which are still of interest.

Silliman (1816–1885) was professor of chemistry at Yale, where he had succeeded his famous father, Benjamin Silliman, Sr. He had helped found the Sheffield Scientific School, edited the *American Journal of Science*, and through his extensive consulting work was one of the most influential scientists of his day. His father had been active during a long period when science in America was undergoing its first major development, and the younger Silliman had grown up in close contact with the leading scientists of the country. In addition, he had access to the records and correspondence of his father. Thus he was in an unusually fine position to record the history of science in America, and in this field lay his major historical publications. His elaborate study of the history of chemistry in America (*14*), in which he described the work of 184 American chemists, was the first such study, and has been invaluable to later historians.

Centennial of Chemistry

At this time, the number of American chemists was relatively small, and the leading workers knew each other personally. However, there were still many chemists who had almost no outside contacts and no opportunity to discuss problems of mutual interest with their fellow workers. This fact had impressed Bolton, and in the April 1874 number of the *American Chemist* (*13*) he published a letter which stressed that the year 1774 had been a notable one for chemistry, being the year of Scheele's discovery of chlorine, Priestley's discovery of oxygen, and other important scientific achievements. He, therefore, proposed that this year be considered the starting point of modern chemistry and that its centennial be celebrated in the current year of 1874 by a meeting of chemists "at some pleasant watering-place, to discuss chemical questions, especially the wonderfully rapid progress of chemical science in the past hundred years."

This suggestion was at once approved by letters from Silliman and other chemists, including Rachel L. Bodley, a "lady professor" as she described herself, at the Woman's Medical College of Pennsylvania. She made the suggestion that the meeting be held at the Priestley home in Northumberland, Pa. Following Bolton's suggestion, she proposed that the date of the meeting be August 1, 1874, the centennial of the actual discovery of oxygen. In accordance with her suggestion, this meeting place was chosen, and the gathering took place (*1, 6*).

The meeting was so successful that near its end Persifor Frazer of the University of Pennsylvania proposed that a national chemical society be formed. Bolton favored the proposal, as did W. F. Chandler, but most of the others thought it would be better to organize as a section of the American Association for the Advancement of Science. Bolton acceded to this view, and the matter was dropped for the moment, but the seed had been planted. Two years later, under the leadership of C. F. Chandler, the seed grew, and the American Chemical Society was founded. There is no doubt that it stemmed directly from the Priestley Centennial of two years before.

In its early days, the Society made no provision for research in the history of chemistry. The older members who had maintained an interest in the field gradually dropped out, and with the cessation of publication of the *American Chemist* in 1877, there ceased to be a convenient outlet for historical papers. The interest in the history of chemistry entered a latent period.

This does not mean that it died out, however. There are always men with a keen interest in the subject, and if they are compelled to work alone, they will do so. Among the younger chemists who became active in the Society at the beginning of the 20th century were two who became outstanding historians of chemistry: Edgar Fahs Smith (*5*) (1854–1928) and Charles Albert Browne (*4, 9*) (1870–1947). Both men had a broad cultural background, both had studied in Germany, and both were interested in the history of chemistry, especially as it related to America. Browne approached the study from the standpoint of agricultural chemistry, and Smith from a study of the history of chemical developments in and around Philadelphia, but both had a full appreciation of the significance of these special studies to the history of chemistry as a whole. In addition, each was an enthusiastic collector of early chemical books and manuscripts, and on frequent trips to Europe, each increased his collection by numerous purchases.

Oddly enough, these men with such close common interests did not meet until 1920. Both were active in administration and research, and these activities prevented personal contact. At length, however, Smith determined to talk with C. A. Browne. At the meeting of the American Chemical Society in Evanston, Ill., in 1920, he sought him out with the intention of discussing their historical studies. Browne has given us a full account of the pleasant hours which they spent on the shore of Lake Michigan discussing their common interests and showing each other such of their treasures as they had brought with them (*2*).

Smith was always ready to talk of historical matters, and in his office at the University of Pennsylvania he had surrounded himself with his collection of historical books and objects. He was accustomed to show these to his visitors, but only too often he was rebuffed by the guests' polite lack of interest in one of his especially valued mementos. Although he was most anxious to advance the cause of the history of chemistry, these experiences had prevented him from taking, up to this time, any positive steps. Now, in conversation with his fellow enthusiast, he began to feel that at last the time was ripe to bring together those members of the American Chemical Society who shared his interests. The two men, therefore, agreed that at the next meeting of the Society, in Rochester in the spring of 1921, they would bring a number of old books and manuscripts and hold an informal meeting of all those interested in the discussion of historical topics.

This meeting was held April 27, 1921, and about 30 chemists attended. Smith showed some of his collection, and Browne talked on New England chemistry and on an early British food chemist, Frederick Accum, of whose life he had made a study. Those who attended were well pleased and agreed that, without any formal organization, such a program should be planned as one of the regular features of future meetings of the Society (*7*).

Accordingly, in New York in September 1921, a notice, probably written by Smith himself, was posted, reading: "History of Chemistry. President Edgar F. Smith and kindred spirits will meet Friday afternoon, September 9, in Room 301, Mines, to discuss their hobbies" (*11*). Smith was president of the Society at this time and was thus in a position to give his activities full publicity. About a hundred chemists responded to the invitation, and a lively discussion followed. It was decided that there was sufficient interest in the history of chemistry to warrant formal organization within the American Chemical Society. At that time, the Society was organized into divisions, which were autonomous, as now, and sections, which did not have the formal organization of the divisions, but hoped to reach divisional status in time. The group at New York set up a Section of the History of Chemistry, with C. A. Browne as chairman and Lyman Newell as secretary. Plans were laid for the first official meeting in Birmingham the following year.

At almost the same time, another section was organized, the Section of Chemical Education. Education was a subject also close to the heart of President Smith, and he was actively interested in promoting the growth of this section as well. Nevertheless, he warned that it must not in any way infringe on the activities of the Section of the History of Chemistry (*16*). Actually,

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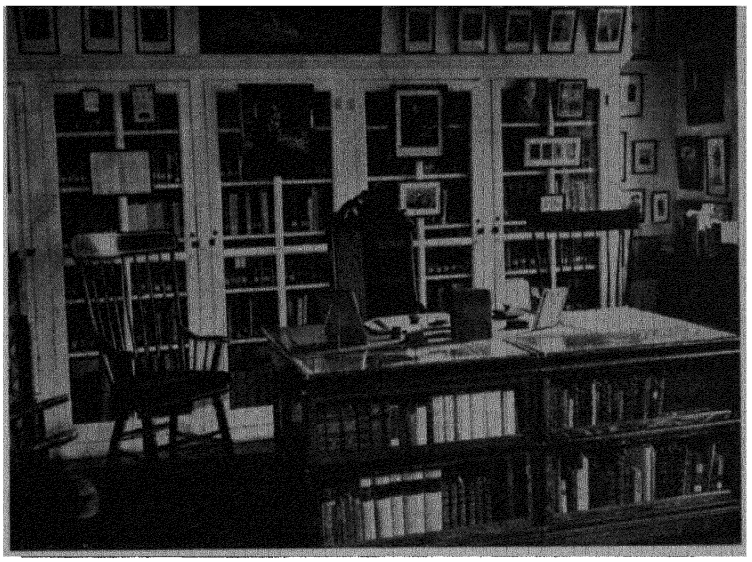
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The pattern for future meetings was now set. Following the example of Smith and Browne, members of the section brought books, manuscripts, medallions, and other illustrative material to each meeting. The informal discussions were as important as the formal papers. At first, the latter were given by a rather small group, much the same at each meeting, but it soon became evident that there was actually a wider interest in history than had originally been suspected. Now that there was an opportunity for presentation of papers in this field, an increasing number of men began to offer titles, and the names which appeared on the programs became more varied.

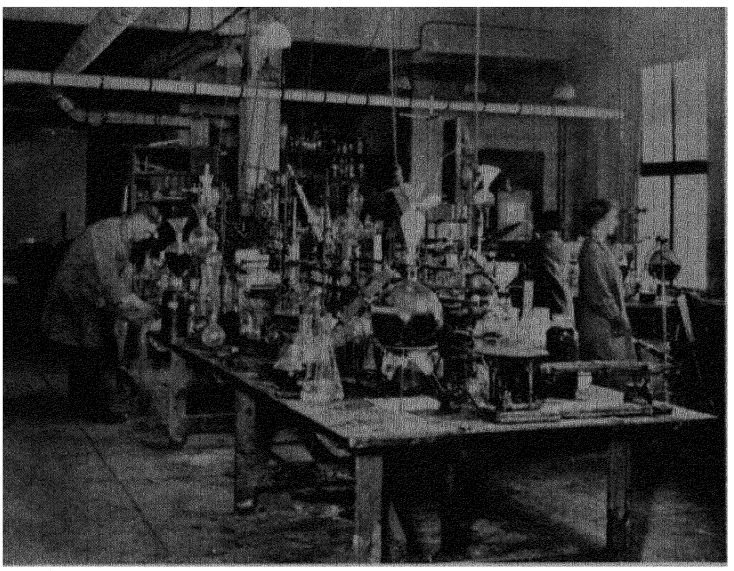
For a long time, Smith had wished to publish a journal in the history of chemistry. Now he felt the time had come. He was not too optimistic about its possible circulation, however. He, therefore, attempted to raise a subsidy to support the projected publication. While he was thus engaged, the Section of Chemical Education laid plans to publish the *Journal of Chemical Education*. This offered a means for printing historical papers, and so Smith laid aside his plans for a special historical journal. The first number of the *Journal of Chemical Education* appeared in 1924, and ever since it has been the official organ of the Section and Division of the History of Chemistry, as well as of the Division of Chemical Education. Once more, as in the days of the *American Chemist*, purely historical papers pertaining to chemistry could be published in America. The editors of the journal have always been interested in historical subjects, and most of the significant historical papers presented at meetings of the AMERICAN CHEMICAL SOCIETY have subsequently appeared in its pages.

The opportunity to hear or present papers on historical topics stimulated those interested to new activity. As a result, the section had little trouble in proving its right to become a division. The report of the Council meeting at Detroit in September 1927 stated: "The Section of the History of Chemistry, having held successfully the six meetings prescribed by the Council, petitioned that it be made a division of the Society, and this request was granted and the bylaws submitted approved."

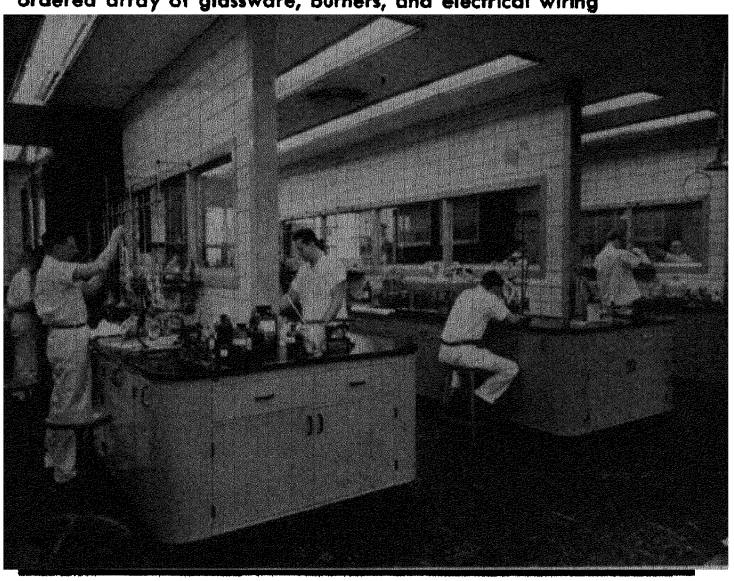
The meetings of the division have been flexible and have often been adapted to a special location or occasion. Among its outstanding symposia have been those on the history of the American chemical industry at New York in 1935 on the occasion of the tercentenary of American chemical industry; symposia on the



Edgar Fahs Smith Collection at University of Pennsylvania specializes in chemical history



In 1920, laboratory of major chemical company was a disordered array of glassware, burners, and electrical wiring



In this modern research laboratory, new chapters are being added to the fast-growing history of chemistry

development of chemistry in the South, held at Richmond in 1927 and at Memphis in 1942; and a symposium on chemical industries in the Chicago area in 1946. Noteworthy joint symposia were held with the Division of Chemical Education in Buffalo in 1931 in honor of Edgar Fahs Smith, for the purpose of discussing the history of American chemical education; with the Division of Medicinal Chemistry at Baltimore in 1939 on the history of medical education in Baltimore; with the Divisions of Agricultural and Food Chemistry and of Fertilizer Chemistry at Detroit in 1940 to honor the work of Liebig as an agricultural chemist; and the two symposia at Chicago in 1950, one with the Division of Industrial and Engineering Chemistry to explain the reasons for the shift of leadership in chemistry from France to Germany during the 19th century, and the other with the Division of Chemical Literature on the history of chemical literature. These symposia make possible a fuller understanding of the forces which have molded present conditions. What is probably more important, they have indicated the factors which have in the past tended to produce progress or stagnation in science and may produce similar results again.

In addition to these symposia, special exhibits have been arranged at many of the meetings. These special features have included an exhibit on New England chemists at the Swampscott meeting in 1928, one on Joseph Priestley at the Washington meeting in 1933, and another on Edgar Fahs Smith and the Smith Collection at Philadelphia in 1950.

The meetings of the division have continued to grow in interest and importance. In the earlier days, programs seldom lasted more than one morning, and when the Society met in cities far from the larger population centers, often no meeting of the division was held. More recently, however, one- and two-day meetings have become common, and they are held regularly. Thus, at San Francisco in 1935 no meeting was held, but in the same city in 1949 a successful session took place.

Officers of the Division of the History of Chemistry, 1927–1951

Year	Chairman	Secretary
1927–1932	Lyman Newell	Tenney L. Davis
1933–1934	F. B. Dains	Tenney L. Davis
1935–1939	Tenney L. Davis	Mildred Grafflin
1940	James Couch	Mildred Grafflin
1941	James Couch	Ralph E. Oesper
1942–1946	Harrison Hale	Ralph E. Oesper
1947	Henry M. Leicester	Ralph E. Oepser
1948–1951	Henry M. Leicester	Sidney M. Edelstein

It is noteworthy that prior to the founding of the division, only a few American chemists devoted any attention to historical matters. Once it had been founded, however, it served to bring together a number of men who felt a real interest in the history of chemistry, and, more important, it stimulated them to begin historical studies of their own by showing what had been done and what remained to be done. Smith and Browne, by their studies on the history of American chemistry, had shown that many of the early chemists whom Silliman had known only by name had actually done much to stimulate the progress of science in this country. Now, in the Division of the History of Chemistry, a group of new workers is carrying on the study with increasing vigor, and the broad outlines of our chemical development have been filled in with new details. Smith's plea for regional studies has been heeded. It is to be hoped that a comprehensive history of chemistry in America will become available in the not too distant future.

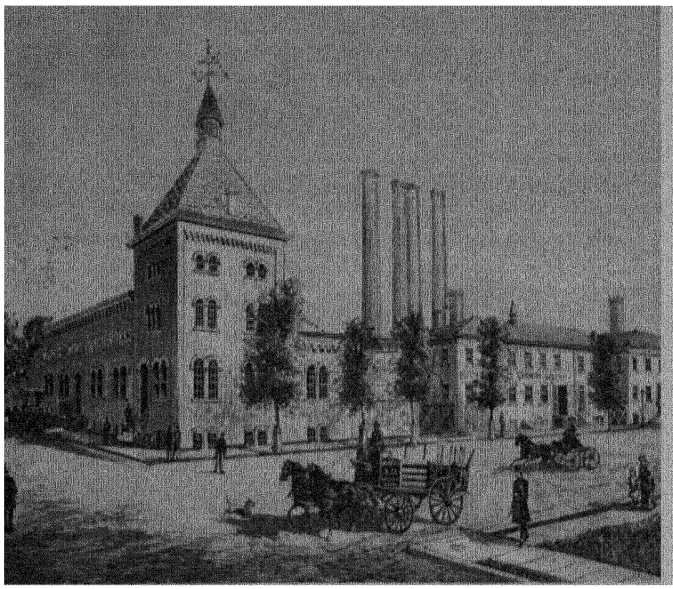
American historians have also taken up the wider field of the whole development of alchemy and chemistry. Pioneering studies, such as those of Hopkins on Greek alchemy and of Davis on Chinese alchemy, have attracted world-wide attention. Most of these investigations were reported before the division in the decade from 1930 to 1940. There is little doubt but that they would not have even been attempted had not the division brought together those of like interests and stimulated them to active research in the history of chemistry.

A further outcome of the division's work has been the strengthening of an interest in the establishment of research centers devoted to the history of chemistry. Bolton's collection was given to the Library of Congress after his death, and it is there available to scholars. However, the vast size of the Library of Congress and its multitude of interests preclude its devoting to its historical collection in chemistry the individual attention which it deserves. The members of the division have realized this and have, therefore, actively supported the growth of specialized research libraries which center around the collections begun by individual members. Such are the Newell Collection at Boston University and especially the Smith Collection at the University of Pennsylvania. The latter is an outgrowth of the remarkable library assembled by Smith. To it have been added, in the course of time, the most valuable portions of the collections of C. A. Browne and Tenney L. Davis, as well as many other gifts and purchases. The library has recently realized the old dream of Smith by its publication of *Chymia*, an annual in the history of chemistry which is unique in its field. It is very evident that the support and interest in the history of chemistry created by the existence of the Division of the History of Chemistry have made possible, as never before, a realization of the value of research in this field.

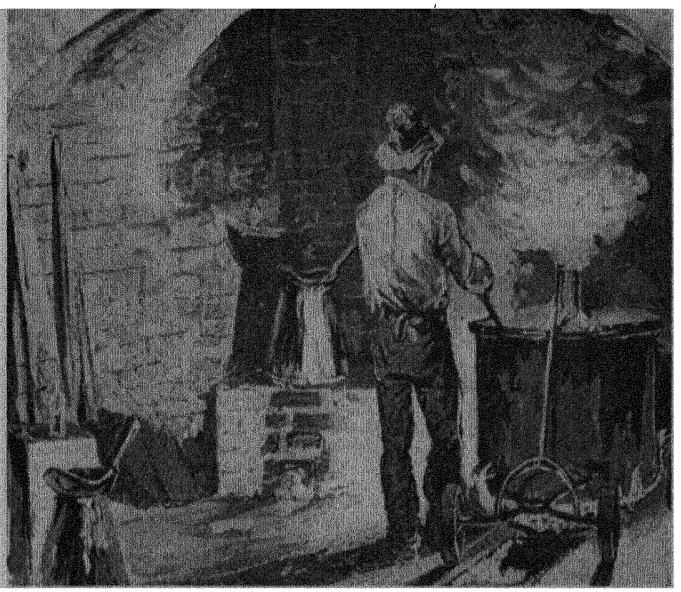
Prospects for the future are bright. Through its general programs, symposia, and exhibitions of historical material, the division has reached a large group of chemists who are greatly interested in historical matters, though they may lack the time for original research in the field. This has created a new demand for more information. Chemical industries are recognizing the value of understanding their own past and the various phases of their growth. An increasing number of colleges and universities are realizing the cultural importance of the history of science, and the pioneer work of such institutions as Harvard and Wisconsin in this field is expanding. The division is one of the few organizations in a position to satisfy the demand for information of this type, and it is well prepared to carry on this task. Although small as divisions go, its membership of 160 is more than double that of three years ago. Its plans for the future include a number of joint symposia which will bring to members of other divisions an understanding of its unique role. The next 75 years may be expected to produce a volume of historical studies which will give to the world an understanding of the significance of chemistry which can be obtained in no other way.

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Famous varnish works of Murphy & Co. in Newark, N. J., looked like this during early 1880's



In first step in varnish cooking, workman melted gums over coke fire before adding oils

Paint, Varnish, and Plastics Chemistry

Out of white lead paint, furniture varnish, and billiard balls grew a multibillion dollar industry

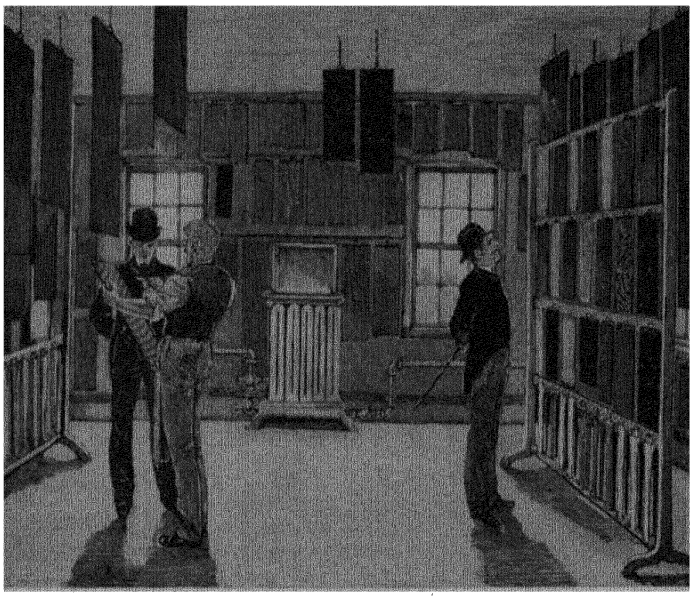
C. R. BRAGDON
Interchemical Corp., New York, N. Y.

M. M. RENFREW
General Mills, Inc., Minneapolis, Minn.

PAINTS, varnishes, printing inks, and plastics embrace a wide diversity of products but use basically the same raw materials and processes of manufacture. From small beginnings in this country, these industries have grown to a combined total of close to $2 billion annual sales. They have made notable progress, particularly in the change from empirical to scientific methods, within the past 50 years. The AMERICAN CHEMICAL SOCIETY—through its individual members and, since 1923, through its Division of Paint, Varnish, and Plastics Chemistry—has enjoyed the privilege of contributing to this advance.

From Early Beginnings to 1876

The manufacture of paint in America began in 1804 with the establishment of a white lead factory by Samuel Wetherill & Sons. In the same year, Charles Eneu Johnson founded his printing ink business, now a part of United Carbon Co. Printing inks had been made here as far back as 1742, but Johnson's company can be credited with being the oldest organization of its kind in continuous existence. Varnishes were first made in 1816 in Philadelphia by Christian Schrack; by 1876 there were a number of thriving varnish concerns scattered about the country. Mixed or prepared paints, in contrast to "white lead in oil," were not placed on the market until about 1858, however. D. R. Averill of Newburg, Ohio, made a fair success with such a mixed paint, which he patented in 1867. The prepared paints of that time were very crude compared with those in wide use today. Throughout this early period, most paints and varnishes were imported from Europe. Even Devoe & Raynolds Co., which now, through its predecessor William Post (1754), claims longest unbroken lineage in that field, handled only imported products until well into the last century.



Purchasers carefully examined test panels before giving their approval to shipments of varnish

The beginnings of plastics are more recent than those of paint, varnish, and ink. In 1876, it was an infant industry, born with the invention of celluloid in 1869 and still in swaddling clothes.

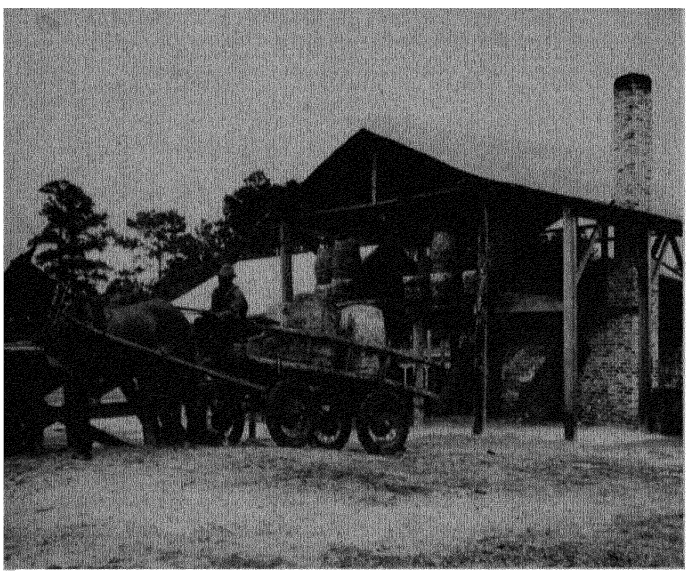
75 Years in Paints and Varnishes

Paints of 75 years ago were almost exclusively white lead (basic carbonate) in linseed oil, pressed from flaxseed. They were ground slowly—but not always "exceeding small"—on iron pot mills, or stone mills of the type used for grinding grain. Barytes, whiting, talc, clay, terra alba, and water were considered adulterants, and reputable manufacturers avoided them. Even zinc oxide, first produced by the American process in 1852, was regarded with some suspicion. Modern science has since shown that judicious amounts of reinforcing fillers add to the serviceable life of outside paints; zinc oxide has become a respected hardening agent for these coatings and a prime pigment for enamels. (Even water is now approved as an odorless thinner for millions of gallons of high-grade emulsion paints!) Lithopone, basic sulfate white lead, antimony oxide, and titanium dioxide and its modifications—all pigments of increasing importance today—were not commercially known in 1876. Tinting colors were confined to the earth pigments—ochres, siennas, umbers, and iron oxide reds, for example—and to such manufactured ones as chrome yellow, iron and ultramarine blues, lampblack, and vermilion. The bright, strong colors we use today in inks and enamels—lithol, toluidine, and eosin reds, Hansa and benzidine yellows, peacock, Victoria, and phthalocyanine blues—were introduced at or after the turn of the century.

At the time of the Society's birth, varnishes depended upon linseed oil, turpentine from our southern pines, and natural resins (copals) which were imported from Africa and the East Indies. Jealously guarded formulas had been handed down over many decades from father to son, with only gradual modifications and improvements by trial and error... Considering how few and crude were the available raw materials and how little science had touched the industry, we have to admire the craftsmanship of those early varnish makers. Such variations in properties as were possible were obtained by the use of different copals (Animi, Zanzibar, Sierra Leone, Angola, Kauri, Pontianak, and Congo), by different methods of prebodying the oil with or without driers, and by changes in the proportion of resin to oil. The copals or "gums" (tree exudations which had been fossilised by burial in the earth for a century or more) were dug up, cleaned, cracked, and sorted according to size, color, and clarity—all by hand labor. They were melted in small pots to a point of just sufficient decomposition to render them oil-soluble. In this melting or "running" process, about 25% of their weight was lost. Then the oil was added and cooked to desired viscosity, and the varnish preparation was completed by thinning with turpentine.

Little was known of the chemical constitution of the resins or of the reactions involved in their pyrolysis. Some European chemists had studied them, but had not progressed beyond finding that they consisted largely of complex, partly esterified dibasic organic acids which were converted by heat treatment to oil-soluble monocarboxylic compounds. There was little information about the reactions involved in the bodying or polymerization of the oil. The drying of the finished varnish was known to depend on the oil's absorption of oxygen from the air, but the mechanism was unexplained; in fact, though much has been learned, there are many questions about drying that remain today without definite answers.

Varnishes were classified as "short," "medium," or "long-oil" depending upon the number of gallons of oil added per 100 pounds



Farmer hauls four-barrel load of crude gum into turpentine still located in the southern pinelands at Lulu, Fla.

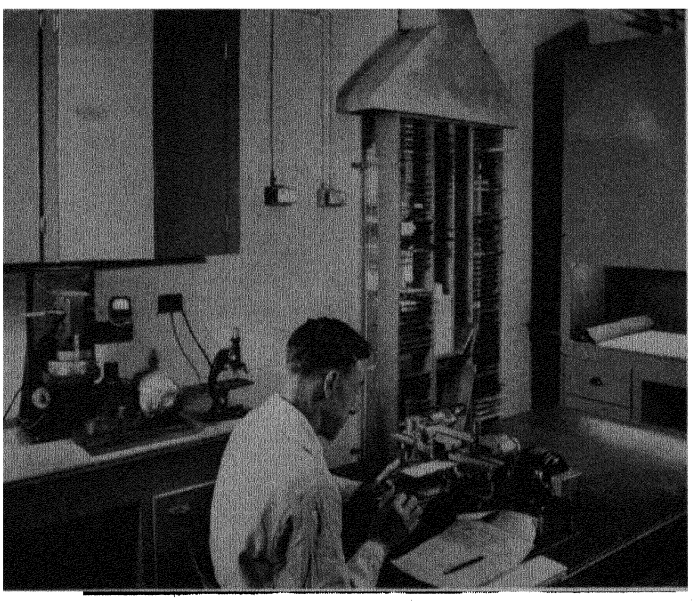
of unmelted resin. In general, flexibility and durability increased with length, while hardness decreased. "Piano polishing" and "furniture rubbing" varnishes might be as short as 6 gallons; "spar" and "carriage finishing" varnishes as long as 25 to 40 gallons, with many intermediate types for various special applications. Although they were comparatively dark, slow-drying liquids, they hardened in two or three days to rich, lustrous surface coatings, many of which showed excellent durability. Of course, there was also shellac or "spirit" varnish, made by dissolving in alcohol the lac resin produced by Indian insects. This varnish dried quickly and served, as it does today, reasonably well as a sealer and floor coating.

The first American varnish chemist is believed to have been Henry M. Murphy, who studied at Columbia University School of Mines under Charles F. Chandler, one of the founders of the ACS. After graduation in 1878, he joined his brother Franklin at the Murphy Varnish Co. plant in Newark, N. J., working on raw material testing and product control. Gradually other chemists were employed by the industry, but the let-well-enough-alone attitude of the practical varnish makers hampered the efforts of the chemists to improve upon conventional formulations. They

did, however, slowly succeed in bettering quality and uniformity by supplanting unscientific control methods (such as spitting into the batch or trying it with a feather) with procedures having chemical or physical foundations. Consequently, American varnishes and enamels became equal or superior to imported products.

The two decades between 1876 and 1896 saw little radical progress. Competition was keen, and the business practices of the period were summed up largely in the warning "*caveat emptor*," although a number of firms established high ideals of quality in an effort to lift the industry to a higher plane.

During the nineties, one of the first incentives to scientific development in varnishes came with the introduction of tung oil, or china wood oil, from China. In the molecule of this oil, three adjoining pairs of carbon atoms, in 80% of the fatty acid chains, are linked by double bonds. This structure imparts extreme reactivity. In linseed and most other drying and semidrying oils, the fatty acids are mixtures containing one, two, or three double bonds which are not usually conjugated in this fashion. Linseed oil had to be cooked for a day or more at 575° to 600° F., often with litharge, red lead, umber, pyrolusite, or other lead,



Researcher at Arco Co. measures the scratch hardness and surface adhesion of various coating materials

manganese, or iron compounds, to produce the molasseslike oils used by the early varnish makers. In contrast, tung oil congealed to a crumbly solid in a few minutes at 540° F. If undercooked, it caused the varnish to dry with a frosty or "crow's-footed" film.

One of the chemists who, by careful study, learned how to take advantage of the oil's unique virtues and avoid its cooking difficulties was Robert A. Worstall. After service at Glidden Varnish Co. and Chicago Varnish Co., he became consultant to a number of progressive manufacturers. In a few years, the superior properties of correctly processed tung oil made it much more popular and high-priced than linseed oil. This tempted the Chinese handlers to adulterate it. But Worstall had developed a heat test to reveal such adulteration and it was specified as a control on all purchases. There was a troublesome period when adulteration might vary, in a single 70-barrel carload, from zero to 20%. One of the duties of a young chemist was to sally forth with bung starter and cans and take samples for subsequent testing from each one of the wooden barrels in which the oil had just arrived from across the Pacific. Because the oil froze at about 50° F., this was a particularly difficult chore in winter weather.

When the practical varnish makers had to acknowledge defeat in handling this tricky "goose-grease oil" (so called by some because of its peculiar odor), they came to the laboratories for help. The chemists responded with sweeping changes in formulation. Cheaper resins (even despised American rosin) in combination with tung oil gave varnishes of much paler color and greater resistance to water, chemical attack, abrasion, and weather than could be obtained with linseed oil and copals. Nevertheless, as late as 1910, one leading varnish manufacturer proudly advertised: "We use no Chinawood oil."

Labeling Law

In the paint field, an early externally applied stimulus to progress was the North Dakota Labeling Law. This was passed in 1905 as a result of the investigation conducted by E. F. Ladd of the State School of Agriculture. Ladd sought to determine the prevailing standards for paints then on the market. Some of these were shown by analysis to contain high percentages of inert fillers, thinners, and water. In weathering tests, such paints failed rapidly. The new law required that in the case of "impure paints" (those containing anything other than white lead, linseed oil, and turpentine), percentages of all ingredients must be shown on the label of the can. Other states adopted similar laws, and the resulting publicity had a healthy effect. It drove the relatively few unscrupulous manufacturers out of business and encouraged the others to find scientific basis for their formulations. However, since that time it has been realized that, while composition gives some evidence of quality, it cannot be relied upon as an infallible means of evaluation. Performance, where it can be established, is by far the safer guide. A leader in advancing this viewpoint was Percy H. Walker, paint chemist at the National Bureau of Standards, who helped to shape the policy on the writing of government specifications during World War I and for a number of years afterward.

Since 1900, chemists have become more and more necessary in paint and varnish factories, to meet the increasing demand for specialized products and to take full advantage of the new raw materials as they become available. New techniques of application and drying of finishes were introduced, including the dip tank, the spray gun, the roller coater, the box oven, the continuous conveyor oven, and the infrared method of heating. These new methods required industrial finishes with carefully engineered properties.



Varnishes used in manufacture of laminated plastics are formulated in deep kettles at General Electric plant

The first synthetic resin, introduced to the American coatings industry about 1900, was "ester gum," made by neutralizing rosin with glycerol. Thus, a weak water-sensitive resin was converted to one which, when combined with tung oil, had excellent durability. Valentine & Co. advertised that its Valspar, the forerunner of many such finishes, withstood the boiling water test. Some years later, Kurt Albert found that Baekeland's phenol-formaldehyde molding resins could be made oil-soluble by heating with rosin or ester gum. The resulting modified phenolic resins, in combination with oil, had better drying speed, hardness, and water-resistance than ester gum. Beck, Koller & Co., and Rohm & Haas (through its subsidiary Resinous Products & Chemical Co.) introduced these in the United States. The era of "4-hour" varnishes had begun. The subsequent development of the "100% phenolic" resins resulted from the discovery that if para-substituted phenols were condensed with formaldehyde, the product was directly soluble in oils and was less subject to yellowing than the previous types.

The neutral coumarone-indene polymers, introduced by the Barrett Co. in about 1920, are now available in a wide range of hardnesses, from liquids to fairly high-melting resins. They have excellent alkali resistance and are used in a number of specialty applications.

Shortly afterward appeared the so-called maleic resins. These are made by combining rosin with maleic anhydride and neutralizing the product with glycerol. They are so similar to the phenolics in many physical and practical respects that some manufacturers use the same trade name for both. Strictly speaking, they are a special class of alkyds but they bear little resemblance to the main (or oil-modified) group of alkyds, to which we shall come next. They have better color-retention properties than the phenolics, with comparable hardness, but do not withstand the effects of weather quite so well.

Up to this point, progress centered around the almost direct replacement of natural resins by the "hard" synthetics which we have been discussing. These synthetic materials can be cooked with the oil directly without initial "running" and loss of weight, and they possess paler color, with equal or greater hardness and alkali-resistance. In using them, drying oils were retained as essential flexibilizing components of the varnish. Argument continues even today over the question of whether these drying oils act merely as dispersants for, or enter into chemical combination with, either the natural or the synthetic resins. However, in the alkyd resins, whose development had gone forward simultaneously with that of pure phenolics, such combination unquestionably does occur to a measurable extent. In the manufacture of alkyd resins, the hard core of glyceryl mono- or diphthalate (or other polyhydric alcohol–polybasic acid radical) is combined with one or more equivalents of a monobasic acid, ordinarily a fatty acid which imparts both flexibility and desirable drying properties. For most purposes, no further addition of oil is necessary in order to obtain adequate toughness and durability. These resins, first developed in the General Electric Research Laboratories, possessed improved resistance to weather and discoloration. Over the years, they have found wide acceptance for interior and exterior uses, and for baking as well as air-drying applications, because of their susceptibility to extensive modification.

Lacquers

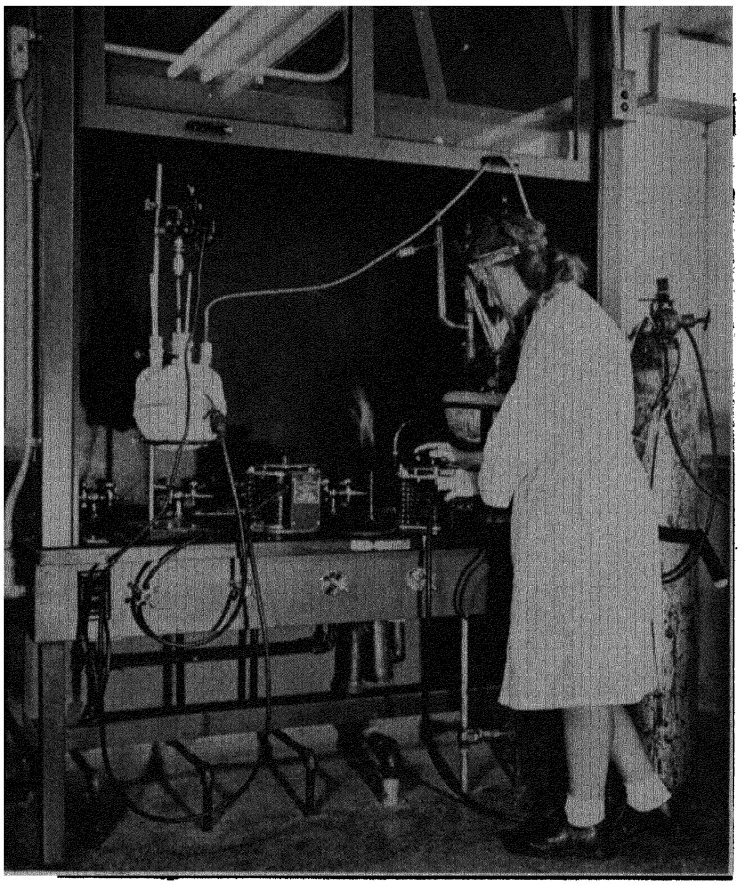
Shortly after World War I, a radically different type of finish rose rapidly to prominence and for a time seemed to threaten the continued use of conventional varnishes and enamels. This newcomer, known generally as "lacquer," was based on low-viscosity cellulose nitrate, or pyroxylin. By simple evaporation of the solvent, lacquers dried rapidly to a hard, tough film. Although they lacked the depth and richness of oleoresinous finishes, their speed, ease of repair, and durability were just what automobile manufacturers desperately needed. With the increasing demand for cars and the shift to closed models, manufacturers could ill afford to add more acres of floor space for the slow drying of numerous coats of old-style oil-base finishes, when a few coats of pigmented lacquer, sprayed over a baked-on primer and readily polished to a gloss, would produce a durable finish in a fraction of the time.

Cellulose nitrate was not new; solutions of it had been known for many years as collodion or "newskin" in medicine, or as "banana oil" in industry. But the early type had very high molecular weight, so that not more than 1 or 2% could be dissolved without making the lacquer too viscous for application. Nevertheless, it did find limited use as an antitarnish coating for brass bedsteads, chandeliers, and other household items. There were a number of drawbacks besides high viscosity. Unmodified films of cellulose nitrate had high shrinkage and low adherence. However, in the early twenties, chemists not only found ways to lower the viscosity so that much higher solids could be used and much thicker films deposited with fewer coats but they discovered new plasticizers to overcome shrinkage and brittleness, and new resins and resin combinations to improve adhesion. Alkyd resins modified with fatty acids of nondrying oils proved especially advantageous. Chemists also succeeded in converting tremendous wartime surplus stocks of guncotton into film-forming nitrocellulose of lower nitrogen content, thus keeping the price down. Last but not least, they brought to commercial production new solvents of lower cost and with far greater ranges of evaporating rates than the old acetone-alcohol-ether combinations, or ethyl or amyl acetates. Butanol, by-product of the Weizmann fermentation process, became (with its esters) more valuable than the acetone originally sought. The monoethers of the glycols and their esters were inexpensively made from hydrocarbon stocks. Lacquers became popular for many articles other than automobiles. Their use has increased over the years and has recently gained new impetus from the hot-spray technique. Among other claimed advantages, this method lowers the viscosity of high-solids compositions sufficiently so that fewer coats are needed for the same film thickness.

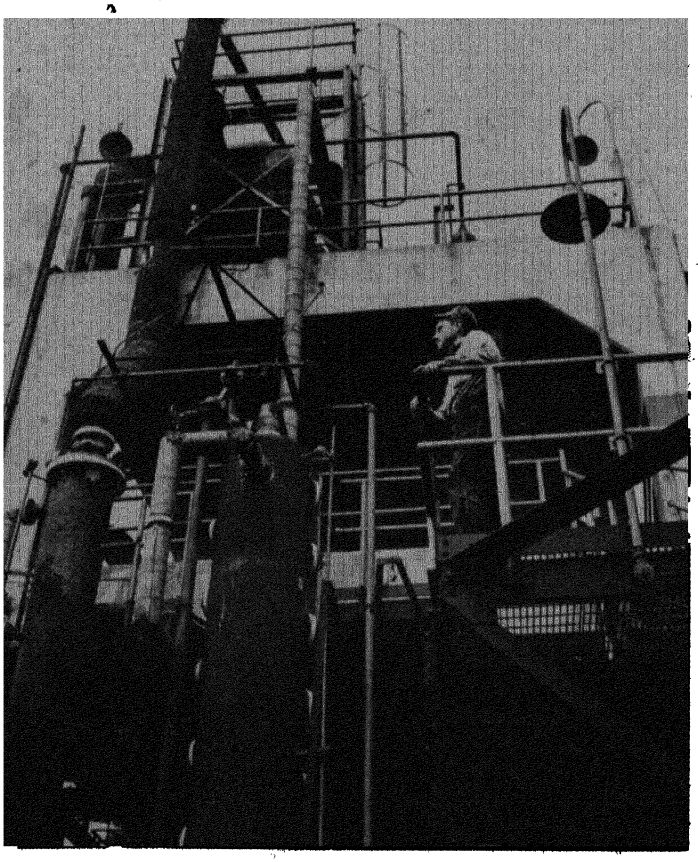
To the cellulose nitrate which made the lacquer boom possible have been added many other film-forming raw materials. Some are cellulose derivatives: the acetate, the propionate, mixed esters (like the acetate-propionate and acetate-butyrate), and ethylcellulose. Others are compounds of starch and sucrose, various acrylic and methacrylic polyesters, allyl and polyamide (including nylon) resins, and some of the modified phenolics. Numerous vinyl polymers and copolymers (some in the form of solutions, and some as plastisols and organosols) and many other new macromolecular compounds extend the usefulness and versatility of lacquer-type coatings.

The fear that oxidizing and baking finishes might almost disappear from the market was unjustified. In fact, new raw materials have made possible great improvements, with corresponding increases in acceptance. The urea and melamine resins, developed first (as we shall see) for plastics uses, were made soluble in organic solvents by the formation of their butyl and higher alkyl derivatives. These are compatible with many of the alkyd resins, to which they contribute hardness, toughness, and speed of cure. Some of the polyvinyl compounds can also be blended to advantage with compositions of this type. In addition, we have terpene polymers, terpene-phenolic resins; chlorinated diphenyls, paraffins, and rubbers; cyclized rubbers; modified rosins of several varieties; silicones, polystyrenes, urethanes, and compounds of the GR-N and GR-S types. Some of the latter, in latex form, are the basis of the amazingly successful modern water-reducible emulsion-type paints.

The chemist has been just as busy with drying oils as with resins. Besides adding to his repertory natural oils such as perilla, soybean, and oiticica, he has found it possible to impart greatly improved drying properties to oils. Scheiber found that by removing a molecule of water from the fatty acid of nondrying castor oil, he could derive from it a partially conjugated, doubly



Laboratory technician adjusts temperature of reaction mixture while cooking up new type of varnish



Vinyl chloride is purified in distillation columns before it is polymerized to form polyvinyl chloride resin

unsaturated drying oil. This discovery set off a train of new studies on the composition of oils and the mechanism of their polymerization and oxidation. As a result—and particularly with the stimulus of World War II scarcities—several methods for improving the drying speed, hardness, and chemical resistance of oils were put into practice. Segregation, reconstitution, substitution of higher polyalcohols for glycerol, and copolymerization of oils with unsaturated compounds (such as maleic anhydride, styrene, pentadiene, and others) have given the paint, varnish, and ink technician a wide range of choice. The time necessary for drying or curing has been reduced, in many cases, to a small percentage of that formerly required.

Turpentine has been almost entirely replaced as a paint and varnish thinner by petroleum distillates, carefully tailored to meet varying requirements of evaporating rate and solvency, and fortified when necessary by aromatic hydrocarbons from coal tar or petroleum. There is available a growing assortment of ketone, ester, nitroparaffin, and alcohol solvents for the formulations that require them. Plasticizers are numbered in the hundreds.

White lead is still one of the standard pigments for outside paints, but the need for better opacity for these and for industrial enamels has favored the successive introduction of lithopone, titanium pigments of the anatase type, zinc sulfide, and rutile titanium oxide. Inorganic and organic pigments in all colors have multiplied and have been improved in light-fastness, strength, and brightness. The introduction of the sunfast phthalocyanine blues and greens marked a great achievement. Study of interfacial phenomena has brought new understanding of the relations between pigment and vehicle. It has made possible the intelligent surface treatment of pigments, easier and more complete dispersion, higher luster, and longer wear—not to mention the successful production of the modern emulsion paints.

Progress in printing inks has followed closely that in the allied field of paints, in so far as mechanical limitations of presses would permit. Revolutionary advances in formulation made by the chemist, aided by skillful engineering, enable a web of paper fed in at one end of a press at 1200 feet per minute to emerge at the other end completely printed in four colors on each side, fully dried, cut, folded, and ready for binding and mailing.

Today the maker of finishes or inks also has greatly improved equipment of many kinds. He has processing kettles holding 1000 gallons or more and provided with all necessary accessories for chemical transformations. He has a variety of fast dispersion machinery—ball mills, roller mills, colloid mills, and others, as well as flushing machines by which wet precipitated pigments are transferred directly to an oil phase. He has greatly improved testing apparatus of all sorts.

Thus well provided with materials and tools, he can supply—quickly and in quantity—products which meet specifications as to uniformity, speed in application and drying, chemical resistance, durability, and adhesion that would surely have astounded his predecessor of 1876. Washing machines, toothpaste tubes, motor windings, ships, buttons, and tank cars for shipment of corrosive chemicals of many kinds, can all be protected against destructive forces and given long-lasting beauty. Large sheets of steel may, in hardly more than an hour, be transformed into handsomely lithographed shipping drums with chemical-resistant linings. House paints cover better and are more durable than ever. Interior paints may be easily rolled on and may be more easily scrubbed, with less damage to the finish, than those of even a few years ago. The best of the old is supplemented, after thorough screening, by the best of the new.

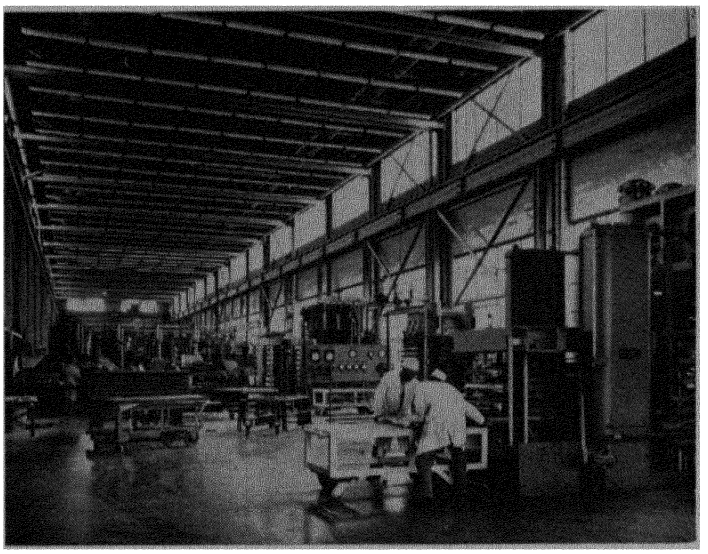
Paint, Varnish, and Ink Organizations

As a community of interest began to be felt, individuals engaged in various departments of the field of organic coatings were drawn together.

Trade associations, beginning in the eighties, eventually became a constructive influence for technical advance. Starting with the Paint and Oil Club of New England (1884), various organizations were founded: the National Paint, Oil, and Varnish Association (1888), the National Association of Varnish Makers (also 1888), and the Paint Grinders' Association (1899). Originally formed either for strictly social or for trade-defensive purposes, they came to see that the success of the industry depended upon the strict integrity of its products and its fullest service to the trade, both requiring the utmost in technical resourcefulness. Much credit should go to the pioneering efforts of George B. Heckel, who served as executive secretary of both the Varnish Makers' and the Paint Grinders' Associations. He gave impetus to the movement which eventually, after some transformations, mergers, and changes of name, culminated in 1933 in the formation of a single organization, the National Paint, Varnish, and Lacquer Association. With Ernest T. Trigg, Norris B. Gregg, Robert S. Perry, and others, Heckel was instrumental in setting up in 1904 the Bureau of Promotion and Development of the Paint Grinders' Association, which in 1908 became the Educational Bureau. Under this bureau there was established in 1907 the Scientific Section, which exercised valuable technical leadership. Perry was the first director of the section. Its first laboratory was established in the plant of Harrison Bros. at Philadelphia. In 1910 the laboratory was moved to the Institute of Industrial Research at Washington, D. C. Perry's assistant, Henry A. Gardner, who succeeded him in 1909, headed the laboratory for nearly 40 years, and its numerous circulars and bulletins have made him and the Scientific Section known to technical people all over the world. His book, "Physical and Chemical Examination of Paints, Varnishes, Lacquers, and Colors," sometimes called the "paint man's Bible," has gone through 11 editions. He had a large part in establishing in this country the commercial cultivation of tung trees, so that today we are much less dependent on imports of tung oil from China than we were in years gone by. John C. Moore now directs this laboratory.

In the ink industry, the National Association of Printing Ink Makers, established in 1915, is the counterpart of the Paint, Varnish, and Lacquer Association. In 1946 an allied group, the National Printing Ink Research Institute, established its laboratory at Lehigh University, now under the direction of A. C. Zettlemoyer.

Testing of the paint industry's raw materials and products was an absorbing subject on which technical people early sought a common meeting ground. In 1902, 20 of them formed Committee E (on Preservative Coatings for Iron and Steel) of the American Society for Testing Materials, which had just been founded as the successor to the American Section of the International Association for Testing Materials. In 1910 the name of this committee was changed to D-1 on Preservative Coatings for Structural Materials, and again in 1936 to D-1 on Paint, Varnish, Lacquer, and Related Products. Under the successive chairmanships of S. S. Voorhees, P. H. Walker, Allen Rogers, H. E. Smith, and W. T. Pearce, it has grown to 340 voting members and has developed an excellent body of specifications and test methods. Similar work in the field of insulating varnishes has been carried on by Committee D-9 on Electrical Insulating Materials, organized in 1910. Rosin, turpentine, and other related materials became the specialty of Committee D-17 on Naval Stores (1925). One of the subcommittees of D-9 studied molded insulating materials; its work on plastics led eventually to the formation of Committee D-20 on Plastics. This was organized in 1937, almost simultaneously with the Plastics Section of the ACS Division of Paint and Varnish Chemistry. The chairmen of Committee D-20 have been W. E. Emley, Robert Burns, W. A. Evans, L. W. A. Meyer, A. J. Warner, and G. M. Kline. Having a membership of 153, this group now has 11 subcommittees. Members of the AMERICAN CHEMICAL SOCIETY have taken prominent parts in the work of all these committees.



General Electric's laminated plastics plant contains scores of hydraulic presses ranging up to 5000-ton capacity

The expanding group of technical men engaged in formulation and production was the next one to respond to a mutual need for periodic discussions of noncompetitive problems. John R. MacGregor of Eagle-Picher Lead Co. sensed this need, and in 1914 he helped to organize a Superintendents' Club in the Cleveland area. This was followed by others in the Louisville, St. Louis, Philadelphia, New York–New Jersey, Cincinnati-Dayton, and Chicago areas. The paint and the varnish manufacturers' associations, at first hesitant, later welcomed them as plant managers' committees and gave them financial support. In 1922, again with MacGregor's help and with assistance from George Heckel, these combined in a Federation of Paint and Varnish Production Clubs. Now grown to a membership of 23 clubs (including one in Birmingham, England) and 2700 persons or firms, this organization carries forward a program of betterment on the technical side of the industry, publishes an *Official Digest* of papers given at club meetings, supports educational work, and has formed an international alliance with the Oil and Colour Chemists' Association in Britain and the Federation of Technical Associations of the Paint, Varnish, and Printing Ink Industry of Continental Europe.

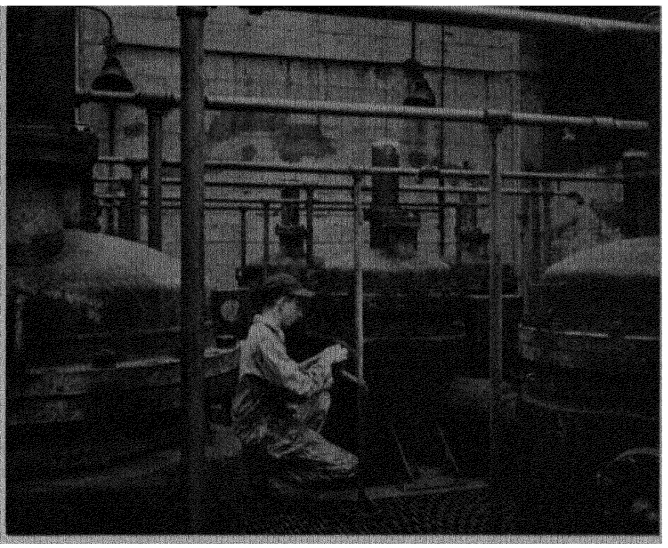
Printing Ink Production Clubs (independent of the federation) were organized in New York in 1936 and in Philadelphia in March 1950.

Paint and Varnish Division of ACS

Even before the production clubs arose to deal with practical and technical aspects of organic coatings, chemists of the industry felt the need for an organization devoted to the study of fundamental principles. Some of the pigment chemists, especially those who attended early meetings of the ACS Rubber Section (established in 1919), began to urge the formation of a similar Paint and Varnish Section. Henry Gardner, aware of this sentiment, invited chemists of the industry to informal conferences in Washington in May 1922 and April 1923; and there was further discussion of the idea. Formal action was not taken until, during the Society's sessions in Milwaukee the following September, Paul R. Croll called a meeting of paint and varnish chemists at the Pittsburgh Plate Glass Co. laboratory. About 30 attended. Among those active in supporting the proposal were John MacGregor, F. G. Breyer, A. H. Sabin, W. T. Pearce, J. H. Calbeck, F. L. Theurer, H. A. Nelson, and P. E. Marling. A committee consisting of Pearce, Theurer, and Marling was appointed not only to take the necessary steps for the organization of the section



Polymerization of vinyl chloride requires elaborate instrumentation for control of temperatures and pressures



These reactors are essential elements in U. S. Rubber's vinyl plastics plant at Painesville, Ohio

but to prepare a program for an initial meeting. The committee lost no time in drawing up a petition which was signed by about 100 chemists and presented to the Council in October. It was promptly approved; Gardner was appointed chairman and Pearce, secretary-treasurer. Beginning with the very first session, held at the Washington meeting of ACS in April 1924, interest was keen and attendance large. In 1927, the section became a full-fledged division.

Early programs included Symposia on the Wetting Power of Paint and Varnish Liquids; Applications of Colloid Chemistry to Paint and Varnish Phenomena; Particle Size Distribution and Its Function in Paints and Enamels; Effect of Heat, Light, and Oxidizing Conditions on Drying Oils; Lacquers and Solvents; Polymerization as Related to Paint and Varnish; Painting Problems in the South; Priming and Finishing of Nonferrous Surfaces; and the Scientific Approach to Paint and Varnish Problems. About 20 years ago, the division, along with other organizations in the paint and varnish field, participated in a survey of protective coating research. It also undertook the preparation of a monograph on lacquer raw materials, which (in spite of much hard work by many participants) never reached fruition.

How the division came to include "plastics chemistry" in its name will be seen later, after we trace the growth of that industry.

Beginnings of the Plastics Industry

Although the manufacture of paints, varnishes, and inks ranks among our oldest continuing industries, the plastics industry has developed almost entirely within the period now being celebrated by the Society. Its birth is popularly credited to John Wesley Hyatt and his brother, Isaiah, who around 1869 hit upon the combination of camphor with cellulose nitrate while looking for an acceptable substitute for ivory in the fabrication of billiard balls. A $10,000 prize offered for the successful attainment of this goal reportedly furnished the incentive for their work. Whether or not the Hyatts actually collected the money has been the subject of conjecture, but they did eventually produce good billiard balls. The superior properties of the new synthetic were immediately recognized, and in 1870 the Albany Dental Plate Co. was formed to exploit a flesh-colored form of the plastic in dentures. To take care of expanding demands in other fields of use, the Celluloid Manufacturing Co. was organized in 1872 with a plant in Newark, N. J. From this nucleus came the Celluloid Co., now a part of the Celanese Corp. On the birth date of the AMERICAN CHEMICAL SOCIETY, the plastics industry was a recognizable entity, but its modest past hardly offered a sound basis for predicting its phenomenal future.

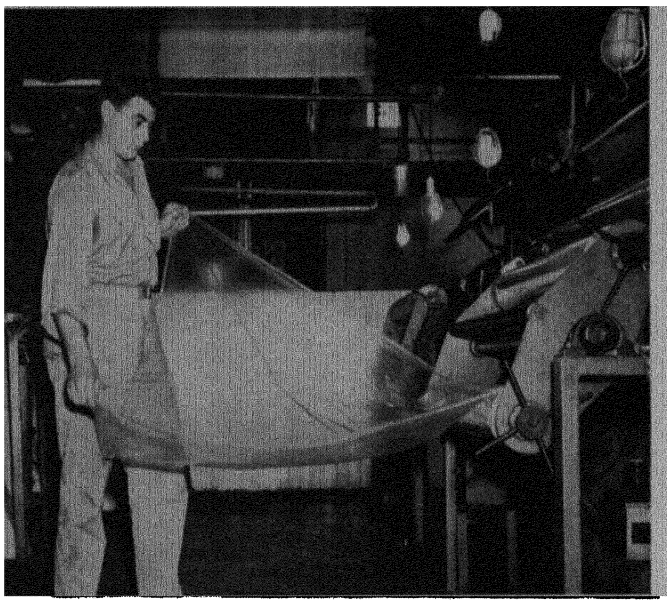
Historical truth may demand that we carry the story of plastics back to an earlier date; actually there are far-reaching roots, if we choose to dig for them. Utilization of asphalts, gums, and natural resins began in ancient times; in fact, they are mentioned in the earliest Biblical writings. Synthetic polymers received attention early in the annals of organic chemistry, but were normally passed over in favor of crystallizable or distillable compounds which lent themselves more readily to exact scientific study.

Among the polymers of contemporary importance which were known to early 19th century chemists are cellulose nitrate, polyvinylidene chloride, and polystyrene. Cellulose nitrate had been anticipated by H. Braconnot, a Frenchman, who had reported the treatment of various carbohydrate materials with nitric acid in 1833. Five years later, a compatriot named Pelouze prepared cellulose nitrate from paper and from cotton fabrics; subsequently he studied the effects of variation in the degree of nitration of cellulosic materials. Monomeric styrene had been isolated from naturally occurring storax balsam in 1831, and Simon described the polymerization of this substance in 1839. At about the same time, Regnault in France had observed the photopolymerization of vinylidene chloride in a sealed tube.

This description of origins has purposely omitted mention of rubber, although many historical treatments do include, as part of the chronological record, the remarkable contributions of Charles and Nelson Goodyear to rubber vulcanization. The question of just what is a "plastic" has not been precisely settled, and, in fact, is still being argued within the ACS. The widely circulated "Handbook of Plastics" regards plastics as synthetic organic materials whose chief component is a resinous or cellulose-derivative binder. At successive stages in production, they must be capable of being shaped or cast, afterward becoming more or less rigid. Recognizable forms include molded shapes, bristles, yarns, and sheeting. Synthetic rubbers, elastomers, and natural resins are considered borderline materials. (The border at times becomes indistinguishable!)

Regardless of where the line is drawn, all authorities agree that plastics have had a tremendous impact upon business and industry. With ever-expanding production in this country—an increase of over 600% in the past 10 years alone—plastics now exceed aluminum and lead in annual tonnage. On a bulk volume basis, their consumption is greater than that of zinc or copper. For 1950, the production of more than 1.5 billion pounds of plastics was reported, with a value in excess of $500 million.

Seventy-five years ago, any well-informed consumer found it relatively easy to decide whether he "liked plastics." Today,



Operator at Reynolds Research Corp. inspects plastic film used in packaging industry



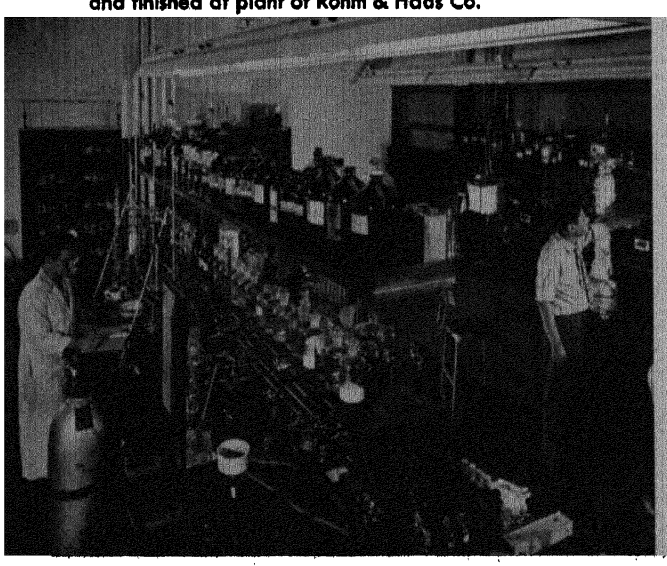
Nylon flying suit can be plugged into plane's electrical system to keep pilot warm at high altitudes



Gleaming rows of Plexiglas "bubbles" wait to be trimmed and finished at plant of Rohm & Haas Co.



To ward off corrosion, Pratt & Whitney Division packs its aircraft engines in special Pliofilm bags



At laboratory of Celanese Corp. at Summit, N. J., chemists study syntheses of new plastics and synthetic resins



Liquid acrylic monomer is poured over biological specimen, then polymerized to form transparent block

with such a variety of types—as well as trade names—to choose from, the question is complex. Manufacturers are currently attempting to make the problem of the end consumer simpler by guiding plastics into proper uses for proposed applications. Policing by enlightened leaders in such agencies as the Society of the Plastics Industry has been instrumental in reviving confidence in plastic products after disillusioning experiences. This society, similar to the National Paint, Varnish, and Lacquer Association in its relation to its industry, was formed about 1936 as an amalgamation of various informal trade groups, and incorporated the following year. It has 540 company members in the United States, Canada, and abroad. The Plastics Materials Manufacturers Association has also been active in the field. This group, which stemmed from the Pyroxylin Plastics Manufacturing Association (founded in 1919), has recently merged with the Manufacturing Chemists' Association, Inc.

Early in World War II, plastics were oversold as substitutes for the diminishing supply of metals. Then, as key plastics went on allocation, many inferior formulations were used as replacements. In the public mind, the term "plastic" began to connote "short-lived" and "unsatisfactory." After the war, this condition persisted because fabricators, bewildered by the multitude of new materials, selected injudiciously. Unfortunately for the innocent customer, manufacturers often chose the least expensive one which would produce an article of acceptable appearance. Happily, however, the importance of putting plastics only into suitable applications is today generally recognized. Technical information on the properties of new materials, distributed through trade literature and the publications and meetings of the AMERICAN CHEMICAL SOCIETY, has been helpful in this campaign; leading plastics producers have aided materially by corrective programs.

Classification of Plastics

Plastic materials can no longer be adequately classified in just the two broad types, thermosetting (those which cure or set on heating and cannot be remelted) and thermoplastic (those which soften on heating and can be remolded). Differentiation on the basis of chemical structure is more informative. Development of the most important types will be described briefly; some have already been mentioned for coating uses, but will be discussed again to make the plastics picture complete.

The industrial development of the so-called phenolic plastics—the phenol-formaldehyde condensation resins—is properly credited to the genius of Leo Hendrik Baekeland. In 1907, while searching for a shellac substitute he found a way to interrupt the condensation to yield a heat-hardenable resin, which he called Bakelite. The original Bakelite products were used as binders for laminated sheets of fibrous materials, and later in varnish coatings. With L. V. Redman, Archie J. Weith, and J. W. Aylesworth among the pioneers, techniques were developed for quickly converting the resinous products into molded articles having superior mechanical and electrical properties. In recent years, competition from new materials has pushed phenol-formaldehyde molding compounds from their predominant position, though they still hold an important place, particularly in the bonding of plywood and fiber laminations. Production in 1950 was about 375 million pounds for laminating, cementing, molding, and casting applications.

In 1928, after initial developments abroad, urea-formaldehyde thermosetting plastics were marketed in this country by the American Cyanamid Co., which also pioneered the use of thiourea in place of urea. The urea-formaldehyde materials could be pigmented in pastel shades, an esthetic attraction over the phenolic resins. They found rapid acceptance, though never to the extent of the less expensive and more durable phenolics. The kindred melamine-formaldehyde resins, introduced in 1939 and useful in electrical equipment, have also been largely developed in the United States by the American Cyanamid Co. Their greater stability, with equally light color, adapts them readily for molded tableware. Total production of plastics in this group during 1950 was about 175 million pounds.

Polyester resins are of many kinds. The most common types are condensation products of maleic anhydride (or fumaric acid) with ethylene glycol to give a resin which is polymerized in the presence of coreacting styrene monomer. American Cyanamid, Plaskon (a division of the Libbey-Owens-Ford Glass Co.), and others have developed such materials, with industrial use dating from World War II. The Owens-Corning Fiberglas Corp. has actively pushed low-pressure techniques for curing these resins containing glass fiber or glass cloth reinforcements. Interest has been sustained by successful specialty applications, such as the molding of small boats. Markets are increasing. In particular, a quick-setting filled molding powder offered two years ago by Plaskon has been well received for the molding of electrical parts.

The Viscoloid Co. at Leominster, Mass., and the Arlington Co. of Kearny, N. J., were among the first U. S. firms to investigate cellulose acetate as a less flammable replacement for cellulose nitrate. (Both companies were bought by E. I. du Pont de Nemours & Co. in 1916 and 1925, respectively, and now form part of the Du Pont polychemicals department.) Shortly after World War I, the Celanese Corp. marketed a cellulose acetate safety film. Molding powders and extrusion compositions were developed by a number of manufacturers around 1928. Just as cellulose nitrate declined in importance with the introduction of cellulose acetate, so the acetate is now being replaced by newer molding materials.

Cellulose acetate-butyrate, a mixed ester of cellulose with superior toughness, lower water sensitivity, and better stability at high temperatures, was introduced as a molding material by the Tennessee Eastman Corp. in 1938. During the war years, many important applications were developed. The Celanese Corp. in 1945 marketed cellulose propionate for competitive service.

Ethylcellulose, now manufactured by the Hercules Powder Co. and by the Dow Chemical Co., was first sold commercially in 1935. Its considerable toughness at low temperatures accounts for a small but growing market.

The so-called "vinyl polymers" encompass a great multitude of materials with an extremely broad range of properties. Starting with polyvinyl acetate (1928), Carbide and Carbon Chemicals (a division of the Union Carbide and Carbon Corp.) pioneered the development of vinyl chloride–vinyl acetate copolymers which are now so widely used in the form of films as fabric replacements and in electrical insulation for wiring. In 1950, Union Carbide and other manufacturers made approximately 400 million pounds (including fillers and plasticizers) of polymers in this class. Dow Chemical Co. manufactures vinylidine chloride polymers and copolymers (some containing vinyl chloride) under the generic name "saran." Carbide and Carbon, Du Pont, and Monsanto Chemical Co. (the latter in association with Shawinigan) all make polyvinyl butyral resins by hydrolyzing polyvinyl acetate to polyvinyl alcohol and condensing with butyraldehyde. Since 1938, motoring has been safer because of the superior properties, over a wide range of temperatures, of these highly plasticized, tough polyvinyl butyral plastics used as safety-glass interlayers. New vinyl monomers, obtained by the acetylene pressure reaction developed by Reppe in Germany during the recent war, will increase the number of vinyl polymers in the days ahead.

In particular, the methyl methacrylate polymers and copolymers, with their crystal clarity, have brought home to the public the wonders of the Plastics Age. The trade names of Plexiglas (Rohm & Haas Co.) and Lucite (Du Pont) are widely recognized, thanks to the well publicized "blisters" on wartime aircraft. Injection and compression-molding powders, as well as cast sheeting, rods, and tubes, were introduced in about 1936. Shortly thereafter, dentures molded conveniently from mixtures of the monomer and polymer were hailed by the

dental profession for their remarkably lifelike appearance and good general properties. Direct fillings for teeth are now being compounded in this fashion.

Polystyrene was introduced in this country about 1930 by the Naugatuck Chemical Co. (now a division of U. S. Rubber Co.), with a process based on the Ostromislensky patents. The company ran into difficulties with surface crazing and brittleness and within a few years withdrew the product. Naugatuck did not reenter the market until 1948, when it introduced the copolymer, Kralastic. Meanwhile, Dow Chemical Co. entered the field; its research and that of Bakelite Corp. improved the properties and lowered the cost of polystyrene from well over a dollar in 1936 to 45 cents per pound in 1942. Huge facilities built for quantity production of the monomer for wartime rubber production permitted a further price reduction to below 26 cents in 1948. The excellent injection molding qualities of the material have steadily broadened its acceptance. The 12 firms currently manufacturing polystyrene and copolymers with modified properties sold approximately 270 million pounds in 1950 for molding applications.

Wallace H. Carothers was the first to distinguish clearly between simple addition polymerization and condensation polymerization (where water or some other small molecule is eliminated in the course of the polymer formation). He headed the group of chemists at the Du Pont Experimental Station in Wilmington, Del., which developed the nylon (polyamide) resins, so well known in the textile field. Nylon molding powders first appeared in 1940, but the extruded monofilament had been offered a couple of years earlier for use in hosiery and as bristles, fishline leaders, sutures, and tennis-racket strings. The success story of the nylon-bristled tooth brushes has been often told. However, despite their great toughness and high softening temperature, the relatively high priced molding and extrusion compositions have been slower in finding volume markets. The great variety of diamines and dibasic acids which can be used in making polyamide plastics opens many unexplored potential applications. Du Pont's two new polymers—polyacrylonitrile, marketed as Orlon, and polyethylene terephthalate (called Terylene by British manufacturers and Dacron by Du Pont)—may to some extent replace nylon in fiber and bristle uses, though they have not yet proved themselves as molding materials.

Polyethylene is a relatively new, but extremely popular plastic. This low density, readily moldable material was developed by Imperial Chemical Industries, Ltd., in England before World War II. Military applications in radar and in other electrical equipment, where its low dissipation factor over a wide range of frequencies was of critical importance, promoted its manufacture by the Union Carbide and Carbon Corp. and by Du Pont in 1943. Its future looks particularly bright in the packaging field, both as extruded film and in squeezable bottles and other injection-molded containers. Electrical insulation also consumes large amounts. The compounded polyethylene, Rulan, announced in 1950 by Du Pont as a flame-resistant molding and extrusion material, will open new markets. Current estimates of the production capacity for polyethylene indicate facilities for 60 million pounds annually. Recently, both producers were said to be ready for considerable expansion, and others are rumored to be entering the field.

The silicone plastics, developed by Dow Corning Corp. and by General Electric Co. and released in 1943, find their way largely into industrial outlets as gaskets, motor insulation, foam inhibitors, baking-pan release agents, and other applications where extreme stability and efficacy outweigh their relatively high price. They are becoming well known, too, in automobile polishes, optical glass cleaners, and other consumer uses.

Fluorocarbon plastics are of marked interest because of their great heat stability, extreme insolubility, chemical inertness, nonadhesive surface, and low dissipation factor. Their high cost has tended to limit their use to industrial applications where no other materials can perform the functions afforded by these unique properties. Just last year Du Pont announced commercial production of Teflon (polytetrafluoroethylene) patented in 1941 by R. J. Plunkett. Du Pont has also released a new aqueous suspensoid form of the polymer which is easier to fabricate into films and wire coverings. The M. W. Kellogg Co. and the Bakelite Division of Union Carbide produce polychlorotrifluoroethylene under the names Kel-F and Fluorothene, respectively. It is more readily moldable and more rigid than polytetrafluoroethylene. However, it has a lower maximum service temperature and higher power losses. The patent literature currently abounds in references to plastics from other fluorine-containing polymers and copolymers, including vinyl fluoride, vinyl trifluoroacetate, perfluorovinylidine chloride, and others, but none of these is known to be in commercial production.

Significant quantities of cold molding materials which are derived from the bituminous compositions developed in 1909 by Emil Hemming are still in use, but research in this field is less active. Shellac, which Emil Berliner first used for molding phonograph records in 1895, appears to have lost this market completely, but still serves in specialty jobs, such as the bonding of mica. Casein plastics also reach back into the early days of the industry but have declined in relative importance. Coumarone-indene resins (introduced here by the Barrett Co.) have a large market as a binder in floor tile. Alkyd resins (developed by General Electric, American Cyanamid, and others) are largely used as plasticizers rather than as plastics bases; however, several companies, notably Plaskon, are making special alkyds for molding applications. Among the new materials, Ciba's nonshrinking casting resin, Araldite, is reportedly based on the bisphenol-epoxy condensation reaction similar to that employed in the manufacture of the new Epon and Devran finishes.

Plasticizers, stabilizers, pigments, and fillers, though secondary to the resin binders in plastic compositions, have considerable influence on their properties. Such subjects are of vital concern to members of both subdivisions of the ACS Division of Paint, Varnish, and Plastics Chemistry and have often appeared on its programs.

Space limitations do not permit adequate mention of the methods and equipment for converting the various bulk products into useful final forms. These are as important as the materials themselves but belong in the province of engineering. The first molding techniques (used with cellulose nitrate) were borrowed from the rubber industry. From these to the modern compression, injection, jet, and other molding and extrusion machines, and low-pressure laminating processes, there is a record of steady progress.

In manufacturing thin sheeting from plasticized vinyl chloride copolymers, calendering has been commonly employed, but the organosol and plastisol technique, originated in Germany during World War II, permits the production of thinner films—as low as 0.0005 inch in thickness. This involves the formation of a slurry of the finely divided polymer in a nonsolvent volatile liquid, or in a plasticizer, which at normal temperatures does not dissolve it. Then, when the temperature is raised after the paste mixture has been properly spread, homogenization takes place. American firms are now exploiting the method, which is useful not only in making unsupported film and in forming relatively heavy pieces, but also in a variety of coating applications.

The casting of liquids which can be converted to hard polymers in a mold by the action of heat or light has been practiced both with the phenol-formaldehyde thermosetting resins and with thermoplastic materials, such as methyl methacrylate. The Catalin Corp. has led in the casting of phenolic resins. The Rohm & Haas Co. is credited with major advances in methods for forming acrylic sheeting by casting between sheets of glass. D. E. Strain of Du Pont and B. S. Garvey of the B. F. Goodrich Co. were among the first to employ monomer-polymer mixtures

to advantage in a combination of molding and casting procedures.

While a few names have been mentioned for special credit, those of many other important contributors, usually working as members of teams, have necessarily been omitted. Some of these are among the winners of such honors as the John Wesley Hyatt award, set up by the Hercules Powder Co. for special recognition of men who have given distinguished service to the plastics industry; the Leo Hendrik Baekeland biennial award established by the North Jersey Section of the ACS for the encouragement of younger chemists; and the Mattiello award of the Federation of Paint and Varnish Production Clubs for the recognition of pioneers in the field of organic coatings.

DIVISION OF PAINT, VARNISH AND PLASTICS CHEMISTRY

It is evident that modern plastics have depended upon chemistry from their very beginning—and members of ACS have contributed to the striking advances. It was natural that, soon after the formation of the Paint and Varnish Division, chemists in the plastics industry, finding close kinship with it, became increasingly interested in its work and began offering numerous papers. Accordingly, in 1937, they were given a voice in its management. A Plastics Section, with its own cochairman, was organized. In 1940, by a change in bylaws, the name of the division was altered to its present form and now the chairman-elect is chosen alternately from the Paint and Varnish and the Plastics Subdivisions.

During the thirties, the custom grew up of requesting speakers at the divisional meetings to furnish mimeographed copies of their papers for distribution to those present; since 1942, as a special service to its members, the division has provided these papers in the form of a preprint.

Symposia of recent years (some jointly sponsored with other divisions) have discussed, among other subjects: organic plastics, automobile finishing, colloid chemistry of inorganic pigments, chemical engineering in the plastics industry, cellulose and cellulose plastics, alkyd resins, plasticizers, drying oils, phenolic resins and molecular weights of high polymers. In 1948, a 25th Anniversary Symposium reviewed over-all progress in the industry.

From its inception, the Division of Paint, Varnish, and Plastics Chemistry has sponsored discussions which have materially contributed to an understanding of the complex chemistry of drying oils, resins, and other polymeric substances. Alkyd resins as film-forming materials were first described at the fifth annual meeting of the division in 1928. The functionality theory, proposed by Kienle in another divisional paper in 1930 and advanced by Carothers, Bradley, and others, has helped to elucidate not only alkyd formation and structure but many of the other reactions of resins, oils, rubbers, and plastics.

Officers of the Division of Paint, Varnish, and Plastics Chemistry, 1927–1951

Year	Chairman	Secretary
1927	W. T. Pearce	P. E. Marling
1928	W. T. Pearce	E. W. Boughton
1929	P. E. Marling	E. W. Boughton
1930	J. S. Long	P. R. Croll
1931	P. R. Croll	R. J. Moore
1932	H. A. Nelson	R. J. Moore
1933	F. E. Bartell	R. H. Kienle
1934	R. J. Moore	R. H. Kienle
1935	W. R. Fuller	R. H. Kienle
1936	E. W. Boughton	G. G. Sward
1937	R. H. Kienle G. M. Kline	G. G. Sward
1938	E. E. Ware H. A. Bruson	G. G. Sward
1939	W. H. Gardner H. R. Dittmar	G. G. Sward
1940	E. J. Probeck	A. C. Elm
1941	G. G. Sward	A. C. Elm
1942	S. L. Bass	A. C. Elm
1943	W. W. Bauer	A. C. Elm
1944	C. S. Fuller	W. H. Lutz
1945	A. C. Elm	W. H. Lutz
1946	A. C. Elm	W. H. Lutz
1947	R. H. Ball	E. E. McSweeney
1948	P. O. Powers	E. E. McSweeney
1949	M. M. Renfrew	E. E. McSweeney
1950	C. R. Bragdon	H. F. Payne
1951	E. E. McSweeney	H. F. Payne

The Division of Paint, Varnish, and Plastics Chemistry early took a leading part in furthering the study of macromolecules, which in the form of resins, polymerized oils, etc., are of considerable importance to the members of the division. While C. S. Fuller was chairman in 1944 and A. C. Elm chairman-elect, they conceived the idea of organizing a High Polymer Forum, to be jointly sponsored by these divisions. Elm, who had been active in the work of the Division of Paint, Varnish, and Plastics Chemistry for several years, particularly as chairman in 1945–1946, successfully carried out the plan, with ready cooperation from the Divisions of Cellulose, Colloid, Organic, Petroleum, Physical and Inorganic, and Rubber Chemistry. The first session was held in April 1946. To give fuller and more varied scope to these forums, chief sponsorship was placed on a rotating basis, each division taking charge in turn. This proved to be a fruitful arrangement; it brought out papers of excellent quality by leading authorities in all sections of the field, with crowded sessions and spirited discussions. In the nine meetings at which the forum was a feature, 173 papers were presented. As a medium of expression for the rapid development of experiment and theory in macromolecular chemistry, it was outstanding.

DIVISION OF POLYMER CHEMISTRY

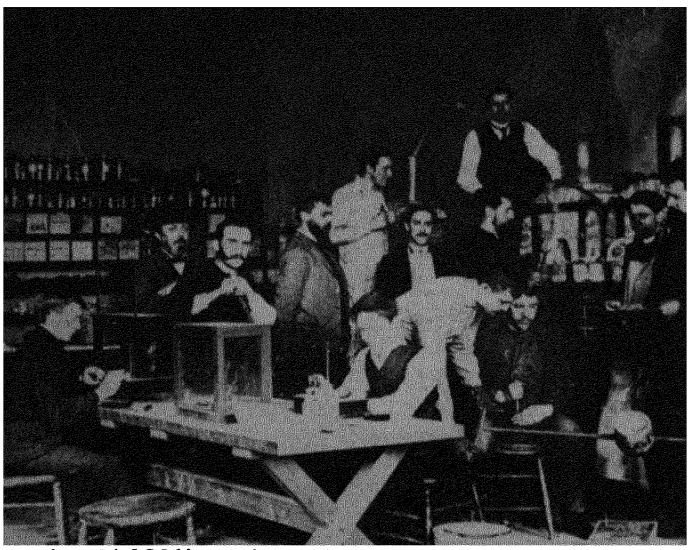
So great did the interest become that in 1949 a petition was presented for the formation of a Division of High Polymer Chemistry (now the Division of Polymer Chemistry). A vote of the Council at its spring 1950 meeting authorized provisional organization of the division, and even before its first program, a further vote gave it full divisional status. It made its bow at the September 1950 meeting under the chairmanship of Carl S. Marvel, with Herman F. Mark as secretary. Five well-attended sessions were held, three of these consisting of symposia on the role of free radicals in polymerization, reactions of macromolecules, and macromolecules in solution.

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Drawing indicates size and layout of quantitative chemistry laboratory supervised by H. C. Bolton in 1873



In mid-1880's, undergraduates posed for photograph in assay room at the University of Pennsylvania



Wolcott Gibbs was one of the first scientists to apply electrolytic methods to the determination of metals

Analytical Chemistry

Thanks to instrumentation, the analytical chemist of today has at his command high speed tools of phenomenal precision

C. K. DEISCHER
University of Pennsylvania, Philadelphia, Pa.

"Analytical chemistry, or the art of recognizing different substances and determining their constituents, takes a prominent position among the applications of the science, since the questions which it enables us to answer arise wherever chemical processes are employed for scientific or technical purposes. Its supreme importance has caused it to be assiduously cultivated from a very early period in the history of chemistry, and its record comprises a large part of the quantitative work which is spread over the whole domain of the science"—"The Scientific Foundation of Analytical Chemistry" by Wilhelm Ostwald, 1895.

ALTHOUGH the Division of Analytical Chemistry is the third youngest of the 20 ACS divisions, the history of analytical chemistry is, in many ways, so integrated with the story of chemistry itself that it is properly regarded as "the oldest branch of the subject." As chemistry developed, the need for knowledge concerning the composition of all kinds of matter was a necessity. Consequently, "it came about that many, if not most, of the great chemists of the time were of necessity analysts and the analytical branch of chemistry stood in high repute" (*5*). Little wonder that Robert Bunsen stated earlier: "He who is not an analyst is no chemist."

In order to detect and determine the constituents or purity of substances, chemists had to develop a large number of methods, both gravimetric and volumetric. It is true that many were long tedious procedures and subject to many factors which were not understood. But they served their purposes. Volumetric

methods were available for some determinations of acids, alkalies, oxidants, and reductants. Common gaseous mixtures also were capable of separation and analysis.

But this "high estate" of analytical chemistry did not maintain itself. In the latter half of the 19th century, this branch "came to be looked upon more or less as a handy tool for ulterior ends, a tool, moreover, which need not for most purposes be of the sharpest or the best, or entrusted only to the most careful and skilled operators" (*5*).

The three chief reasons for the apparent loss of interest in analytical chemistry itself was the newer and more appealing development of (1) the use of voltaic batteries in electrolysis studies and the subsequent speculations and experimental researches in electrochemistry; (2) the synthesis of urea, resulting in the era of organic chemistry, its theoretical conceptions, and the discovery of many new types of reactions; and (3) the interest in the borderline studies between physics and chemistry, giving rise to physical chemistry. All these appeared as unexplored fields and thus gave greater promise of new achievements and discoveries. More glamor and far more spectacular results seemed to be associated with these new fields. Some chemists felt that the field of analytical chemistry "was an exhausted one—with little reward for the research worker."

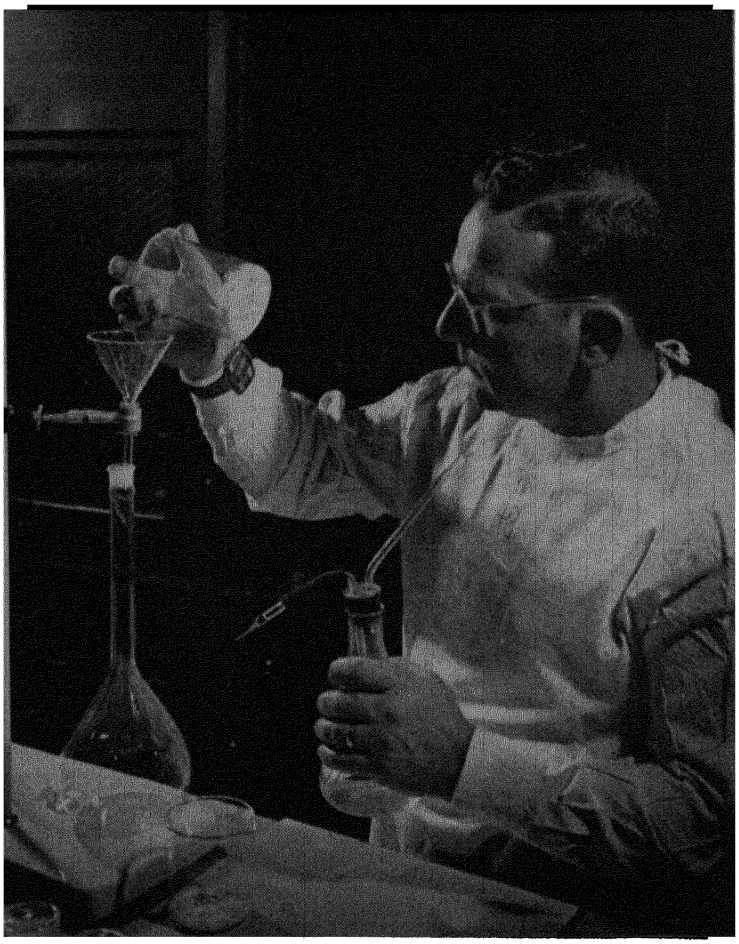
Three quarters of a century ago, practically no graduate work in chemistry was done in this country. It was still considered highly desirable to obtain a degree from a foreign university. Therefore, most American students went to study at Göttingen, Berlin, or Bonn. Although a majority of them studied organic chemistry, a few sought to do analytical work with K. R. Fresenius at Wurzburg. Many preferred to publish their articles in the older and more established European journals.

Another reason given for the pro-European trend was that laboratory instruction had not yet become a part of the American college curriculum. Frequently, chemistry professors who suggested that some provisions be made for the installation of laboratory equipment were rebuffed. In some schools, students were forbidden to enter and work in laboratories. In other schools, if they did work in laboratories set up by assistants, such work was optional and not considered a part of the regular college training. The instruction usually was given in experimental and analytical chemistry. The majority of students in these colleges were preparing either for law or divinity schools.

Privately owned laboratories offered the best openings to students—especially those interested in analytical and applied chemistry. Here the first lessons were given in the art of chemical analysis and research. Outstanding examples of such laboratories were those of J. C. Booth in Philadelphia and C. T. Jackson in Boston, founded in 1836 and 1838, respectively. By training individuals and by encouraging Americans to examine and develop their native resources, these laboratories helped to establish a strong school of analytical chemists in this country. Aside from the numerous contributions by Booth, Jackson, and their coworkers, many others contributed significantly to analytical chemistry. Included in this group were J. Lawrence Smith, T. H. Garrett, Wolcott Gibbs, C. F. Chandler, John W. Draper (first ACS President), and Augustus A. Hayes.

Periodic Table

Another factor that aided the development of analytical chemistry was the first foreshadowing of the periodic law by the historic memoirs presented to the French Academy of Sciences in 1862 and 1863 by Alexandre E. Béguyer de Chancourtois. Béguyer's concept of a cylindrical spiral arrangement of the elements in the order of their increasing atomic weights went unnoticed for some time. The first clear statements of this periodicity were made independently by Lothar Meyer and Dmitri Mendeleev about eight years before the founding of the ACS. This led a number of chemists, both abroad and at home, to study the



Wearing film badge, researcher at National Institutes of Health begins analysis of radioactive product

relations between the atomic weights and more especially the physical properties of the elements and their compounds. This revival of interest in studies of the elements resulted in attempts not only to discover new elements (those missing in these arrangements), but to develop more detailed or exacting methods of separation. It was soon recognized that the rarest and least investigated elements were as important as the well-known ones. However, this latter aspect was not developed fully until the second decade of the 20th century.

With the growing importance, from both industrial and scientific standpoints, of the presence of small amounts of elements in a given material, it became highly desirable to review many methods of determination which heretofore had been considered reliable and accurate. In time, these critical studies revealed defects or errors. Analytical chemists soon discovered that these errors often compensated each other or that the presence of rarer elements, either known or unknown, must be sought. Quantities of constituents which heretofore were considered too small for determination or thought to be unworthy of determination, had to be determined with some degree of accuracy. Obviously, new tests or methods were required.

Toward the close of the 19th century, Wilhelm Ostwald's volume, "The Scientific Foundations of Analytical Chemistry," was the first real attempt to systematize the mass of data and put analytical chemistry on a sound theoretical basis. Physicochemical researches, demanding more exacting methods, shed new light on such phenomena as solubilities, hydrolysis, and equilibria, and thus opened up new fields of research. These investigations later proved to be immensely fruitful and helped restore analytical chemistry to a high plane.

Textbooks on analytical chemistry used in the United States

during this same period were, for the most part, either translations or reprints of foreign volumes. The most widely used texts were those of K. R. Fresenius, "A Manual of Qualitative Chemistry" and "A System of Instruction in Quantitative Chemical Analysis." Various English editions of this latter work appeared in this country. Another text, "Elementary Quantitative Analysis," written by Alexander Classen, was translated in 1878 by Edgar F. Smith (a three-time President of the ACS) and somewhat later by W. Hale Herrick. By 1890 "A Systematic Handbook of Volumetric Analysis" by Francis Sutton had reached its sixth edition. Clemens Winkler's "Handbook of Technical Gas Analysis," printed in 1884, was translated into English by G. Lunge in 1885. Within a short time several other volumes written by Americans began to receive recognition and adoption as textbooks in analytical chemistry.

The development of analytical chemistry was further influenced by the researches of American chemists in the introduction of electrolytic methods for the determination of metals by Wolcott Gibbs and extended shortly thereafter by E. F. Smith; studies in double and complex salts by Wolcott Gibbs, E. F. Smith, and Allen Rogers; atomic weight determinations by Frank W. Clark, J. P. Cooke, Jr., J. W. Mallet, T W. Richards, and G. P. Baxter; rare earth and rare element separations and determinations by W. L. Dudley, J. Lawrence Smith, T. H. Norton, and Charles James; liquid ammonia systems by H. Seeley, E. C. Franklin, and H. P. Cady; and the important generalizations on solvates by H. C. Jones. In addition, the ever-expanding chemical industries in our country necessitated the development of new techniques and instruments for rapid determinations.

Use of Instrumentation

The older slogan of "dry, ignite, and weigh" no longer served as a satisfactory conclusion to a day's work in analytical chemistry. New analytical tools, in the form of instrumentation, were found to be applicable in the solution of special problems. With the extensive and impressive development of instruments, the analytical chemist had to "become familiar with a bewildering array of techniques and at least become moderately acquainted with the dialect of the physicist and engineer" (*9*).

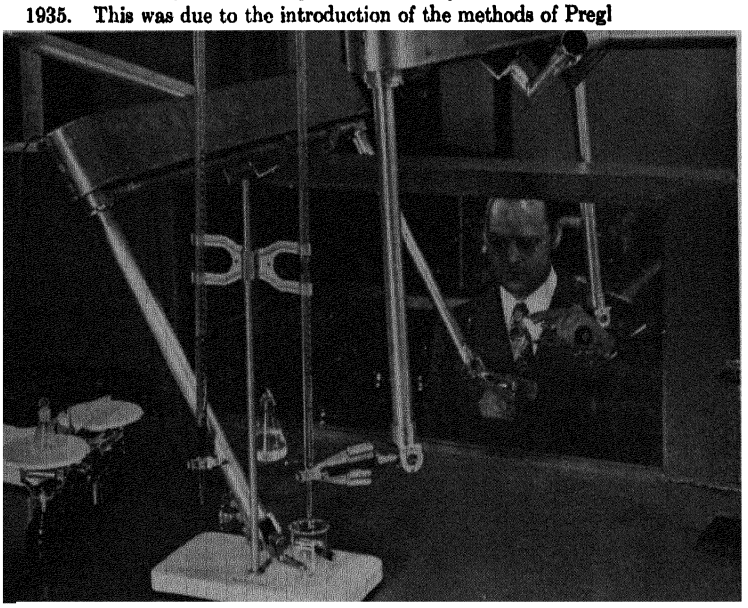
These newer developments and applications of instrumentation seemed to follow four general directions. First were those dealing with the classical methods. Improved and more highly refined methods, combined with the use of instruments, gave greater speed, higher precision, and, in some cases, a degree of automatic operation. Second was the introduction of self-recording devices to the study of second-order effects or feeble reactions. Third were the conductometric, refractometric, and thermal methods applied to determinations of constituents. Fourth were the purely experimental and theoretical studies which led to a more intelligent use of instruments, a wider applicability, and incomparably better analytical tools. Some of these studies were extended by the constant flow of small technical improvements in the instrument itself and by changes in technique.

In the first quarter of the 20th century, a few special analytical instruments were known, but their acceptance as such was very limited. Chromatographic adsorption, discovered by the Russian botanist M. Tswett and published in 1906, did not become an important tool until 1931, when Kuhn and his coworkers used it to separate certain isomeric substances. Since 1939 many significant improvements of apparatus and procedure have been made. Many new absorbents, solvents, and methods of separating the bands or zones have made the resolution of mixtures possible. Spectroscopic methods, as late as 1910, were of little quantitative value and appeared to be impractical. Great advances have resulted since 1940.

Electroanalysis, one of the older methods of analysis, was considered as "belonging to the museum class" at the close of this quarter of the century, but since has become very useful.

New compact, portable instruments employing new techniques have aided greatly in the development of the field of polarographic analysis. Polarography, one of the five most popular instrumental methods of analysis (*15*), was originated by the pioneer work of Heyrovský and Shikata of Prague in 1925. Polarographic references did not appear in American journals until 1937. The end of the "unaccountable incubation period" was marked by the appearance of the Kolthoff and Lingane monograph, "Polarography," and the E. H. Sargent & Co. "Bibliography of Polarographic Literature," both in 1941. Because so many diverse substances are subject to electrolytic oxidation-reduction, the instrument is useful in the rapid determination of trace impurities or in the amperometric titration of relatively small concentrations of various metal ions.

Microchemistry, introduced into the United States in the late twenties or early thirties, began its more rapid growth about 1935. This was due to the introduction of the methods of Pregl and Emich by Benedetti-Pichler and Niederl; the pioneer work of Chamot and Mason in chemical microscopy; the applications and extension of new techniques to the problems of American industry by B. L. Clarke, H. W. Hermance, G. L. Royer, L. T. Hallett, and others; the offering of courses of instruction in certain schools; and the appearance of suitable textbooks (*1*, *2*, *11*).



At Argonne National Laboratory, chemist titrates dangerously radioactive sample by remote control

Bibliographies in recent reviews of inorganic and organic microanalysis contain extensive listings of references. Quantitative ultramicroanalysis, currently considered by some to be in the developmental stage, has been highly useful in work with radioactive analytical tracers. These tracers make it possible for investigators to determine the completeness of analytical reactions.

So rapid was the growth of instrumentation in analytical analysis that by 1946, 50% of all the analytical papers were on instrumental methods of analysis. This indicated their future importance in chemistry. As W. J. Murphy stated at the Symposium on Modern Analytical Methods at Baton Rouge in 1950: "We may rejoice that recognition by analysts of the latent possibilities of instrumentation has brought almost a renaissance in analytical chemistry.... Instrumentation will not supplant, but will rather supplement, wet methods."

Analytical Edition

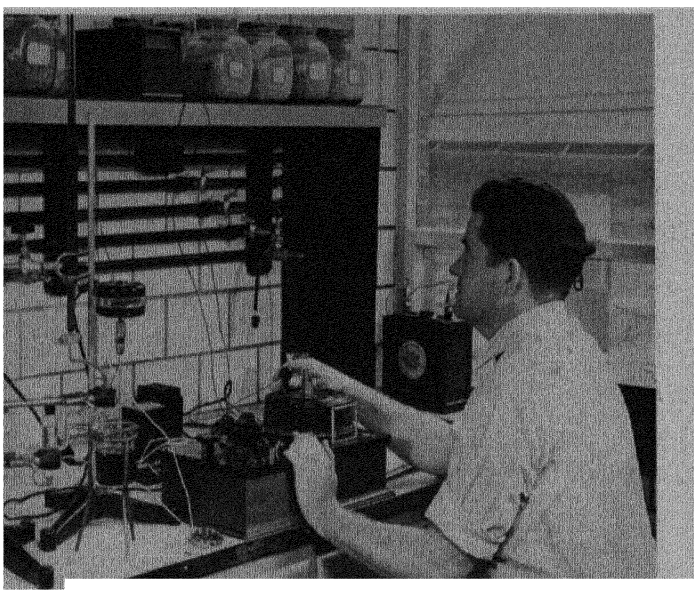
Because of the ever-increasing activity in chemistry and the growing numbers of original papers of an analytical nature, it became necessary in 1929 to issue a supplement to *Industrial*

and Engineering Chemistry known as the *Analytical Edition.* This was a quarterly publication. Eight years later (1937), it became a monthly supplement. By this time, the *Analytical Edition* had "attained a world-wide circulation and, because it is a tool of great utility and immediate value, it has achieved an enviable place in chemical literature" (*6*).

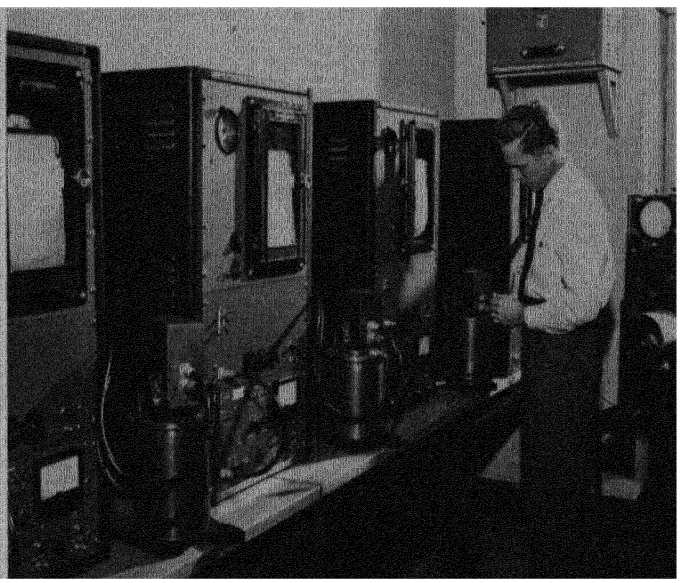
A survey made by the Opinion Research Corp. prior to 1948 disclosed that 57% of the ACS members read or referred regularly to the *Analytical Edition.* E. J. Crane, editor of *Chemical Abstracts,* reported in 1950 that the analytical chemistry section in *Chemical Abstracts* rated third highest among the sections most regularly read or scanned. The long established and familiar name, *Analytical Edition,* was changed in 1947 to *Analytical Chemistry.* Circulation was made independent of *Industrial and Engineering Chemistry* and the scope was broadened to include editorials, news items of interest to analytical chemists, and other feature material. Since 1949, the publication has issued an annual review of developments in analytical chemistry. The first group of papers in 1949 not only reviewed theoretical and fundamental material from the previous year but provided a five- to 10-year review of each field of analytical chemistry and a survey of the development of various analytical tools. A total of 40 articles appeared.

The second progress report in 1950 included 27 articles on fundamental developments and 11 on practical applications during the previous year. The third annual review in 1951 contained 18 reports on theoretical and fundamental material and eight reviews of applications of new developments in a number of industries and fields of specialization.

That there is renewed interest in analytical chemistry is evidenced by the appearance of excellently written articles on this subject within the past six months (*4, 7, 8, 10, 12–14*).



Analyst, watching deflection of light beam, runs potentiometric titration of sorghum starch with iodine solution



Apparatus at New Brunswick Laboratory is used to determine minute amounts of radium or radon in ore samples

DIVISION OF ANALYTICAL CHEMISTRY

About 20 years after the appearance of Fritz Pregl's noteworthy monograph on quantitative organic microanalysis, interest in this subject had increased to such an extent that by September 1935 a Symposium on Microchemistry constituted a half-day session of the Analytical Chemistry Section of the Division of Physical and Inorganic Chemistry. In February 1936, the *News Edition* commented: "Since microchemistry cannot be included wholly within the scope of any of the existing divisions of the ACS and because of the general applicability of this technique to almost all of the major branches of chemistry, a separate division of the ACS devoted entirely to microchemistry is under consideration."

Accordingly, a group of chemists, headed by A. A. Benedetti-Pichler and F. Schneider, was authorized to arrange a separate program for the April meeting in Kansas City. Their efforts resulted in the first half-day program of the Microchemical Section. The nine papers given on that program covered at length the precise techniques of using smaller analytical samples than those which had previously been required in the classical methods.

At subsequent meetings, the number of papers increased and more detailed studies of the problems and applications of microchemistry in the research laboratory were made. So successful were the meetings and so great was the interest they aroused that a petition was presented to the Council session in Milwaukee requesting official recognition of a Division of Microchemistry. On September 5, 1938, this group was granted divisional status.

In his introductory remarks to the Section of Microchemistry in Milwaukee, L. T. Hallett said: "The granting of divisional rank to the microchemical group marks an important milestone in the development of microchemistry in the United States." The Milwaukee program consisted of 15 papers and a special report, which was the first of a series aimed at standardizing microchemical apparatus for the gravimetric determination of carbon and hydrogen.

The first official meeting as a new division was held at Baltimore in April 1939. No sooner had this group begun to function when in September 1939 a committee representing the Analytical Section (Willard, Furman, Kolthoff, and G. F. Smith) held a joint meeting with the Executive Committee of the new division. This analytical group had voted to separate from the Division of Physical and Inorganic Chemistry and accordingly outlined a proposal for merging their membership with the Division of Microchemistry. Both committees agreed that "a change of title and bylaws of the microchemical group should be made (provided this was approved by the membership of the latter group)."

At the Division of Microchemistry's business meeting in Boston in 1939, the merger which had been suggested by the analytical group was announced to the membership of the Microchemical

Officers of the Division of Analytical Chemistry,[a] 1938–1951

Year	Chairman	Secretary-Treasurer
1938	W. R. Kirner	L. T. Hallett
1939	L. T. Hallett	G. L. Royer
1940	C. W. Mason	G. L. Royer
1941	G. E. F. Lundell	F. W. Power
1942	G. L. Royer	F. W. Power
1943	H. L. Diehl	F. W. Power
1944	E. W. D. Huffman	C. M. Alter
1945	F. W. Power	C. M. Alter
1946	W. M. MacNevin	R. A. Burdett
1947	Mary L. Willard	R. A. Burdett
1948	P. J. Elving	R. A. Burdett
1949	W. A. Kirklin	W. G. Batt
1950	G. T. Wernimont	W. G. Batt
1951	H. H. Willard	W. G. Batt

[a] Originally called the Division of Microchemistry, the division changed its name to the Division of Analytical and Microchemistry in 1940 and to the Division of Analytical Chemistry in 1949.

Division. The minutes stated that "in general this discussion was favorable." The secretary was asked to "write a letter to the members to get an opinion on the matter." The question was to be finally voted upon in Detroit in the fall of 1940. The opinions expressed by a postcard questionnaire gave an overwhelming 76-to-2 vote in favor of combining the groups. Accordingly, petitions were prepared by the joint executive committees and presented to the Council in Detroit, suggesting that the name of the division be changed to the Division of Analytical and Microchemistry.

The Council approved the merger and on September 11, 1940, the two groups met to elect officers for this new division. The minutes stated that "it is to be an unwritten understanding that the chairman and vice chairman be elected to represent the two fields." Accordingly, G. E. F. Lundell was elected chairman of this newly amalgamated group; G. L. Royer, vice chairman; and F. W. Power, secretary-treasurer.

The first notice to prospective authors of the division bore evidence of a retained individuality. It was proposed that the division hold separate as well as joint sessions. Those planning to present papers were requested to underscore the preferred group before which they wish to speak:

"Micro" group (formerly the Division of Microchemistry)
"Analytical" group (formerly the Section of Analytical Chemistry of the Division of Physical and Inorganic Chemistry)

The first officially arranged program of the new division (April 1941) was a two-day session at St. Louis. A Symposium on Newer Analytical Techniques constituted an all-day meeting, with half of the second day devoted to analytical chemistry and the other half to microchemistry.

A review of the succeeding programs of the individual and combined groups shows that an extraordinarily varied list of subjects, including both macro and microanalysis, were given detailed consideration. The educational aspects—methods of teaching courses in quantitative analysis, their content, and the interpretation of results—were also part of these discussions.

Many symposia, sponsored either by the division or jointly with others, have appeared on the national programs of the ACS in the past 15 years. Some of the more important titles deserve mention.

Recent advances in methods for the determination of traces
Application of micro and semimicromethods to industry
Standard chemicals and reagents
Purity and identity of organic compounds
Statistical methods in experimental and industrial chemistry
Spectrochemical methods of analysis
Polarography, electrolysis, and overvoltage
Teaching of analytical chemistry
Infrared spectroscopy
Determination of functionality in organic compounds
Adsorption
Microchemistry and the petroleum industry

Also in this period, numerous committees made studies and rendered reports on such subjects as the standardization of apparatus, both macro- and microchemical; the naming of analytical methods; nomenclature in analytical chemistry and in chemical microscopy; and the precision of microbalances.

Further evidence of divisional activity, not associated with the national meetings of the Society, was the selection and preparation of a list of speakers on topics pertaining to analytical and microchemistry. Prepared in 1948 by a special committee of the division, this list included, in addition to analytical chemists, some nonanalytical chemists. Of the nonanalysts, all of the listed speakers were workers in fields closely allied to analytical chemistry. It was felt that such a list, in the hands of the secretaries of ACS local sections, would be an aid in the preparation of stimulating programs. Some of the topics included electroanalysis, polarography, the electron microscope, fundamentals of analytical chemistry, instrumentation, nucleonics, chromatography, fluorescence, spectroscopy (x-ray, infrared, ultraviolet, emission, absorption, mass, or Raman), metallurgical analysis, organic reagents, electrometric methods, optical methods, low-pressure techniques, and extractions.

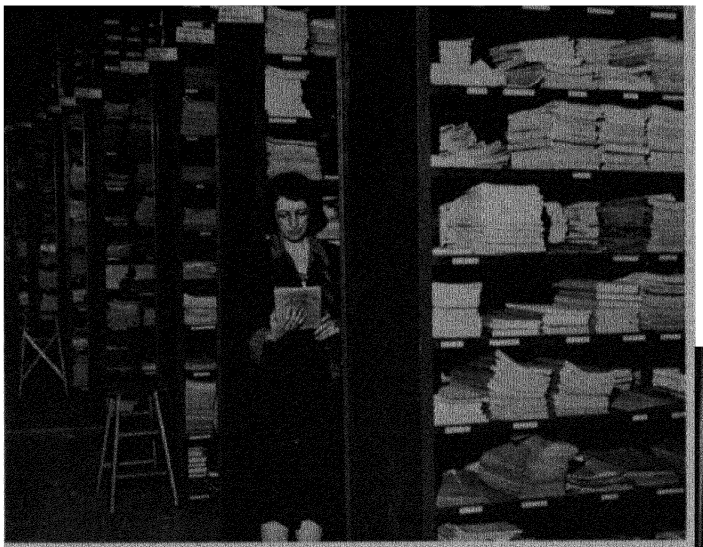
All these varied activities initiated by the division or other ACS divisions and ably championed by many persons interested in chemistry have so extended the scope of analytical chemistry that it has become a part of every branch of chemistry. Much of the progress can be credited to the individuals who have been leaders in the division's activities or who have served on committees appointed by these officers.

As we reflect and pay our respects "to the great, the near great, and the unnamed workers who laid the foundations and built the structure that has brought analytical chemistry to its present high estate" (*3*), we must also accept the challenge of tomorrow. Analytical chemistry of today is but a promise of what is to come. Its future must of necessity be "influenced by the thoughts and actions of the analytical chemist himself; it will take skillful driving and attention to the road if one is to avoid the ditches on the bumpy roads the analytical chemist has ridden in the past" (*14*).

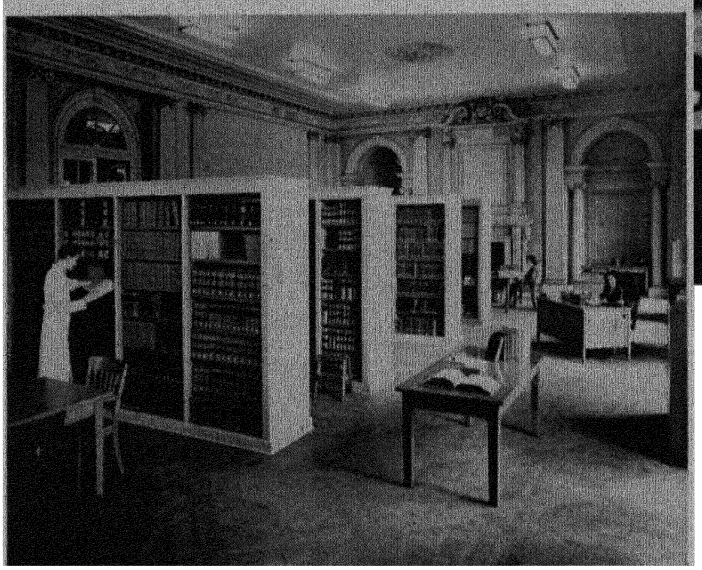
As analytical chemists were the men who helped make the past, most certainly they must also be the men who are making the tomorrow.

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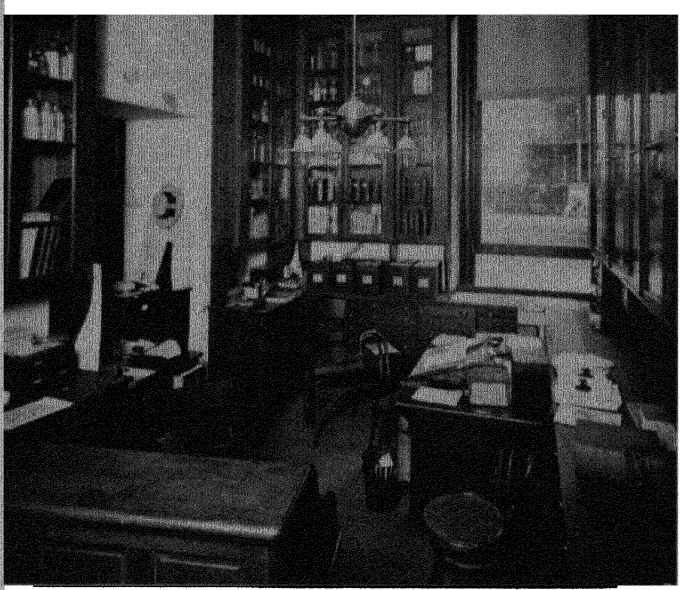
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Experienced librarian knows scientific journals from A to Z —from *Abhandlungen* to *Zeitschrift*



Research laboratory of Pennsylvania Salt Manufacturing Co. contains well-stocked technical library



Columbia University housed the editorial offices of the *Journal of Industrial and Engineering Chemistry* in 1916

Chemical Literature

By its many publications, the American Chemical Society has quickened the flow of scientific knowledge to all the world

J. F. SMITH
Office of Naval Research, Washington, D. C.

Chemistry is a French science, founded by Lavoisier of deathless memory.

Thus Adolphe Wurtz began his book, "Histoire des doctrines chimiques" (1869), by claiming for France a chemical pre-eminence which soon thereafter passed to Germany and later to America. Some nations think it belonged elsewhere all the time. Nationalism can be perverted, but not killed. This brief history is nationalistic; it traces chemical literature in America as a factor in American chemical pre-eminence, but it recognizes the use of foreign technical literature as part of the story.

The literature has steadily contributed to American chemistry's phenomenal growth in breadth of inquiry, depth of perception, and height of achievement. The AMERICAN CHEMICAL SOCIETY, from its beginning in 1876, was a leading influence.

Like the Royal Society of London, chartered in 1662, the AMERICAN CHEMICAL SOCIETY grew out of less formally organized groups, notably the chemistry sections of the New York Academy of Science and the American Association for the Advancement of Science. Chemistry and its literature had traveled far since 1662, when it was commonplace to conclude instructions for an experiment with the remark, "When you have finished this work, give God thanks and remember the poor" (*1*).

The new Society's objectives included publication of research results. No grass grew on the path from resolve to action. Charles F. Chandler of Columbia promptly opened his *American Chemist* to papers read at meetings. In 1876–1877, the papers appeared there and were reprinted in the *Proceedings* of the ACS, the first issue of which carried nine papers in 58 pages.

The *American Chemist* bowed out in 1877; the *Proceedings* carried papers through 1878.

The monthly *Journal of the American Chemical Society* was launched in 1879 with a triple issue (January-February-March) carrying eight papers, the proceedings of three meetings, a library accessions list, and an exchange list, all in 78 pages. The editor was Hermann Endemann; he, with Arno Behr and Gideon E. Moore, comprised the Publications Committee; these three and eight others constituted the staff of abstractors.

From this modest start, the ACS grew to its present position of world leadership among chemical publishers. The Society, its divisions, and its local sections now publish or sponsor more chemical periodicals than were issued in all America in 1876. Today, many European periodicals eagerly seek papers by American authors, and foreign authors are delighted to have papers accepted by ACS publications.

In 1876 the chemical journals in America could be counted on the fingers of one hand. The *American Chemical Journal* was as yet unknown, the *American Laboratory and Journal of Applied Chemistry* had just died, and Chandler's *American Chemist* stood out like the lonesome pine. *Druggists' Circular and Chemical Gazette*, perpetuating the British tradition of identifying chemists with pharmacy, lasted until 1882. *American Gas Light Journal and Chemical Repertory* actually had a broader scope than its title indicated. General science periodicals carried much of the chemical load—e.g., Silliman's *Journal of Science* and the *Journal of the Franklin Institute.*

There was much reliance on foreign literature. German immigrants supported (into the 1880's) two American periodicals in German—*Amerikanische Bierbrauer* and a German-language edition of *American Agriculturist.*

Textbooks of chemistry were fairly numerous, mainly at the high school and college undergraduate level. The fashion then was to go abroad (chiefly to Germany) for the doctorate. The Ivy League of graduate instruction might have included Harvard, Yale, Princeton, Columbia, and Pennsylvania. Johns Hopkins and Cornell were still too young to attract many of America's future chemists.

Dissertations by American students studying abroad outnumbered those of their stay-at-home brothers. American fondness for anything exotic doubtless added stimulus to the wanderlust, but foreign research (much of it in Germany) was the main attraction. Ambition to follow in the footsteps of Germany's most eminent scientists led many young American chemists overseas. Modern press agents would call it the "big name appeal," but actually the underlying motive went deeper. Some doctoral dissertations of that era were:

Charles F. Chandler, Miscellaneous Chemical Researches, University of Göttingen, 1856.
J. B. Barringer, Investigations on Sorbic and Parasorbic Acids, University of Tübingen, 1871.
Arnold Eiloart, On the Chlorine Compounds of Tolane, Johns Hopkins University, 1890.

Patents

Under the present numbering system, dating from 1837, United States patents reached 182,000 in September 1876, passed the million mark in August 1911, and the 2 million mark in May 1935. They are now well above 2.5 million.

In 1876 only about one invention in 20 was chemical; now the ratio is nearer one in five. Chemical interests have broadened. For example, a coking oven would have been regarded as strictly a mechanical invention in 1876 even though it would one day have immense significance in the development of the coal tar chemical industry. Some obviously chemical inventions of 1876 were:

U. S. Patent 178,447, June 6, Philipp Kramer, Waterproof Compounds for Leather
U. S. Patent 182,647, September 26, Louis de Planque, Artificial Marble
U. S. Patent 183,185, October 10, Wm. Maynard, Sulfurous Acid Gas Manufacture

Universities, institutions, and manufacturers were not prolific chemical publishers in 1876. Ignoring the flamboyant literature of the patent medicine producers, we can still cite some chemical publications from nongovernment sources:

Verplanck Colvin, Certain New Phenomena in Chemistry, Albany, 1872
Henry A. Mott, Chemist's Manual, A Practical Treatise, New York City, 1877
James R. Nichols, Chemistry of the Farm and the Sea, Boston, 1867
Ira Remsen, Principles of Theoretical Chemistry, Philadelphia, 1877



Ohio State University is the site of the present-day headquarters of *Chemical Abstracts*

By 1951 standards, all the American chemical literature extant in 1876 would not make a large collection even for a college professor's home library. American chemists liked to read, but relied greatly on foreign literature. Their loyalty to the *American Chemist* did not make them less fond of its parent *Chemical News* or of the *Journal of the Chemical Society, Annalen der Chemie*, or *Annales de Chimie.* They even published some of their papers in foreign journals in order to reach a greater audience.

Thus, the lines between American and foreign chemical literature were hazy in 1876. Some literature was published in German even in America; some was published abroad by American authors.

Publication activity waxed strong in the warm glow of favor accorded it by the newly organized AMERICAN CHEMICAL SOCIETY. Pure and applied science were then entering a period of growth in which cause and effect are hard to distinguish. To say that the ACS merely followed the trend toward chemical publication would falsely imply lack of leadership. To say that the ACS created the trend would be a tall story. Hewing to the straight line of facts, primary publication of American chemical findings increased more and more rapidly year by year in the last decades of the 19th century. Some milestones of progress were the *American Chemical Journal* (1879); *Bulletins* of the Division of Chemistry, U. S. Department of Agriculture (1883); Association of Official Agricultural Chemists (*Proceedings*) (1884); *Journal of Analytical Chemistry* (1887); and *Journal of Physical Chemistry* (1896). All this while, the Society's *Journal* was growing in stature and in favor.

Chemical books—from the ponderous alchemical tomes of the Middle Ages to the texts of a century or so ago—were largely media of primary publication (new work or speculative contemplation). But periodicals multiplied and, in turn, became the chief outlets for original work. More and more books acquired the characteristics of textbooks, manuals, compilations, and monographs containing little or no new knowledge. Scientific periodicals are now so burdened with papers for publication that investigators are becoming increasingly prone to release their research findings in books. A chapter contributed to a composite book may reach the public faster than a paper sent to a periodical. Many journals are patiently whittling away at huge backlogs, whereas book publishers can sometimes set and meet a deadline of three or four months from accepted manuscript to bookstore shelf. A few American chemical periodicals have worked back to within sight of the shortest possible time lag. Chemical books have not actually cycled back from secondary to primary publication, but any worsening of the periodical situation will undoubtedly promote such a tendency.

Among inventors, one good idea often sired two or three more ideas. Hence, patent grants increased. Agricultural and engineering experimental stations were established in one state after another; university graduate schools attracted more and more students; the industrial giant slowly awoke to the profit possibilities in research. The result was more publications. Report files and libraries bulged; people were needed to keep them serviceable. The growth rate became so rapid that guides to the literature were needed lest control be lost entirely.

The ACS gave a powerful impetus to secondary publication by taking responsibility for the *Review of American Chemical Research* in 1897 and by broadening it to world-wide coverage as *Chemical Abstracts* in 1907. The Monographs, which combine primary and secondary publication, and *Chemical Reviews* (1924)



Chemical Abstracts staff members use magnetic wire recorders in preparing decennial index

are other potent searching aids provided under ACS sponsorship.

The history of *Chemical Abstracts* under its four editors (W. A. Noyes, 1907–1909; Austin M. Patterson, 1909–1913; J. J. Miller, 1914–1915; E. J. Crane, 1915–) has been recorded elsewhere (*3*) and was brought up to date at a Symposium on the History of Chemical Literature at the 118th meeting of the ACS at Chicago in September 1950. Its present state has been described by Crane (*2*); its position of world leadership is acknowledged both at home and abroad.

The preparation of handbooks and tables of data is a tedious, dreary job for the compilers, but they are blessings to the investigator who finds an answer in minutes instead of grubbing for it all day in the library or all week in the laboratory.

Francis H. Storer, a pioneer compiler, turned out a modest product (*7*) but pointed the way toward International Critical Tables and other modern compilations. By backing *Chemical Abstracts* and *Chemical Reviews* and by participating in a variety of compilation enterprises such as International Critical Tables, the ACS has demonstrated its appreciation of secondary publication. Its Monographs offer additional evidence of the Society's interest and support.

Bibliographies, another form of secondary publication, were sporadic efforts in 1876, when no field was hard to cover. As bibliographic needs expanded, the art of searching also developed, but not apace. As searchers struggled to keep abreast of all branches of pure and applied chemistry, the demand for better searching aids became more insistent. Patent searching became an art in itself, having special requirements that depended upon whether novelty, priority, validity, or infringement was the issue.

Better subject indexes, especially of abstract journals, and better bibliographic practices evolved as the pressure increased. By 1925 bibliographies were so numerous that the National Research Council issued its "Bibliography of Bibliographies on Chemistry" for 1900–1924. This compilation has been partially modernized but completion and publication of a new edition have been left to the future.

Primary publication sufficed to keep chemists informed until about the end of the 18th century. Secondary publication, needed by chemists for searching the primary literature, expanded slowly in the first half and much more rapidly in the second half of the 19th century. In the 20th century, even the secondary literature became so cumbersome that some relief was vital.

Literature about chemical literature was slow to develop. A pioneer effort was the syllabus (*6*) prepared by Marion E. Sparks for her course in chemical literature (1914). It was useful, but chemical searchers needed more comprehensive guides to the literature. Three of the best aids which finally emerged were those of Crane and Patterson (*3*), Mellon (*4*), and Soule (*5*). In addition, the literature on the arts of indexing, classifying, coding, and searching has now become so voluminous that it, in turn, needs a bibliography of its own.

As literature searching became more burdensome, libraries began to expand and systematize their information services. A few individuals and firms went professional, notably H. W. Wilson Co. (1898) with its Industrial Arts Index (1913), and D. D. Berolzheimer, the dean of chemical bibliographers.

The Engineering Index (1884), as reactivated by the Engineering Societies Library (1929), became an outstanding current information service. "Reference Service" (1928–1930) offered a similar current service in chemical technology.

Industrial research laboratories, like Omar Khayyam, "when young did eagerly frequent doctor and saint, and heard great argument." Staff discussions of current literature kept research men alert and alerted, until they were compelled by three factors to systematize the alerting:

The research staff outgrew the round table.
Subject interests broadened, sometimes mushroomed.
The literature crop grew faster than group receptivity.

Internal routing systems helped, but not enough. Information bulletins followed, starting with quickie productions which seem crude now but were sufficient then.

Some of the academic and institutional technical libraries which contributed to better utilization of chemical literature are:

Chemist's Club Library
University of Illinois Chemical Library
Purdue University Chemical Library

University of Michigan Chemical Library
Ohio State University Chemical Library
Carnegie Institute of Technology Library
Institute of Paper Chemistry Library
Kresge-Hooker Scientific Library
Engineering Societies Library

Research libraries of Du Pont, Hercules, Monsanto, Dow, and other chemical companies, and of several large laboratories in petroleum, rubber, and other industries are also contributing.

Out of these efforts "documentation" slowly emerged as an art with many devotees. The term has been appropriated by producers of "documentary" films, but otherwise has not yet passed into the language to encounter such abuse and distortion as are suffered by "science" and "research." Its chemist practitioners, who during World War II increased faster in work load than in numbers, felt the need for an organization more chemical in its interests and approach than the Special Libraries Association, in which many of them are members.

DIVISION OF CHEMICAL LITERATURE

A symposium on chemical libraries and their problems was presented at the ACS meeting in Buffalo in April 1919, when the stimulus of World War I was still active. During the next two decades, there were papers, dissertations, and books (*3–5*) at intervals, but no organization within the ACS.

Early in World War II, a number of chemists who were concerned with efficient utilization of the literature felt the lack of organized effort within the AMERICAN CHEMICAL SOCIETY. Their flicker of interest was fanned into a steady flame by the heartening response accorded to "Problems of the Scientific Literature Survey," a paper by Gustav Egloff, Mary Alexander, and Prudence Van Arsdell (105th meeting, ACS, April 1943).

Officers of the Division of Chemical Literature, 1948–1951

Year	Chairman	Secretary
1948	Norman C. Hill	Robert S. Casey
1949	Norman C. Hill	Robert S. Casey
1950	E. J. Crane	Robert S. Casey
1951	J. W. Perry	Robert S. Casey

Recognizing the opportunity, Norman C. Hill (University of Akron) discussed with Egloff the possibility of group effort. It was necessary to have a division sponsor the group. Paul H. Fall and Norris Rakestraw, of the Division of Chemical Education and its *Journal of Chemical Education*, had receptive minds and hospitable hearts.

The first result discernible to ACS members was a Symposium on Technical Library Techniques, organized by Norman C. Hill (106th Meeting, A.C.S., Pittsburgh, September 1943). Later the Division of Chemical Education officially took the literature practitioners under its wing as the Chemical Literature Group. From May 1943 to date, there has been only one ACS meeting (108th, New York, September 1944) without a program by the group or its successor, the Division of Chemical Literature.

Guided by Norman C. Hill and a few of the faithful, the Chemical Literature Group sought and obtained divisional status. Its petition was granted by the ACS Council at the St. Louis meeting in September 1948.

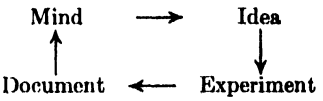
In its first independent election (by mail ballot) the division elected officers for 1950: E. J. Crane, chairman; J. W. Perry, chairman-elect. Response to membership invitations exceeded expectations; more than 700 members had enrolled by the time of the spring meeting in 1950.

The first issue of the division's publication, *Chemical Literature*, appeared in November 1949. Substantial aid was given to its editor, Ben H. Weil, by the Georgia Institute of Technology. Beginning as a four-page leaflet, *Chemical Literature* is expanding at a modest rate as warranted by the demand from members.

Prospects for Fast Searching in a Mechanized Age

Defining documentation simply as the art of making literature searchable, we can define searching as the art of utilizing documentation. Like other definitions in reverse pairs, this is more resounding than enlightening. It is used here to illustrate the lack of any generally accepted definition among producers, processors, and users of technical information.

Machines are needed for searching great stockpiles of recorded information. Machine enthusiasts have rosy visions of push-button searching, while enjoying perfect immunity from the drudgery of reducing the world's literature to a searchable state. To retrieve an item from the mass of known facts, the retrieving mind, hand, or machine must enter some point in the cycle:



Documentalists, discoursing glibly about primary, secondary, and tertiary publications, often forget that no publication can be a primary source of information. Minds and their ideas are the wellsprings of information; publications are necessarily never higher than secondary mediums in the flow. Research men do not forget this; they are forever swapping facts and fancies.

Their tendency to seek first sources first has an enormous influence on the history of chemical literature. Savants, meeting to pick each other's minds, formed the Royal Society of London in 1662. Its *Proceedings*, the first enduring scientific journal, started in 1665.

Other savants, also meeting to pick each other's minds, formed the AMERICAN CHEMICAL SOCIETY in 1876 and lost no time starting a publication program. From that small start, the Society has become one of the most potent forces in the world for publishing (facilitating the trek from mind to document) and abstracting (facilitating the trek from document to mind).

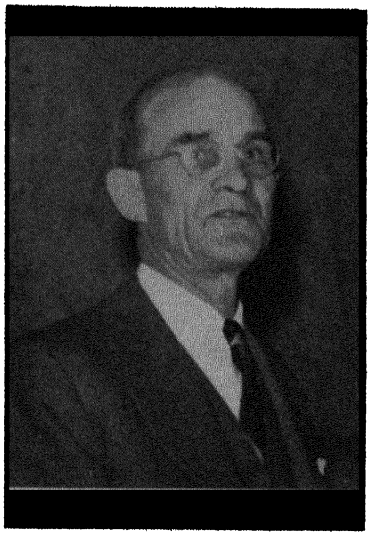
The trek from mind to document was first mechanized by Gutenberg half a millennium ago. Mechanizers of the trek back can say that the goal is in sight, but not that they have reached it. There are difficulties, the most formidable of which involves the tracing of a boundary between routine (truly mechanizable) searching operations and those operations in which thought and imagination are needed.

Actually, the machines are at present ahead of the minds. We have machines offering great utility to searchers but demanding a state of literature organization not even remotely approached at present. The main problem of mechanized searching now is not machine design, but a dingy, grubby job of hard work. Somebody must organize tens of millions of observations so that the machines can handle them.

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A review of the past cannot be complete without a contemporary look at our science and its environment... In this series of four articles, a scientist, a philosopher, a business executive, and a teacher express their views



Science and Civilization

When considered in the light of the best ideals of all sciences, the idea that men could apply the scientific method to social problems is not so far-fetched

ROBERT R. WILLIAMS, *Research Corp., New York, N. Y.*

WE ARE all familiar with the frequent complaint in the popular press that the latest advances of science threaten to be used for the destruction of civilization in a third world war. We cannot deny this threat, though our spirits protest that science is potentially and inherently a civilizing force.

For those nations of the earth who have engaged most extensively and successfully in scientific endeavor, science has profoundly contributed to release from back-breaking toil, to the saving of life, to bringing within the reach of the masses abundance of food, good housing, and a vast array of comforts, entertainments, and pleasures as well as the tools for further and further progress.

The 20th century, however, has also seen the application of science to war bring new and wider barbarities to entire populations in wartime so that there remain no civilian noncombatants, no private property, no peaceful occupations. When humans are united, science civilizes; when divided it barbarizes. If another world war comes there may well be not enough left for humanity to begin over again. Unprecedented advance stands side by side with unprecedented threat.

We of the scientific fraternity are compelled to ask ourselves whether there is something wrong with science that it has produced such an impasse. I see two defects on which I wish to comment. (a) Science enlists men unequally in different parts of the world. (b) Science does not make the contribution it might to sociological and political ideas and ideals.

East and West

The human race at the present juncture is roughly divided into two segments: one with a longer history, more pervading artistic interests, more attachment to metaphysical philosophy, less mastery of science. The other, on the whole younger and more virile, enjoys an altogether higher standard of living in the material sense, has far more of the world's wealth, a vastly greater literature, and capacity to read. An examination of the contrast may give us a better insight into what science buys us. Such an examination soon leads us to certain convictions: that more science in the West has created much of its superior wealth; that the East's poverty is a great handicap for which a partial solution, at least, is to be found in the greater, though tardy, use of science.

One tangible measure of the progress of civilization, and one which is close to our hearts, is the length of life of those who are dear to us. The average life expectation of a new-born babe in India is 27 years; in the United States it is 67 years. Few will deny that the latter is a more satisfactory state of affairs nor that it has been achieved by the application of science. Since the turn of the century our own life expectancy has been increased by almost 50% by bringing infectious diseases under control. We are just beginning to face the degenerative diseases which take us off in our maturer years.

Now this sort of modern scientific medicine has had and is having a profound effect on the life span of Asian peoples. Japan

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Robert R. Williams, who is in charge of grants at Research Corp., New York, is a towering figure in the world of biological chemistry, with a concern for the feeding of a hungry multitude in his heart. Perhaps his origin as the child of missionary parents in India has something to do with this concern. He came to the U. S. for his education, then was chemist in the Bureau of Science in Manila for a few years. From 1919 to 1946 he was chemical director of Bell Telephone Laboratories, and it was during this time that the efforts of scores of workers in many countries, representing nearly 40 years of effort and several hundred thousand dollars, finally came to fruition in the successful synthesis of vitamin B_1. On the occasion of his receiving the Willard Gibbs Medal in 1938, which was given him by the Chicago Section of the ACS for this synthesis, Dr. Williams spoke on "Science East and West." He stated that the deficiency disorders, a new chapter of medicine opened up by contact between the Orient and the Occident, "may some day be regarded as rivaling in importance the discovery of microorganisms as causative factors in disease." In 1946 Dr. Williams founded, with R. E. Waterman, the Fund for Combat of Dietary Diseases. As chairman of this fund he went to China and the Philippines to set up projects through local agencies for production and distribution of a nutritionally improved form of rice, in connection with a study of beriberi.

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leads in this regard but there has been progress in every country. The improvement in water supplies, principally by chlorination in the great cities of Asia is truly astonishing. As a youth I learned that drinking water must always be boiled in the Orient; now one has to resort to this only in backward and out-of-the-way places. Nearly all the great infectious plagues of the Orient are coming under control. That success does not come faster or more widely is due primarily to poverty of governments and lack of technically trained personnel.

Correction of malnutrition requires revolutionary changes in agriculture for the production of foods of greater diversity and higher protective value. Control of tuberculosis, leprosy, and malaria requires intensive application of difficult measures of sanitation among hundreds of millions of people. The East is at present just too poor and too ignorant to keep well. Hence, Asia still has a long way to go in public health and life expectancy.

Asia's Attitude Toward Western Science

Having recently returned from a tour of all the countries of the Far East which are now accessible, I can testify not only to Asia's need for modern science, but also to the recognition of that need by Asia's intellectual leaders. Everywhere I found my connection with science an open sesame to the utmost, cordial hospitality, especially of university people and public officials. The limits were set only by my digestive apparatus and the strength of my vocal cords. Often I was told "the people will be disappointed if you do not lecture two hours."

Asia's welcome to the West is by no means limited to science, though her interest now centers largely about what western science can do for the solution of her age-old problems. Western education, western religion, and western music and culture are welcome on their own merits. The residual values of past western contacts through the colonial system are still very much alive. In fact, at present, the Asian estimate of their worth is rising as the heats of nationalistic feelings subside. Asia now faces more frankly her practical economic and social problems whose existence can no longer be blamed on imperial politics. This is especially true in India, Thailand, Philippines, and Japan; it is less conspicious in Burma, Viet Nam, and Indonesia where the tides of violent nationalistic feeling have not yet ebbed so fully.

In passing, one may remark that in the present darkening conflict between Russia and the West there is only one thing upon which both sides are in approximate agreement, namely the value and worth of science as practically applied to the problems of human existence. No denunciation of America's social philosophy and practice is too vigorous to suit the official Russian temper but the Kremlin pays us the silent tribute of emulating our technology.

Japan

While the other countries of Asia will contribute to our theme largely by illustrating what science has yet to do, Japan furnishes potent examples of what science has already done in an Asian environment almost within the memory of persons now living. While India, in order to match imports with exports, is denying herself foreign goods which she needs, while the Filipinos are distressed over import control of luxury goods for which they have a strong taste, the Japanese are meeting the situation by making for themselves what other Asians must either import or do without. A bewildering variety of manufactured goods of Japanese origin is offered in every market in quite good quality and remarkably cheap. Only foods for which they lack land remain on their import lists.

Japanese technical skills are varied and many; her labor is adapted to meticulous training and accustomed to hard work. All materials both for wooden and reinforced concrete structures are made in Japan: cement, tile, brick, light steel, pipe, other plumbing, and hardware. Textiles and clothing of all sorts are abundant. A very great variety of pharmaceuticals in retail packages is offered in good quality and at prices often incomparably lower than they can be bought anywhere else in the world.

An excellent illustration of the technical resourcefulness of the Japanese is their use of charcoal burners to supply fuel for taxis, trucks, and other commercial vehicles. Water gas is generated by a flow of water, controlled by back pressure of reserve gas, to an incandescent bed of charcoal in a generator situated at the rear of the auto. The mechanism is well controlled and the reserve power of the engine is comparable to that of a gasoline-fueled one. How much better than the rigorous system of scanty gasoline rationing with which India has to be content!

Japan thus proves that it can be done. That Japan has achieved this result much more rapidly than any other Asiatic country is probably due primarily to the fact that she has had a continuous, unified, indigenous, and progressive government through the momentous first half of the 20th century.

India and China

In Asia, China and India present the largest masses of population demanding escape from their present miseries. China's problems are dominantly political now as they have been for 20 years or more. Having, rightly or wrongly, ceded the field to Communism we of the West can do little, indeed, know little, about China for the present.

India, however, is largely at peace and her major problems are social and economic. Politics can now only contribute secondarily to their solution or aggravation. Her economic problems are more acute than those of any other nation in Asia or of any other large nation on earth. Her large and growing population strains to the utmost the productivity of her land, a vast proportion of which is semiarid. The long-cultivated irrigable lands often approach exhaustion of their fertility through intensive cropping.

It is true that want and misery have been recently aggravated by riots and bloodshed and the consequent evacuation in each direction of millions of people from their homes across the borders of India and Pakistan. The maintenance at public expense of millions of refugees is indeed a vast economic burden for the already indigent taxpayers of both countries. Little progress is being made in the permanent resettlement of these unfortunates as the land is already crowded. Nor does the Indian government appear very efficient in dealing with the manifold problems of her vast populations.

The major solutions for India's problems are to be found in order of relative importance, approximately thus: more abundant, wider spread, and more reliable sources of water; better methods of agriculture including fertilizers, seed selection, diversification of crops, better tools for cultivation (not labor-saving but land-saving machinery); factory development to utilize the abundant supply of labor at tasks requiring little land but producing goods which will reduce or offset her large import requirements; electric power.

These solutions require above all things high-grade and well adapted technology. It is often impossible merely to transplant from the United States, for example, the technology of the West. There is need for an indigenous technology making use of the principles of science but carefully fitted to the local, social, and economic scene. Our American emphasis on labor saving is utterly inappropriate for India. "Make jobs," not "save manpower," is the slogan for India.

One neglected possible transplantation struck me. I could learn of no practical experimental trial of artificial rain-making in India. In South India when we were there, there had been four successive failures of the annual monsoon and nearly all irrigation tanks were dry, many of them for the first time in the his-

tory of their weather bureaus. Day after day clouds came up in the morning and often the sky was heavily overcast during much of the day. Yet no rain fell. Even an inch or two of widespread precipitation would have saved, at least partially, thousands of acres of crops. Rain making should be tried.

A second requirement, of course, is a vast amount of capital. Successful technology will call forth a considerable amount of Indian wealth, which at present tends to be stored in idleness; in jewels, land, and showy buildings. Much more capital must come from abroad. To invite this a more cordial attitude on the part of government is required. At present there is an undue fear of foreign domination by great investments.

Indian science strongly tends to be academic. Sir C. V. Raman's distinction as an Indian Nobel laureate has made theoretical physics the favorite choice of ambitious Indian scientists though this field has little relation to India's present needs. A number of India's leading chemists are devoting their energies to the solution of problems of chemical kinetics or structures, again little related to the Indian scene. Hence young Indian science graduates have great difficulty in finding jobs at any sort of scientific calling though there is a keen demand for men with practical technological experience.

Lesser Nations of Asia

The problems of Burma, Thailand, Malaya, Viet Nam, Philippines, and much of Indonesia are very different from those of India. The former have fairly abundant supplies of food. Only in Java is the problem of population pressure acute. Even there the shortage of land is less severe for the country is far better watered and more fertile than most of India's hills and plains.

In these less densely populated countries of Asia relatively low standards of living exist primarily because of under-development of resources. The remedy for this is more widely disseminated scientific learning adapted to the technological problems of local agriculture and related industry and more capital to put people to work at profitable tasks. Merely the facilities to supply electric power and light to the thousands of villages of these countries represent a tremendous future investment of capital and technical skill. Light to read by, incidentally, represents both an incalculable civilizing influence and almost a prerequisite to other technological advances.

All that these countries need for decades to come is peace, stable and honest government providing a steadily expanding dissemination of education, and a reasonably favorable opportunity for both domestic and foreign investment of funds in productive enterprise. Most of these countries are rather suspicious of foreign capital and laws are often unduly restrictive.

A stable and honest government is easy to say. It is by no means so easy to achieve. Certainly if Asian countries are to achieve it within the foreseeable future there will have to be considerable participation by experienced western administrators who will serve as advisers. This is by no means unthinkable. There is already a rising sentiment in Asia in favor of such a course. The old colonial system of foreign domination based as it was in great measure on the supposed superiority of a white skin is gone for good. The old colonial system, however, had some genuine virtues and these must be revived as nationalistic tensions decline.

Shortcomings of Science in the West

What makes science so unequal to the challenging tasks which the Orient presents in such conspicuous fashion? Or even coming closer home why is science so helpless to avert the threat of a third world war which may bring all civilization tumbling down about our ears? "Oh! that is not a shortcoming of science," I can hear someone declaim, "that is the fault of politics or economics or the plain cussedness of human nature." No, my fellow scientists. That is not the answer. That is just passing the buck. Surely all truth is a self-consistent whole and it is the business of science to find out the truth.

No Science of Human Relations

The fact is we have no science of human relations and few scientists are much concerned with discovering one. Natural scientists in general are very impatient with the controversial debates which characterize discussions of social problems so they withdraw into their laboratories and examine further the minutiae of their specialties. There they can appeal to experiment and settle something, however inconsequential, compared with the vast and cogent problems which face mankind.

Now it is perfectly true that the experimental method has in large measure created modern science. It is also unfortunately true that the experimental method can rarely be applied to human problems. One cannot isolate a segment of society effectively nor does law or custom permit the experimenter to prescribe a routine for his experimental human animals. Social reformers often talk about social experiments but we of the laboratory well recognize that such experiments are never adequately controlled nor of sufficient duration to give trustworthy results. Shall we therefore give up?

Observational Science

Any one who pauses to analyze the matter must realize that there are many sciences of a highly developed character which do not enjoy the advantage of the experimental method. For their advancement, we must depend on observation. Astronomy is an excellent example. We cannot turn the stars in their courses to ascertain how their neighbors will be affected. Yet we have learned a great deal about the laws which govern their courses by careful observation and calculation. No science can be said to be more highly organized. None can boast more accurate predictions. Yet it is a purely observational science.

Another important though less perfect example is geology. We cannot repeat at will the age-long processes by which the earth's crust has taken on its present form. Yet by intercomparisons of many careful observations, by critical analysis of the results, we have built up a knowledge of the earth's crust which certainly rates classification as a well-ordered science. So numerous and so independent are the observations and so good is the fit among them that we can put great faith in the validity of our conclusions. We have successfully built great industries upon them.

There are many other examples of sciences based on observation. Many of the branches of biology lie largely or wholly in that sphere. Observation has proved a valid and fruitful method of science when experiment is infeasible. Indeed observation often furnishes the basis of choice of experiments in the predominantly experimental sciences.

Evolution

One of the most profoundly influential ideas of modern science is that of the progressive development of life. It is almost entirely a product of observation rather than experiment, yet it has come to be universally accepted by all scientists. As the years have passed, the evidence amassed in support of it has mounted tremendously in volume and variety. The larger part of it has accumulated incident to the pursuit of other objectives and is not the result of a desire to prove the doctrine.

I say that the progressive development of life is accepted by all scientists and so it is at least in the sense that it gives them a satisfying account of the past. Beyond that, few physical scientists appear to believe in it except casually. They do not think of it as a continuum, a process which is still operating and which must in great measure determine the future of life on the planet. Further they appear commonly to think of it as primarily a matter of morphology, a process which has determined the shapes of

molds, mosses, and mollusks; of bacteria, bugs, and saber-toothed tigers; of apes, *Pithecanthropus erectus*, and Piltdown man. According to this view the progressive process of development stopped with the earliest *homo sapiens* and it has no practical bearing on his future.

We Do Not Believe in Continuing Evolution of Man

It may be profitable to examine the reasons for this lack of faith in the principle of gradual biological development as applied to present-day human affairs, for this principle is ignored by the great mass of educated people, both those who are scientifically trained and those who make no such pretensions.

One encounters active opposition to this idea among physical scientists who, absorbed in the extension and application of formal science to the intellectual and physical needs of man, have gained little perspective of our prehistoric past. Of all the inventions to date, the more numerous and important ones were cosmic and came before man. Before houses came birds' nests. How long did the birds and their progenitors study to make them? Before clothing came hair and feathers to conserve body warmth. Before either came the body's processes of generating heat and energy from food. Before autos came shanks' mares; before airplanes the flight of birds; before telephones the animal ear; before cameras the eye itself. Before any of these came the power to reproduce, a power which still defies our scientific understanding. While man is increasingly self-directing he has by no means yet escaped from the cosmic processes which made him what he is.

The Spirit of Man Is Also a Product of Evolution

Other opposition comes from the moralists who indignantly declare that man has freed himself from "the law of tooth and nail" as they call it. Well, "tooth and nail" were never prominent features of natural selection and "dog eat dog" is a myth. Few creatures ever eat their own kind. Species loyalty and mother love are almost as old as life. They form a part of the evidence that our moral and ethical concepts are also derived by evolutionary processes from our past experience.

The roots of altruism, akin to which are love, mercy, sympathy, and kindness, are found far down among the lesser creatures, who lived millions of years before the advent of man. Many an unthinking lowly creature will willingly die in defense of its young. Even little snakes may be seen to cuddle affectionately together intermingling their coils with those of the mother. Truly if nature teaches the fierce tiger to fight with a rival over a mate, it also teaches the value and usefulness of tenderness and solicitude.

Or consider the growth of social ideas. Joining of creatures in swarms, flocks, herds, and bands is as old as the hills. Many lower forms of life which antedated man by millions of years have social organizations far more thoroughgoing than any that man has ever practiced. To the honey bee the hive is God and country and home. The bee dies when it stings in defense of the hive. It can rarely withdraw its sting successfully.

The spiritual and social qualities of man were not originated by him *de novo*. They are derived from nature, or from God as you may prefer to put it. They came to man by inheritance because they had survival value. Our very religion and philosophy as well as our home fires, our patriotism, our economic system, and even our aspirations are in substantial part from our antecedents.

The History of Life Can Be Applied to Human Affairs

How foolish then to plan our political and economic life without regard to their consonance to the laws of biological evolution. Yet everybody does it. All men in public life assume that we are perfectly free to improvise any political or economic device that we think may work without inquiring whether it is consistent with the laws of nature. Indeed it would be thought laughable to raise such a question in the halls of Congress. Truly science has taken only a very superficial hold on popular thought even in the most advanced countries of the world.

The developmental process seems above all to explain our inherited love of liberty. It derives from the fundamental factor of individual variation in evolution. Each of us has an inner urge to be himself, to follow his own will and judgment in his own affairs. Without freedom to do so the merit of his ideas can never come to trial nor can they make their contribution to the future of the race. Stupendous progress has been made since the first tiny blob of jelly in some ancient mud grew in intelligence and man came to weigh the stars and measure their distances, to guess the source of the sun's heat, and reproduce atomic energy on our planet. Are we now wise enough to set a pattern for others whereby future progress shall be achieved? Is there any basis for believing that man has arrived at a stage where he can strike out for himself on some predetermined road? God tried millions of little experiments side by side. Can we dispense with them?

These questions are at the root of the world's most profound social conflicts today. Those conflicts are international, they are interracial, they are interclass, they are economic and cultural, and they involve political ideologies. I submit that life's history has something to tell us about these problems, if we will but seek it.

Group Segregation

Man has increasingly sought to solve his problems by segregation of people into groups and this process has been greatly accentuated in the 20th century. Increasingly the individual is subordinated to the group. Racial groups came about by natural processes, chiefly the effect of geographical barriers. Political groupings, prevailingly along racial or geographical boundaries, have long existed and been recognized as nations but only in historical times. Originally the purpose of governments was to control relations among the individuals of the group, but the idea of mobilizing one nation to enforce its will on another in war is of long standing historically. In spite of increasing intercommunication and transport which physically tends to unify nations, artificial barriers to unity have greatly increased. Restrictions on freedom of travel and trade are characteristic of our century. Nations are no longer primarily for self-government. They aim to become closed economic and cultural units. Through armaments they threaten one another. Domination of the individual, who is all-important in the light of life's history, by the national group which has little biological significance, grows ever more complete.

There is not space for further examples. I am merely raising the question whether science cannot help to make sense of the problems of human relations. I point to the history of life as a vast province of science which we have used very little, except to breed race horses, milk cows, and loganberries.

Scientific Progress Depends in Part Upon Mores

It will be agreed that we in the West can make little use of the principles of biological evolution in our current human affairs until we inculcate a knowledge and appreciation of those principles in the minds of our leaders. I can do no more at the moment than recommend that a systematic course in biology should be required of all college graduates, and (dare I say it?) particularly in law schools and theological seminaries.

Any thesis that artificial groupings of people into nations, corporations, or labor unions run counter to evolutionary principles will have little effect in the West until those principles take hold on our mores—on our daily life and thought. Our mores in turn are shaped in great measure by our religious traditions. It will be seen that I am referring to a change that can happen only in the relatively distant future.

In the Orient, mores even more rigorously determine what can be done for the application of science to the current crucial prob-

lems. For example, the Hindu's approach to his present problem of food supply is much affected by his veneration of the bovine species. There are 200 million cattle in India. A fifth of them, perhaps, are mendicant strays, a drain on the human food supply. The only direct contributions of cattle to India's food are milk and ghee, for beef is not eaten. Indian cattle are notoriously poor milkers, yet bettering the breeds is much inhibited by the Hindu's abhorrence of destroying unsuitable stock. Similarly, the much needed practice of birth control among humans encounters religious or, at least, traditional taboos. At the same time the thought of keeping populations in check by neglect of public health measures is as abhorrent to the Asian scientist as to us.

Science and Clear Thinking

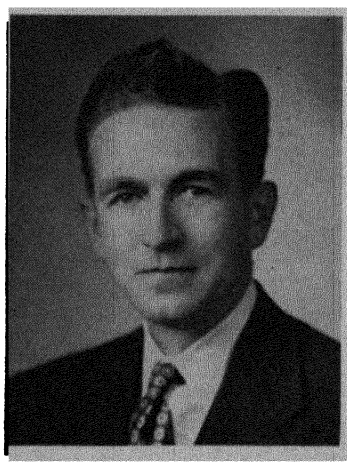
The influence of science on civilization affects all aspects of human endeavor. Science constantly tells us to re-examine our every past conclusion and prejudice in the light of all new evidence. Natural science is a steadily increasing body of knowledge concerning which there is no continuing debate. Social science remains a field of debate, yet the principle of critical re-examination can be and is being applied. The human mind, trained in science, East or West, acquires this critical bent which is communicated to other educated persons, thus gradually leavening society. This leaven is at bottom the outstanding contribution of science to civilization.

Science is not essentially and of necessity materialistic. Pure science contributes to the world of ideas by which philosophy, religion, and mores are ultimately swayed. The theory of biological evolution has had most profound scientific consequences; it has also deeply influenced religion in the modern world. Today I feel it is bringing the various religions together measurably.

Past contact between West and East has been in no small measure the result of religious missions as one can see from the predominance among present Asian leaders of those who have gained some part of their education in mission schools. More important than the numbers of adherents is the infusion of the ethical content of one religion into another. Witness the great decline of caste prejudice in India.

Asian scientists believe in science just as firmly as we do. Science, and particularly the concept of evolution, is thus furnishing a strong mutual bond among the religions. A scientist may well be a Christian, a Hindu, a Buddhist, Confucian, or free thinker. Leaders of all faiths in Asia, as in the West, are increasingly ready to interpret their ancient sacred writings in the light of modern science. Thus, in the present impasse between science and civilization, which takes on different forms in different parts of the world, we must count heavily upon science to influence popular thought and custom through its infusion into the organized religion of every land. It will not come in a year or a decade but there is progress in that direction.

Science and the Future



After only a few centuries of scientific method, this philosopher is wondering whether our western civilization has run out of fuel

VINCENT EDWARD SMITH, ***University of Notre Dame, Notre Dame, Ind.***

The giant strides of the physical sciences during the modern period have been made without the escort of a similar progress in ethics. Thinkers as varied in view as Russell, Toynbee, Dewey, and Maritain all agree in admitting this lag in the career of morals and in the urgent need to overcome it. Indeed, after only a few centuries of scientific method, men are wondering whether our western civilization has run out of fuel.

Some there are who would blame our difficulties on science itself and turn back the clock to whatever century their recluse life could comfortably inhabit. Many more feel that our cultural outlook, far from being too scientific, is not scientific enough. Awed perhaps by the feats of physics and chemistry, such thinkers want to stretch the method of these sciences into the much more mountainous terrain of ethics. Great stores of energy have been invested by recent philosophy in the project of reducing ethical values to what the physical scientist regards as laboratory fact.

Midway between these two extremes, the romanticism of the recluse and the demand for science *über alles*, there is a third view which respects the obvious achievements of scientific method in its proper sphere, yet admits an equally obvious and concentric sphere of other knowledge embracing science by giving it meaning and value. This more moderate position admits with Margenau a frontier beyond science; with the great master thinkers of the past, it holds that this meta-sensory region is in some way knowable to man's mind. In the area of ethics, this moderate view of science holds that the findings of the laboratory yield man tools for carving out his destiny but are silent about the nature of that destiny itself. While indifferent to science taken directly and alone, such apparently philosophical issues matter much to civilization; and if science depends on a civilized climate, they have an indirect but vital bearing on science. That is why, if for no other reason, even a theoretical scientist can no longer safely remain a mere scientist, Platonically aloof from all other concerns.

What, then, are the values that identify western civilization?

Vincent Edward Smith, a Thomistic philosopher who knows science, spent most of the decade beginning in 1934 studying in various universities—specifically, Xavier University, University of Fribourg, Switzerland, Institutum Divi Thomae, Catholic University of America, Harvard University, and Massachusetts Institute of Technology. His scientific field is physics, and during the interruption of World War II he was a U. S. Navy electronics officer and radar expert. He is now on the faculty of Notre Dame University, and is editor of the *New Scholasticism*, the quarterly journal of the American Catholic Philosophical Association.

And why is the scientific method unsuited to operate at the level where these values are touched? Putting this question in different form, why do we need thinking beyond science to keep our culture alive and alert?

Civilization vs. Civility

In 1772, Boswell tried to persuade Dr. Johnson to include the word *civilization* in his dictionary. Johnson refused, preferring instead the term *civility*. Since that time, usage has prevailed over Johnson's stubbornness, but the term *civilization* has held on to the overtones of Johnson's *civility*. To be civilized still means somehow to be civil, considerate, kind, or in Matthew Arnold's term, humanized. To be uncivilized is to be barbaric.

Civilization is related to society in the way that art stands to nature, where art includes any product of the intellect and will. Thus society is something natural, for man is naturally a social animal. A civilized society adds to nature the works of reason which, at the social level, become institutions. Yet a cautious approach must be made to such a general definition. If a society is to be civilized, its art must imitate and develop nature, not challenge it. If it contradicts nature, to that extent it is poor art and bad civilization. In fact, it is a lack of civilization.

For example, Nazi concentration camps and Soviet torture methods have shocked western minds as outrages against civilization. Standing before the Nuremberg tribunal, the Nazi leaders were charged with "crimes against humanity," i.e., crimes against the unwritten laws of human nature. The Nazis had institutions, a government, educational machinery—all works of intelligence and will. But such arts ran counter to nature, even to the point of being called criminal by civilized men.

Apart from the technical apparatus of the various historical sciences, *civilization*, as the term is generally used, has preserved the meaning of Johnson's civility. Good plumbing, supersonic aircraft, and rural electrification, valuable as they are, do not comprise civilization, and neither does modern science. As shown by Nazi Germany and by Soviet Russia, a criminal government in command of scientific knowledge may wield its science to promote its barbarism. Societies are civilized where their political, social, and economic institutions are arts imitating nature and developing man's humanity to man. According as they approach that ideal, civilizations may be regarded as better or worse since there is good and bad in perhaps all of them. Thus, the Egyptians, the Greeks, and the Romans ascended to lofty summits of civilized life. They had forms of religion, theoretically sound knowledges, engineering feats, and, in the case of the Romans, a remarkable legal system. They thought things, they willed things, they did things that even today, as their heirs, we cherish among the prizes of man's mind. But high as their civilizations were, they were not high enough. There were slavery, tyranny, and polytheism, all of which had serious dehumanizing consequences in life. Western civilization, as we know it, slowly and painfully emerged from a Europe that was barbarian.

There are three truths that are the bedrock of our western culture: the existence of a personal God, the dignity of the individual man, and the destiny of man as unfulfilled by his present mode of existence. There was never an age when these truths were perfectly realized in human society, and in this sense, their concrete applications to life remain ideals. Yet in proportion as society has struggled to put them into practice, the social framework that we call our civilization gradually evolved from a hitherto barbarian society. It became the greatest civilization in recorded history.

Philosophical reason lays claim to establish these three verities on which our civilization reposes, and it is tempting to spread out the proofs here for careful examination. Such a task, however, bulks too large for present purposes, and besides, the issue here being raised is not the philosopher's approach to God's existence and to man's nature but the relation of these facts to civilization. Let us suppose that the three truths that undergird our civilization should be generally repudiated by man. What would the consequences be if those denials were logically carried out?

Without belief in a personal God, human brotherhood would disappear; each man, unmade by a purposeful God, could then claim an absolute status for himself, where he makes and breaks his own laws and designs his way of life according to his own whim. Obligation would cease; obedience would be meaningless. Man would be the man-god of Feuerbach and Nietzsche.

Without regard for man's intrinsic dignity, there is no basis for human right. All right, all privilege would be extrinsic to man as man; it would come perhaps from the state or party or labor union or business connection and could be snatched away at the pleasure of this outside agency. The person would no longer be sacred. More sacred, more privileged would be this exterior thing that conferred the right. Put more positively, man has rights because he has certain prior duties like that of following his conscience, and duty is meaningless unless man is a created person, responsible to a personal God outside of him.

Finally, without reference to an after-life, civilization must eventually collapse. If this life is all there is to man, there is no compelling motive for obeying law except when the police are standing by, and even then, should times grow very bad, a merely biological man could end his life by suicide. It is the awareness of an after-life that deters men from perjury and perhaps even treason. It tends to make public officials loyal and self-sacrificing.

These arguments are not intended to propose panaceas that would automatically underwrite society in its struggle against inside agents trying to subvert it. The argument is simply that the three truths here stated endow a society with certain general tendencies that make for order and peace and civility. And to the extent that such truths are not taken normally into account by a society, the police force, watchdog committees, and loyalty boards must increase and multiply until civilization loses its vitality from below and is shaped almost wholly by enforcement agencies acting from above. In the absence of any of the three basic truths and values mentioned above, western civilization is fated to failure. Every great culture in the past, to borrow the data of Toynbee, has attained greatness in proportion as these values have been more or less implicit in its social structure and has failed to the extent they have been absent or rejected.

Philosophy Is the Foundation

Yet political and social principles are not politics and are not society. Philosophy is not civilization but only the foundation. To confuse philosophy and civilization has been the perennial failure of Oriental culture, from India all the way to Byzantium. Like man himself whom culture imitates—as art patterns itself upon nature—civilization has both a material and a spiritual dimension. The three values outlined above inspire civilization with a soul. Something else provides the body.

Civilization, a hybrid of matter and spirit, may be regarded as the sum-total of the political, economic, and social institutions in a society, good to the extent that such institutions conform to human nature and bad to the degree that they do not. There is still in this definition the initial charge of civility, as Johnson preferred to use the word. For civility is a social virtue, requiring means to express itself, requiring a political, social, and economic framework within which a human life, on both an individual and social level, may be humanly led. Civility demands a public world, formed by traditions and customs and laws and material instruments, even as man is both personal and social, a little microcosm that is a part of a social cosmos.

Angling to the same point from another direction, man is the only animal capable of civilization because he alone in the visible universe has reason and hands. By reason he thinks and wills. By hands he creates in the practical arts. By reason man advances in knowledge, forms moral habits, designs his style of government, and blueprints his social order. By his hands, he makes things from victory gardens to skyscrapers.

Between the hands and the reason, there is a close kinship. Reason generalizes, as in philosophy and the sciences; unlike the senses, it is not shackled to the grasp of singular things alone, like this tree, that electron, or the sidewalk on Main Street. Reason reaches out to frame universal laws that embody something about all trees or all electrons. The hands likewise are general in operation. An animal, limited by its sense knowledge, is limited also in action, operating in the same limited and rutlike way whenever it builds things like beaver's dams or bird's nests. But human hands, like human reason, are general and free. There is a constant variation in their products and a constant betterment in their use. As man is the creature of two worlds, the material and the spiritual, so his civilization bears the two-fold imprint of his reason and his hands. In fact, civilization may even be defined as that which society has done, by human reason and human hands, in the imitation of nature. Oddly enough, the handshake, after an interesting history, has become the sign of civility between men.

This discussion has now arrived at a major intersection of science and civilization. The theoretical advances of the physicist and chemist have spread out a rich field for the engineer to harvest, and engineering progress, as our century exemplifies so well, eases life's drudgery and frees man from material cares. President Conant of Harvard has argued that theoretical science and the practical arts differ by their "degree of empiricism." Perhaps the greatest single achievement of American philosophy has been the pragmatism of James and Dewey, which has its genuine field of application in the scientific method and in the practical arts. Providing material means for the channeling of man's spiritual energies, the physical sciences can contribute vast resources to civilization as they have already begun to do.

Just as man, contrary to Marx and even to Dewey, is first a thinker and only afterwards a man of action and experiment, the physical sciences have made a similar late entrance into civilization as a whole. They do not comprise civilization, and neither do the things they produce. They are the effect of civilization, not the cause. To cite only a simple argument in these days of specialized projects and research pools, the peaceful interchange

Predictions

On this occasion it seems proper to the editors of C&EN to peer into the future. To do this they have collected from various individuals a sampling of what future observers of ACS anniversaries may find commonplace.

Raw Materials . . .

The oil crisis will have been avoided by using coal, lignite, oil shale, bituminous sands. Iron ore will come from iron oxide from taconite and from Quebec and Venezuela deposits.—*Harry N. Holmes*, Oberlin College

Prophets of doom will continue to predict depletion of oil reserves at five-year intervals. Production of liquid hydrocarbons will be 8 billion barrels . . . . natural gas 30 trillion cubic feet.—*Gustav Egloff*, Universal Oil Products Co.

Iron obtained from earth's core will require no furnace treatment. Atomic bombardment will yield stainless steels of any desired composition and nickel, cobalt, vanadium, chromium. Chemists will transmute silicon of aluminum-bearing clays to obtain aluminum oxide, directly reducible to metallic aluminum, while different bombardments will convert aluminosilicates to phosphorus and potassium feldspar directly to potassium phosphate fertilizer.—*John C. Bailar*, University of Illinois

The sea will yield potable water and increased amounts of magnesium, salt, bromine.—*R. Norris Shreve*, Purdue University

Photosynthetic processes will be used to make basic chemicals we now get from coal and petroleum.—*C. C. Furnas*, Cornell Aeronautical Laboratory, Inc.

New Compounds . . .

Fluorocarbon chemistry will be an independent domain of chemistry. Elements 99 and 100, the latter called "centium," will have been synthesized. Transcentium elements will give new types of disintegration. Pure alpha emitters will result in practical application of atomic energy to everyday appliances.—*A. V. Grosse*, Research Institute of Temple University

Hydronitrogens, oxides of chlorine and fluorine, superoxides, concentrated hydrogen peroxide will be important. Ion exchange will assure ample supplies of elements now considered rare. Manganese and chromium will be available in the +1 and +5 oxidation states, copper in +3 and nickel in +3, +4, +5. Properly stabilized by coordination, they will be used in voltaic cells, electroplating, pigments.—*John C. Bailar*, University of Illinois

Carbon will have been polymerized to give diamonds and the other carbon lattices filling the gap between diamond and graphite will be known.—*H. Mark*, Polytechnic Institute of Brooklyn

Foods . . .

Economic synthesis of food stuffs from carbon dioxide, water, ammonia with help of solar energy . . . .—*A. V. Grosse*, Research Institute of Temple University

Proteins and fats from algae, such as chorella, will be an established industry. Cellulose from sawdust will enable us to produce more beef than is possible from farm acreage alone. Knowledge of plant growth will be great, but complete success in test tube photosynthesis lies beyond 2026.—*Harry N. Holmes*, Oberlin College

Synthetic foods will be made but not replace the natural ones. Biochemists will have succeeded in synthesizing pure living matter but not any really sophisticated organisms.—*C. C. Furnas*, Cornell Aeronautical Lab., Inc.

Additional fertilizers will force arable land to yield more and better food. Salt marshes will be farmed with chemical feeding of salt resistant plants.—*R. Norris Shreve*, Purdue University

Seeds will be exposed to cosmic bombardment, resulting in varieties of plants tailored to need through mutation speed-up.—*Harold Vagtborg*, Southwest Research Institute

The farm chemurgic movement will expand and the study of better production methods to cheapen costs and put industrial farming on an economic basis will be of supreme importance.—*Frank J. Curtis*, National Production Authority

of ideas and a swift flow of information—hence a civilized society—are essential to the forward march of the sciences. Science is not a synonym for civilization. It can make men more powerful, but it cannot make them more civilized.

The physical and biological sciences have teamed up to multiply the material means at the command of the truly civilizing forces of the western world. Yet unfortunately while the sciences were gaining ground, morality was losing it. The moral lag, singled out by contemporary philosophers, forms a crucial gap in the battle lines of civilization as the 20th century enters its decisive half. Have the sciences proved too big for us? Has the tapping of atomic energy staggered man to a point where he cannot safely absorb this new Promethean power which his genius has wrested from nature?

The past provides a tradition of rich intellectual achievement and spiritual triumphs; the modern period has witnessed startling progress in exploring and exploiting matter. If the spiritual vitality of western man can be recovered in time and allowed to inspire his new material resources, like the soul animating the body, the golden age of civilization can be swung open. A great danger in the present is to focus upon man the scientific lights that can illuminate only the material world. In great measure, industry and science have cross-fertilized one another today to give man opportunities in the material world that he could hardly dream before. The end result has been a distraction from the spiritual energies on which our civilization rests and, in so many cases, the invoking of science to do away with the older intellectual and moral principles rather than to serve them. Science has often been enthroned by its present-day enthusiasts as the integrating and civilizing force of our society. Science thus becomes not part of the body of civilization but its very soul, its very essence.

The Birthmarks of Science

Scientific method is distinguished by the two birthmarks it had in the 17th century: (a) It experiments, and (b) it measures. There is, of course, a theoretical overhead in science, what Conant has called "conceptual schemes" and what Mar-

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Direct feeding of plants by spraying nutrients on leaves will lower costs and increase yields. Tailor-made crops will dominate genetic research. Sterilization by radiation will compete with dehydration and refrigeration.—*Charles Glen King*, The Nutrition Foundation, Inc.

Man and Health . . .

Blood transfusion will not be an emergency treatment but a way of replacing normal blood proteins with macromolecules completely resistant to micro-organisms and carrying prosthetic groups to destroy detrimental factors. Drugs will be selectively soluble macromolecules which carry the active principle to the proper spot in the system. —*H. Mark*, Polytechnic Institute of Brooklyn

Bacteria and viruses will not be important causes of mortality . . . . Complex chemistry of the degenerative diseases such as cancer, arteriosclerosis, arthritis will be unraveled.—*H. B. Hass*, General Aniline & Film Corp.

. . . . cures or preventives available for infantile paralysis, mental illnesses, allergies, the common cold . . . —*John C. Bailar*, University of Illinois

Tools of Living . . .

Vehicles will be of weight-saving plastic-metal combinations. Housing will make substantial use of synthetics—all piping will be plastic; most roofing and siding will be coated fabrics . . . . . universal two-way wireless between all homes with optional television, also wireless electrical appliances.—*H. Mark*, Polytechnic Institute of Brooklyn

Not only making rain but preventing it will be established practice.—*Gustavus J. Esselen*, U. S. Testing Co., Inc.

Uranium, plutonium, and new elements will be sources of packaged energy for heating and refrigeration.—*R. Norris Shreve*, Purdue University

Interplanetary Travel . . .

First rocket to the moon will have been unmanned but easily observed as it struck the moon by the flash of magnesium in its head. Atomic energy will be one source of rocket power but liquid hydrogen-liquid fluorine will be a close competitor.—*A. V. Grosse*, Research Institute of Temple University

At least one man will have circumnavigated the moon and returned safely.—*C. C. Furnas*, Cornell Aeronautical Lab., Inc.

Sociology . . .

. . . . a new social order—at the top chemists, engineers, composers, authors, others of inventive genius; next, those producing with their hands—farmers, mechanics—followed closely by clerks, policemen, firemen, transportation, and communication workers.—*Otto Eisenschiml*, Scientific Oil Compounding Co.

We will have established comfortable living in areas not hitherto considered—Canada, Alaska, Brazil—with man-made climate (in buildings) and chemotherapy for disease control.—*Frank J. Curtis*, National Production Authority

We will have gained enormously in insight into what makes humans tick.—*Roger J. Williams*, University of Texas.

Knowledge . . .

Though many of the present vacant spaces will have been filled out in the knowledge puzzle, a greater number of new spaces will exist. The mass of accumulated knowledge will require more workers to keep the reference wheels rolling, even with mechanical methods of recording and literature search.—*Wallace R. Brode*, National Bureau of Standards

Growth of catalytic chemistry will be comparable to that of physical chemistry and will be recognized as an independent branch, with catalytic chemistry handbooks more voluminous than Beilstein or Gmelin.—*A. V. Grosse*, Research Institute of Temple University

Chemistry will extend its principles into all physical sciences to the point of affecting psychology, psychiatry, sociology, and religion. While branching of science into new areas will continue, we will have increased interest in integration of isolated facts into more comprehensive and useful pictures of natural phenomena.—*Jerome Alexander*, Consulting Chemist and Chemical Engineer

Subatomic physics will be in a state of as great confusion as it is now—this goes for 1976; anything can happen in 1977.—*Anthony Standen*, Author

genau terms "constructs." But theory, as Planck and Dirac insist, is subordinate to experiment and must be judged on pragmatic grounds. Theory is geared to foster experiment, suggest its form, and predict its measurable outcome. Experiment and measurement remain the warp and woof of the scientific method from Galileo and Boyle and Harvey down to present-day researchers.

Experiment is marked off from common experience by the fact that it is controlled. It reveals nature only as disturbed and isolated through the deliberate interference of the experimenter. For example, to be studied scientifically, electrons must be isolated from atoms and then maneuvered under the calibrated control of a laboratory instrument. Millikan's measurement of the charge of the electron is typical of scientific method.

It is only to the extent that a thing can be controlled and isolated that a physicist, chemist, or even a biologist can bring it within the grasp of a rigidly scientific procedure; and to get at reality not as it is but only as controlled, not in its whole form but only in selective isolation—such restrictions lay serious limits on the kind of things that the scientific method can study. Like civilization with respect to society, experiment is artificial and not natural as the full, uncontrolled, and quasi-total contact with the real that we call common experience. Experiment, to use a phrase of Kant that was later repeated by William James, yields knowledge only of what man can make.

Could Method of Control Reveal God?

Cutting through to the heart of the present discussion of civilization, what knowledge of God could the method of control make available to man? God is an infinite being without potency and without imperfection. The effort to know him by human control would presuppose potencies in his nature. It would require that the Master of the universe become the servant at the control of man, and so the very conditions of experimenting God would put God in man's place and man in God's. This is not to belittle science in its proper field—far from it! The contention here runs simply that the scientific method is structurally unable to answer the question of whether there is or is not a Supreme Being. Knowing only what man can control, scientific method can never grasp what man must obey.

In probing the intrinsic dignity of man, the scientific method fares no better. To admit that man is controllable from the outside is to admit that he is not free because liberty is the power to be controlled by one's self alone. What is intrinsic can never be isolated and studied as though it were an object in a public laboratory world. To the extent that each man has something intrinsically and uniquely worth while, every individual is unrepeatable, and what can happen only once cannot be a matter of experiment. There is no controllable line in man, separating him into what is dignified and what is not. Objects can be experimented; persons cannot.

Finally, the spiritual soul of man can neither be isolated nor controlled. Everywhere present in the body, it cannot be isolated. Not composed of parts and hence not decomposable, it cannot be controlled. If man understands only what he makes, he closes all inquiry about his soul. To know it he would have to make it, and to make it, he would be God.

In summary, the scientist, whether in physical, chemical, or social dress, can grasp only the controllable aspects of the real that can be reshaped according to man's image and likeness. The keynote of scientific method is command, not obedience; control, not submission. In its proper place, such a method must be pushed as far as it can. But if it has no lower limits, it has definite upper limits beyond which lies philosophy, the study of those truths and principles that man must obey. Without such verities and values, commanding our obedience and forcing our consciences even when unpoliced, western culture would long ago have been borne away to the graveyard with the grandeur that was Greece and the glory that was Rome.

Measurement also falls forever short of knowledge about the ultimate values which sustain our civilization. Mathematics works only on data that are quantified, and where number and figure cannot be introduced, the mathematical method has no right to speak about reality. How could one measure such things as dignity, the existence of God, the simple and hence unquantified character of the human soul? In measurement, we equate. But nothing can be equated to God, nothing extrinsic can be equated to what is intrinsically man's own, nothing in the whole universe can be compared to a human soul.

As in the case of control, measurement trims the universe down to human size. All of our standards—in weight, time, and distance—are known first through the senses, and scales are made by reference to some sense experience. For instance, by our sense of effort we are aware of the nature of weight, and we build a scale from units that are in the last analysis approximations of our original sense experience. This reference to the common macroscopic world holds even in the case of instruments like the mass spectrograph.

Time we compute by standards known through common sense. Even a microsecond is known as part of a second, as a second is established eventually in terms of the larger unit called the day; and light-years would mean nothing if there were not the ordinary years of man's experience.

In science, the world is measured by reference to the human body. Just as in control we grasp things by making them, so in measurement we tailor them to suit our senses. In both cases, we reduce the universe to the image and likeness of man.

It might be objected, of course, that measurement is not interested in its units but in their interrelation; just as oxygen and hydrogen can be measured in pounds, so they can be measured in grams: what is scientifically important is the ratio of their weights, what the physicist now calls mass units. Yet without a prior knowledge of weight, the question of ratios of weight would never arise. Eventually, the measures of science are calibrated by our sense experience, and the further work of the scientist is to relate such man-made measures to each other. Once more, let it be said that such a method is nothing but commendable at its own level, but it cannot tell us about the values and principles larger than man and requiring his obedience.

If the above analysis is correct, then the method of the physical sciences, and the social sciences that imitate this method on a different subject matter, turns up with much more anthropomorphism than some scientists are inclined to admit. Physicists, the purest practitioners of the scientific method, recognize this fact. Quantum mechanics pretends no longer to predict the various states of a system, but our knowledge of those states. Relativity mechanics, apart from its formalism, forbids us to speak about content except by reference to a local coordinate system, eventually that of an observer.

The method of modern science cannot rescue civilization from its present moral crisis. Something else is needed. The general disrespect for law on both a national and international scale is a challenge to the 20th century, but it cannot be met by the scientific method. Law, if it is anything, is certainly something that must be obeyed, and yet only those aspects of the real can be understood in the scientific method which admit of human command and control.

Scientists Have Their Say in Public Affairs

Shortly after the atom bomb fell on Hiroshima, several scientists of the Manhattan Project publicly announced that they had a right to discuss the application of this tool that their geniuses had created. The argument ran that since they had made the bomb they had a right to preside over its use. However, in their title as scientists, they understand only what man can make; the laws man cannot make but must obediently observe, the laws of human nature defended in the charter of the Nuremberg proceedings, these cannot be grasped, explained, or applied

through the scientific method. As men, the scientists in question had as much right (but no more) to discuss the bomb as anyone else with experience and education. But should they cease to speak as scientists, and speak as moral philosophers?

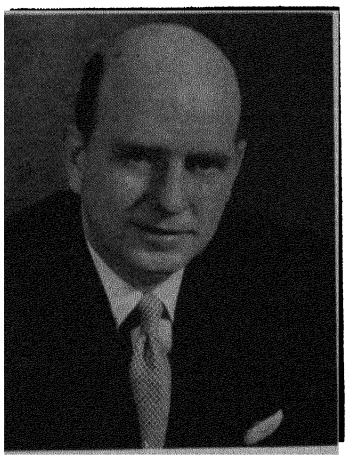
What then is the relation among science, civilization, and the future of man? Science is a good servant of man's humanity but a bad master of it. Our western civilization is deeply dyed by the spiritual energies that come from recognizing a personal God, man's intrinsic and inalienable dignity, and the fact of life after death. Such truths science did not establish, and it is powerless now to confirm or deny them.

If there is no other way of establishing these three truths, then civilization rests shakily upon human whim, and there is no rational basis to act civilly or not except because of (a) a police force, or (b) sentimentality. Given, on the other hand, the spiritual vitality that comes from meta-scientific springs, modern science can continue to lavish upon man material opportunities that no other age has known. No other period ever had more means for being civil, more channels for the spirit of man to express itself, more tools to make material life more human.

Yet the moral discrepancy detected by Russell, Toynbee, Dewey, Maritain, and many others yawns aggressively before us. If it is corrected by a recovery of reason's rule in social and individual life, the future of both science and civilization stretches out brightly beyond the present gray horizon. But if it is not corrected, then the material means which science makes available to civilization will stand alone. The material component of civilization will not be living but dead—a body without a soul.

Nature is what man finds in the world, and art is what he does in imitating nature through the products of his intellect and will. He knows nature through the natural causeways of full experience and knows his own nature in a similar way. The problem of a philosophy, faithful to experience and tracing out the lines of causality that it finds there, is to supplement the sciences by the fuller and pre-experimental grasp of nature that the arts of control and measurement can never attain. The problem of civilization is to keep its social, political, and economic institutions patterned upon the nature of man, a free and intelligent creature.

The problems here involve only one equation, not two. The scientist, as a man, needs today the awareness of the nature that his art can never grasp, uncontrolled, unisolated, unmeasured, hence naturally; and civilization must make reference to the human nature that its political, economic, and social arts should develop. Where nature is respected by art as in a mind open to both philosophy and science and where the arts of civilization are ever in accord with the nature of man, society and science can unite their energies for the betterment of each. Art and nature can then be at peace, and so can civilization.



Science and Industry

Our modern industrial achievement is based largely on the satisfactory interaction between basic science and industry

CHARLES ALLEN THOMAS, ***Monsanto Chemical Co., St. Louis, Mo.***

HIGH up on the main rotunda of the Museum of Science and Industry in Chicago there is a legend that epitomizes a relationship which has helped this country become one of the most prosperous and powerful in the world:

Science discerns the laws of nature, industry applies them to the needs of man.

How well this team has functioned the visitor can see in the hundreds of marvelous exhibits stretching out on all sides. In manufacturing, agriculture, transportation, medicine, and mining, the cumulative and accelerating impact of science has brought about greater productivity, improved quality and performance, and greater abundance.

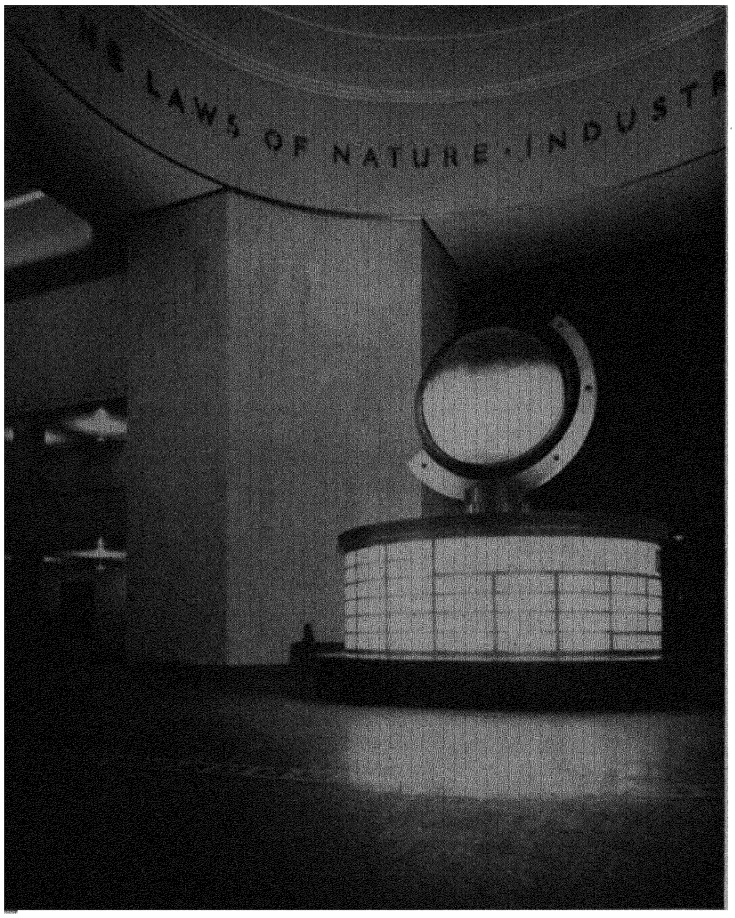
The visitor can glimpse industries, such as the electronics, chemical, automotive, plastics, and aircraft which, with their auxiliary industries, did not exist 50 years ago, and which are primarily the products of science. He can learn about the physical sciences, and their great figures, which have individually and together contributed to the welter of technological progress: physics, chemistry, biology, metallurgy, biochemistry, and others.

And as he steps out of the museum the visitor looks with renewed appreciation at the magnificent skyline of the city on Lake Michigan which a few years ago was a cluster of wooden buildings in a frontier swamp. If he allows his vision to expand, it will take in the whole teeming country which 175 years ago was a newly independent agrarian nation on the fringe of a wilderness. He will have a keener understanding of the triumphs of applied science.

But if we are to maintain undiminished and further strengthen, as we must, our present record-breaking industrial activity, we must stimulate to greater heights the creativeness of fundamental science, particularly in the universities where traditionally the bulk of such work has been done.

It may seem to some observers that the applied sciences which have been nurtured by pure science have not been very grateful offspring. The implication is that the only way they can repay their debt is with financial support. The idea is that the real push for basic science lies in universities, that they need and deserve financial assistance, and industry should use some of its earnings for this purpose. Often we have heard that this is the least industry can do, as its applied science laboratories are so dependent for the long pull upon the results of the university type of research. It is undoubtedly true, and indeed proper, that industry should contribute dollars for basic research, but at the same time it is little recognized that industry, through its own applied science, is giving a tremendous impetus to pure science. Applied science is repaying its debt to pure science in unexpected ways.

As a result of the incredible outpouring of devices, processes, and services which have come from the teaming of science and industry, science has achieved a never-dreamed-of status. News-



papers, magazines, radio, and movies report and dramatize every achievement of the scientists. In short, science has permeated our society. It has prestige. Most Americans would agree with Bertrand Russell when he said, "Almost everything that distinguishes the modern world from earlier centuries is due to science."

As a result, science has become attractive as a vocation. The spectacular applications of science which have come from industrial research laboratories have been a factor in attracting boys and girls of high school age to take up science as a career. The schools, at all levels, have responded with courses to fill the demand. Harvard, for example, which in 1825 taught a single course in chemistry, now teaches 27, ranging from elementary chemistry to radiochemistry. True, most of those who choose science do so from a purely "bread and butter" motive. About half of them go into industrial laboratories. But many of them, with the greatest curiosity and passion for fundamental understanding, remain in universities to conduct pure research and to teach. Thus, the ranks of scientists, who explore the unknown for its own sake, present a far different picture from the thin line of enthusiastic investigators of former days who depended on other means to earn their living. Not only has it become possible for scientists in larger numbers to earn a livelihood at basic research, but many more individuals are entering upon the training necessary for a scientific career.

Although there is and will continue to be a shortage of scientists, certainly without the interest in science stimulated by the widespread appreciation of applied science, the shortage would be more acute. It seems clear that as the reservoir of scientific talent attracted by the successes of applied science becomes larger, the probability of accumulating and drawing off top scientific brainpower increases to a new order of magnitude. It is at this point that applied science is making an important and almost unrecognized contribution to pure science, for in the last analysis, the fruitfulness or barrenness of our basic research efforts depends on the quantity and quality of men engaged in it. But applied science has had an even deeper impact on pure science.

In a giant see-saw pivoting on a fulcrum about the turn of the century, the positions of pure science and applied science have been reversed. Prior to the 20th century the main driving force for scientific work of all kinds was the so-called pure scientist, working on his own initiative because of his insatiable curiosity about the nature of things. But as inventors took what the pure scientists had learned and built modern technology, the impetus for the nation's over-all scientific effort shifted from pure science to applied science. At first very subtly, unwittingly, and in isolated instances, fundamental science prompted ancient industries and practical arts to revise their way of doing things and helped them to solve problems. As the utilitarian aspects of the pure scientists' principles were realized and put into use, infant industries grew and new ones were created. Then, during the last several decades, the accumulated weight of pure scientific knowledge diminished relative to the incredibly proliferated industries, and industry generated a curiosity and enthusiasm of its own. The stimulated became the stimulator. Driven by its own and society's demand, it reached for more and newer knowledge and led the pure scientists into new areas of unexplored phenomena.

This beckoning of science by industry had early beginnings. Lavoisier, for instance, was led to his classic studies in combustion by a problem in street lighting confronting the city of Paris. Pasteur opened the field of microbiology out of a concern for the grapevines of his native France. In our own country, I believe it can be said, new impetus to investigate the important field of high polymers came from the success in the market place of synthetic fibers, plastics, and rubber. The number and concreteness of such challenges to science have multiplied geometrically with the success of applied science.

The Newtons and Einsteins, together with the Edisons and the Steinmetzes, seem to have established a cyclical basic-applied science reaction in which basic and applied science both sustain and are sustained by one another in an endless and fruitful spiral.

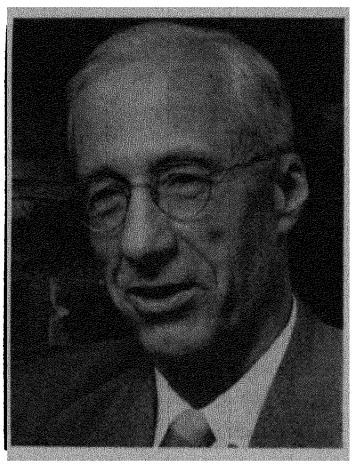
If the life story of Charles Allen Thomas, president of Monsanto Chemical Co., Chairman of the ACS Board of Directors, and a Past President of the ACS, could somehow be portrayed in a picture rather than in words, the artist would have to map out the high points on a grand scale, in order to get all the details in and keep them in proper proportion. His recent accession to the presidency of one of the largest chemical companies in the world was the next logical step in a long procession of tasks important in the world of chemistry and industry which he has been accomplishing in the past 40 years. To begin with, his passion for chemistry appeared at 10 with his experimentation in a makeshift laboratory on his father's farm in Kentucky. In the good old American tradition he worked his way, partially, through college, and by 1923 had degrees from Transylvania College and MIT tucked under his belt. When next we hear of him he is at General Motors and has developed a method for extracting bromine from sea water. His work made it possible to use tetraethyllead in gasoline without damage to the engine. A clue to the stature of his character is given in the fact that when General Motors moved its laboratories away from Dayton, he chose to branch out for himself with a private consulting laboratory with Carroll A. Hochwalt. His intuitive judgment and unorthodox approach often led to the solution of knotty problems and he soon established a highly respected reputation. His laboratories merged with Monsanto in 1936, becoming its central research department. There is not space to tell of the many contributions he has made to chemistry and industry, but an endless procession of them automatically follows from his well-known credo of industrial research: "The chemical industry can best serve mankind through a fusion of fundamental and applied research, implemented by the cooperation, understanding, and mutual respect of all scientists everywhere."

The one drives the other as both reach new heights. An outstanding example today is the development of research in the biochemical field. The achievements in the antibiotics field have raised new hopes that if we can learn more about the chemistry of the human body—in its most fundamental sense—then we may all expect as time goes on to have less sickness and to live longer and more comfortably. The result is that more people are working in the field, more students are coming along, more real scientists may be expected to appear, more basic knowledge will be gained, and industry may be counted upon to apply this knowledge as fast as it can. The basic-applied science cycle seems to be gaining in momentum. New horizons are being opened up daily. New ideas and new enthusiasms for basic research are created. As the stream of pure science is applied to the benefit of man it generates a social acceptance and demand for science out of which come the men, the money, and the challenges which replenish the wellsprings from which it flows.

Although the number of scientists tied up in this basic-applied science cycle are many more than ever before, the major braking action is manpower. This braking action is becoming more obvious every day as it becomes more difficult to recruit able scientists. There simply are not enough of them. The catalytic effect of public demand for application is pushing the cyclical reaction much faster than the number of bodies will permit.

So, although it is perfectly true that industry owes a debt to basic science, it is also true that industrial application is giving basic science a large push through attracting men into the field and in the staking out of new fields of inquiry. It is necessary to the well-being, even survival, of our nation that this interaction continue. For the marvelously complex industrial economy of which we share the benefits is not an automatic, super-electronic national Automat which will, in one way or another, inevitably produce the things we want and need. It must be carefully tended and manned.

Chemistry and Education



Conflicts between science and educational theory will be successfully resolved if the preservation of a free and civilized people is kept as the goal of both

J. H. HILDEBRAND, ***University of California, Berkeley, Calif.***

EVERY teacher of chemistry is aware of the vigorous reaction going on between chemical science and educational theories and practices. The *Journal of Chemical Education* is full of it. The program of the ACS Division of Chemical Education at this meeting includes a symposium on "Subject Matter *vs.* the Student." Books and journal articles carry arguments about "subject education" *vs.* "general education"; professional *vs.* nonprofessional courses; ideal courses and curricula for every type of student. One institution offers a single course in freshman chemistry, another offers separate courses for students in agriculture, chemistry, engineering, and medicine. A committee of the Society tries to construct standard tests to measure the degree of progress towards defined "objectives," undeterred by the fact that chemistry has more infinite variety than a Cleopatra.

It is good for education that chemistry is a subject so living and changing, and, at the same time, so fundamental and important as to furnish a testing ground for conflicting educational theories. It would be difficult, I should think, to be at once good and original in the teaching of Latin, for Latin is static—not much can happen to it from now on; but chemistry is racing ahead like a prairie fire, and its teachers and students cannot see much of it if they sit still. And even if they run at their top speed, they can see only a little of the advancing front. How does one deal with such a subject? Of course, politics, international relations, life itself, are also swiftly moving, like chemistry, so perhaps the reaction between chemistry and education may seem significant even to laymen. I have been in the thick of it for half a century and have contemplated it as a teacher, as a dean of a liberal arts college, and as a dean of a college of chemistry.

In what follows, I am going to stand up for chemistry and for my principles for teaching it. In my Remsen Memorial Lecture, under the title, "A Philosophy of Teaching," (*J. Chem. Education*, 26, 450, 1949) I set forth the fruits of my experiences and reflections, together with my ideal of "presenting chemistry to students in such a way as to activate their minds, to stimulate them to develop some degree of skill to think and act scientifically." I am frank to admit that the results have fallen far short of that ideal. Activation appears to be limited, in many

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Joel H. Hildebrand, dean of the college of chemistry at the University of California, Berkeley, is one of those triple-threat men that make the chemical profession so colorful. He is accustomed to the rarefied atmosphere of the topflight scientist who has received at least a dozen honors in the field of chemistry; to the comparable heights of Olympus (in 1936 he was manager of the U. S. Olympic Ski Team, accompanying it to the games in Europe); and as a lover of symphonic music. This versatility has been synthesized into the warm personality that always characterizes a great teacher. He epitomizes his own theory of a good teacher when he says "How can a teacher interest his students in the subject at hand if he is not sufficiently interested in it himself to ask any hitherto unanswered questions?" Dr. Hildebrand, whether he depended on sound theories and methods of educating young minds or not, would still be able to pass on a knowledge of chemistry by contagion—one could not be around him long and not absorb his interest in whatever he was doing. Each of his four children caught the science bug from him and has pursued anthropology, petroleum engineering, physics, and zoology, respectively.

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cases, to rather low levels, but countless former students have assured me that their minds were activated, and I am not too modest to believe them. I have taught a grand subject with delight and conviction and I am prepared to take on all comers who assert that they have something better for sale.

The role of chemistry in education is central and significant for a number of reasons. First, it is a basic science, and it is therefore not only a natural element for a liberal education but a necessary part of the foundation for various professions. Second, it is difficult. Le bon Dieu made it so, and we teachers, try as we may, cannot make it really easy without killing it in the process. This is all to the good. It confronts with stern reality the demoralizing doctrine that education should be made easy. The principal of a city high school recently stated that he is deliberately "watering down" the teaching in his school. There is a frank doctrine of mediocrity designed to make school easy for pupil and teacher alike. Here is an expression of it by one of its exponents: "A teacher does not need ever to have studied economics in order to give a good course in the subject. All that is needed is a teacher who is alert to the problems of the day, who is open-minded, who can stimulate pupils to bring economic problems to class for discussion, who permits and encourages free and open discussion of all controversial subjects, who instills into the pupils a spirit of tolerance for all views and a respect for the opinions of others, and who shows in all discussion that he or she has at heart the solution of the economic ills of the day in a way that will restore prosperity and happiness to the whole people."

Such a doctrine may get by in a subject like economics, where it must be nearly impossible to prove any other fellow wrong, but in chemistry, fortunately, a false syllogism may explode and injure the perpetrator. Mother Nature cares nothing about your kind heart and good intentions and you cannot get her to reveal her secrets merely by your personal charm or by slapping her on the back. Chemistry presents therefore a serious obstacle to those who are trying to water down education.

Chemistry occupies a strategic position in education, also, because its teachers are continually forced, by the impossibility of "covering" a subject of such vast and growing content, to reconsider their aims and their selection of material appropriate thereto. The teacher of freshman chemistry must face questions as to different aims for different groups of students. It is widely asserted that the chemistry suitable for preprofessionals is not the right sort for nonprofessionals. I have come to the opinion that the chemistry that is best for nonprofessionals is the best, also, for preprofessionals. Some claim that chemistry should be replaced by something considered to be science without being any particular science, which seems to me like striving to develop muscular coordination while carefully avoiding any particular game or sport. Freshman chemistry now has rivals in courses designed to teach students how to think scientifically while going to great lengths to avoid real experience with the basic concepts and materials of any one science. In one such course, considerable time is devoted to the problem "Does the sun go around the earth or the earth go around the sun?" It is not surprising that its apologist frankly says of it, "Whether this approach develops a perspective for better scientific thinking, and whether there is enough carryover to encourage us to go further is still a debatable matter." I should think so!

Another current rival of freshman chemistry is designed to teach an understanding of science by a "historical approach," in which the lecturer describes what he thinks must have been going on in the minds of men responsible for a few great scientific advances of the past. While this can undoubtedly accomplish something if presented by teachers who have themselves done some original scientific thinking, my own belief is that students will understand more about scientific thinking if they do a little of it themselves. Muscular skill cannot be developed by sitting in the grandstand watching athletic contests. The evidence that these substitutes accomplish their purpose seems rather slim compared with evidence I can cite for freshman chemistry. And while a student is trying to improve his thinking machine, why not learn something about the material environment in which he has to live?

Some of these efforts seem predicated upon the assumption that artificial or remote problems are superior as material for scientific thinking; that freshman chemistry is "traditional," which means handed down from one generation to another; that problems which might have practical value are to be avoided as "technical." A critic asks, "Have we any evidence that through taking traditional basic science courses students learn to think and act scientifically? Have we not given lip-service down through the ages to something we have never proved? Have we not through this very fact proved that we have not approached the problem of trying to *teach* students to think in a very scientific manner? As evidence has piled up that we have not done the job we once hoped might be accomplished through traditional science courses, isn't it high time to take a fresh look at this very basic question?" . . . "One wonders if a nonscience student who has taken Prof. Hildebrand's chemistry course or any other *good* chemistry course knows 'what science itself is about,' or even what one segment of it is about. True, he has learned some accepted basic principles of chemistry and many of the accepted modern theories. He has little knowledge of how these ideas of science came into being even though he can apply them to carefully selected problems. He has little appreciation of the struggles which went into the making of these theories and principles, of the mistakes, the fumblings, the relationship to other human struggles for improvement, the heartbreak and the emotions." Well, I wonder whether a teacher can tell very much about the "heartbreak and emotions" of men who discover theories and principles unless he himself is struggling with some of them?

What's in a Name?

We Americans have great faith in machinery. If a problem cannot be solved in a seminar, call it a "workshop"; if your liberal education is not getting desired results, change the name to "general education," even though no two of its advocates can agree upon what it means. Give the A.B. degree after two years instead of four. "Rebuild" the curriculum. "Integrate" the student, or let him integrate himself, since all his professors are presumed to be "narrow specialists" and unintegrated.

I trust that freshman chemistry will continue to be an obstacle to all such nonsense. The world cannot get along without chemistry. Too many professions require it as a foundation. It can furnish superior material, moreover, for liberal education, the education which deals with ideas, those more or less successful efforts of man to synthesize and integrate. The Periodic System of Elements is one of these great ideas; a student who gradually gains an understanding of it can do a lot of scientific thinking with it.

Chemistry is unexcelled as a training ground for scientific thinking. A distinguished engineer, once a freshman in my own quiz section, recently remarked that "Chem 1AB" is one of the few courses in which a lower division student is exposed to inductive reasoning. Instruction in physics is too often mainly deductive, consisting largely in the derivation of formulas by the instructor, and the student may do little but feed the data into them and perform standard mathematical operations. Biology burdens the student with a vast, rather unscientific vocabulary. Paleontology offers the student no opportunity to plan or perform experiments. Chemistry shares with physics a certain amount of its rigid, mathematical character, but shares with biology the necessity for systematizing a wide range of qualitative information. And it is second to no other science in the opportunities it affords for the student to plan and perform experiments and to reason about them. Chemistry is, indeed, more than a single science. The student has the privilege in his freshman year

of learning something about interesting parts of physics which departments of physics usually defer till much later. And he is also made aware of biochemistry, with a window upon physiology. It is indeed "general chemistry."

The historic approach is not neglected by teachers of general chemistry, but the discovery of plutonium, and the interplay of theory and experiment in establishing its chemistry, much of it before there was enough to be visible, offers a vastly more exciting and presently significant historical example than the air pump or the Ptolemaic *vs.* the Copernican system.

Here are some of the questions which have confronted my freshmen in Chem 1AB.

1. Which gas, in each of the following pairs, would you expect to conduct heat faster from a hot body; (a) H_2 or N_2, (b) A or CO_2, (c) water vapor or dry air at the same pressure and temperature?

2. (a) Diagram the structures of the isomers of pentane and of cyclopentane.

(b) Write under each the number of possible monochloropentanes.

3. What inferences can you draw from its position in the Periodic System concerning the following properties of astatine: (a) Ionization potential? (b) Number of valence electrons? (c) Total number of electrons? (d) Electron affinity? and (e) Color of its vapor?

4. How would you expect the pH of blood to be affected by forced, rapid breathing?

5. An "unknown" is made up by selecting one or more of the following substances: $AlCl_3$, NH_4NO_3, Na_2CO_3, CaO, $K_2Cr_2O_7$, $Pb(NO_3)_2$, $CuSO_4$, $SnCl_2$, Hg_2Cl_2. Treatment with water gives an odorless yellow solution, and a white precipitate, which, after filtration and washing, is not visibly affected by either H_2S or NH_3. On the basis of these observations, indicate which of the above substances are respectively present, absent, or in doubt.

In order to answer such questions a student must know something, to be sure - no one can think in a vacuum—but he certainly has to do some thinking, for he has never been told the answers. And we can test the result. Many students do, indeed, learn to put together the facts and logic required to answer such questions as these

And one other thing. Some of the ablest chemists in the country elect to teach freshmen. As many as eight full professors in my department have, in a single term, handled freshman quiz and laboratory sections. I am sure that they would regard it as rather silly to have to turn away from the important, live, problems of chemistry to a consideration of whether the earth goes around the sun or *vice versa*, or to the now dead problems of a century ago. We had better let a distinguished scientist try to infect students with his own enthusiasms than force him to do something cooked up by president, deans, or professors of education. I know many of these teachers of freshmen, and while they are "specialists" they are not "narrow." They include musicians, painters, soldiers, travelers, fishermen, poets, and athletes. If one wants to improve education the effective way is not to tinker with the machinery but to strive continually to secure able teachers, men with a passion both for scholarship and for teaching, and then let them teach each in his own way. And you will find, nearly always, that they will want to teach "subjects," which is as it should be, for, as Oliver Carmichael wrote, "perhaps the best single test of the quality of teaching in a college is the creative activity of the staff. Dull teaching may result from the incapacity of the teacher, but more often it derives from his intellectual inactivity. One thoroughly competent in his field will get poor results if the spark of inquiry and curiosity has gone out. It is, therefore, of great importance that encouragement be given faculty members who are pursuing any form of recognized creative activity. The spirit of learning is contagious. It is caught rather than taught. It is transmitted only by those who are intellectually alive."

Let us now pass on, above the freshman year, to consider a contribution of chemistry to education which becomes strong in the graduate years. It has come from the rapid expansion of chemical knowledge and the realization of the hopelessness of expecting the candidate for a Ph.D. degree to have mastered chemistry, as he could in the days when it was part of "natural philosophy." We are more and more giving up the purpose of turning out walking encyclopedias and trying instead to produce scientists. We cannot expect more than a good grounding in the several branches of chemistry and must judge candidates rather on their possession of the qualities that make a scientist, such as curiosity, imagination, initiative, judgment, and drive. The criticism of the traditional battery of doctoral examinations expressed as follows by Albert Einstein is to be taken very seriously. "The hitch in this was, of course, that one had to cram all this stuff into one's mind for the examinations. This coercion had such a deterring effect (upon me) that after I had passed the final examination, I found the consideration of any scientific problem distasteful to me for an entire year.... It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate plant stands mainly in need of freedom; without this, it goes to wrack and ruin without fail."

A Look at the Future

Now, in conclusion, my instructions for writing this article included an item that I should "look not only at the past and present but into the future." So, here goes. The best method I know for making predictions come true is to predict something that will, or at least ought to take place, and then to do all one can to achieve that result. Accordingly, I predict some things we had better do to our education if we intend not to cease to be a free, civilized people.

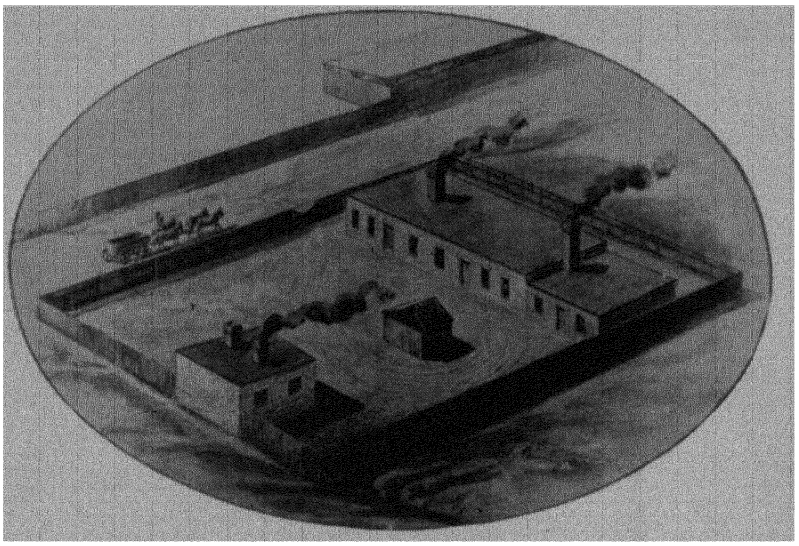
1. I predict, first, that we will not tolerate educational practices which seriously interfere with the development of each intellect to its highest capacity, therefore, (a) enlightened citizens will rise up in wrath against the "watering down" process going on in many schools; (b) mathematics will be revived and taught by well-prepared teachers: and (c) the rewards of teaching will be raised so as to attract teachers of high ability and with adequate training in the subjects they teach.

2. I predict that freshman chemistry will retain its place against the attacks of those who would substitute for it one of the various brands of "general education." It will be seen that, as I. L. Kandel once wrote, "Educational salvation will not come either by discarding content as traditional or by substituting the new as the best." But these attacks will, I predict, cause teachers of chemistry to improve their courses from the standpoint of liberal education and to remove grounds for the criticism that their courses are only factual and technical.

3. I predict that continual improvement will be made in the handling of graduate students so as to assist them to become productive scientists.

I believe that our very survival, in these precarious times, will depend upon substantial progress toward making these predictions come true. The basic sciences are an indispensable part of the means necessary for maintaining a free world. As Haldane wrote after World War I: "If then in future wars we are to avoid gross mismanagement in high places, and panic and stupidity among the masses, it is essential that everyone learn a little elementary science, that politicians and soldiers should not be proud of their ignorance of it.... If we persist in the belief that we can be saved by patriotism or social reforms, or by military preparation of the type which would have sufficed in former struggles, we shall go down before some nation of more realistic views.

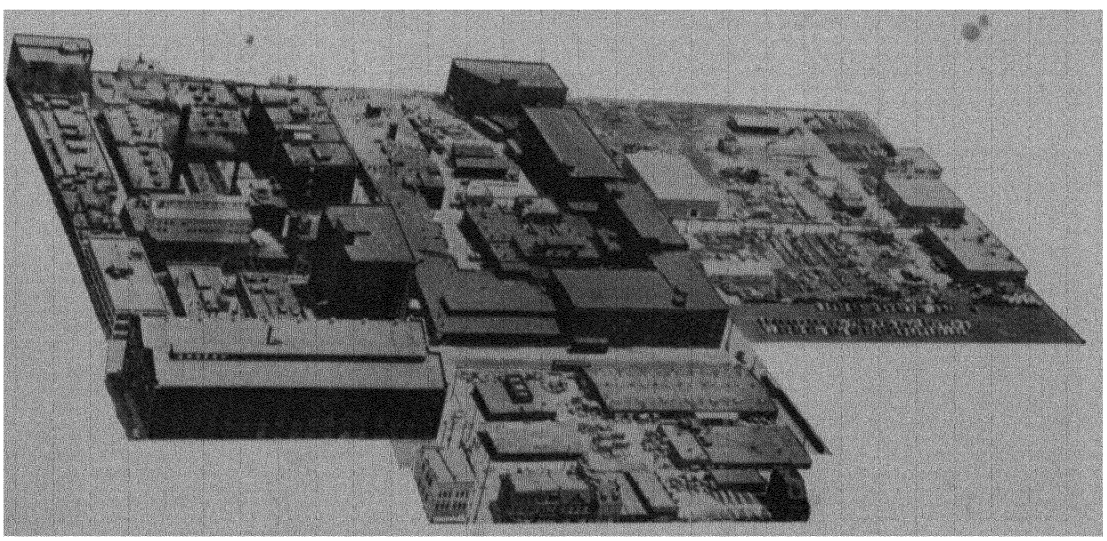
"The Roman and Spanish Empires appear to have perished largely from intellectual torpor. Are we going to go the same way?" My final prediction is that we shall not perish because we *will* not.



Four years before the American Chemical Society was founded the brothers Mallinckrodt established a plant for the manufacture of fine chemicals in the sparsely settled Midwest

A Pictorial Review of Chemical Progress

A story in pictures of the period in which a nation, a great industry, and the American Chemical Society grew and progressed together

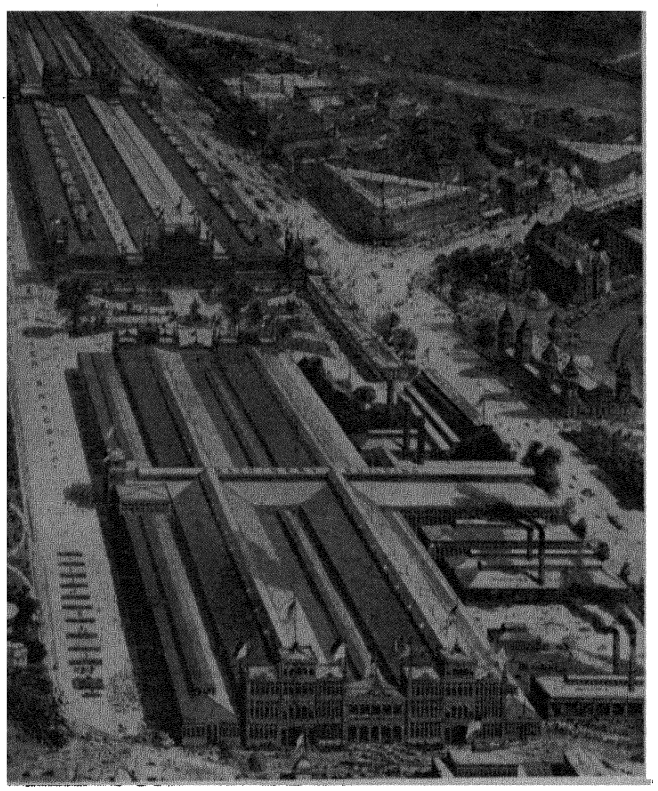


Today the Mallinckrodt Chemical Works is one of the great chemical institutions of this country which have participated in the progress of the past 75 years

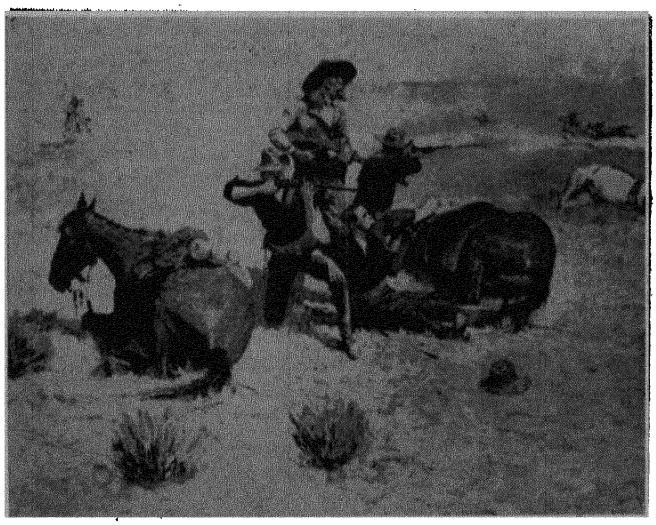
1876 . . . The Early Years



In the same year that a small group of chemists was organizing the American Chemical Society, people crowded into Cleveland's Public Square to see the new "tremendously bright" carbon arc light

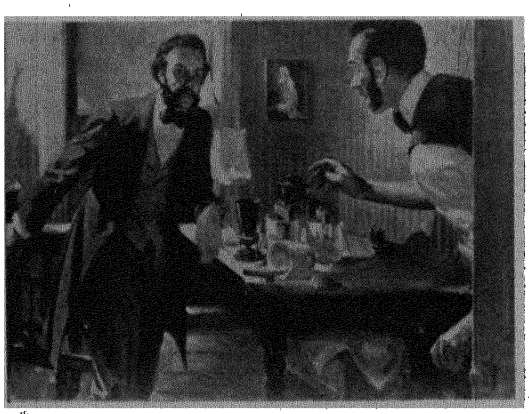


The Centenary Exposition in Philadelphia, celebrating the signing of the Declaration of Independence, saw the first extensive exhibit of American chemical industries. . .



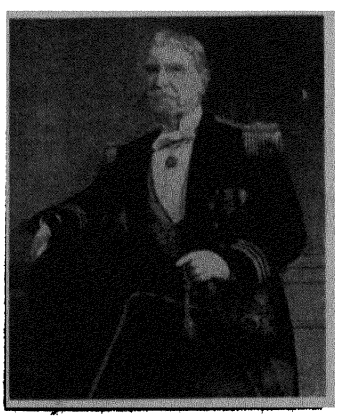
In the West, Indians were still a problem and Custer was making his brave stand against Sitting Bull. . .

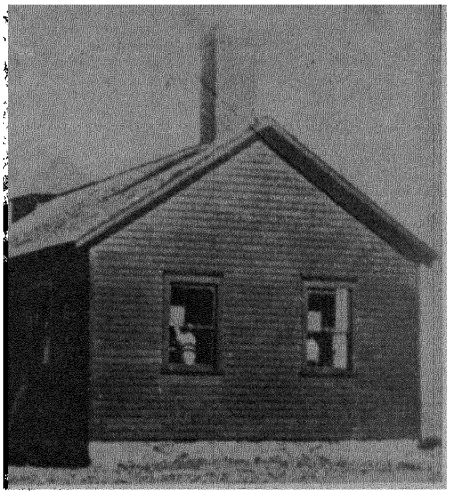
In the pages that follow the editors attempt to bring to the reader through the medium of pictures a sense of the achievement and change that have taken place in the past 75 years. No attempt has been made to be all-inclusive, rather the aim has been to give some concept of the broad scope of the fields ranged by chemists and chemical engineers. It is hoped that a by-product of this effort will be the stimulation of interest in the maintenance of adequate pictorial records of passing events, for often years may pass before the full significance of a particular moment is recognized. An attempt to gather the picture material for this story has convinced the editors of the uselessness of hindsight when such a development occurs.



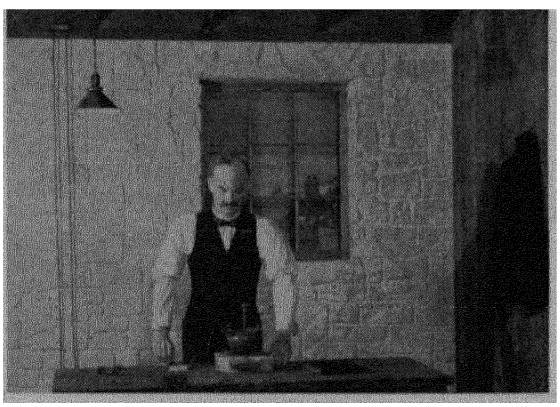
Also born in the Year One, ACS, was the brain child of Alexander Bell, the telephone, which on March 10, 1876 carried its first complete sentence

Thomas Harrison was serving as the first president of the Manufacturing Chemists Association (founded 1872)





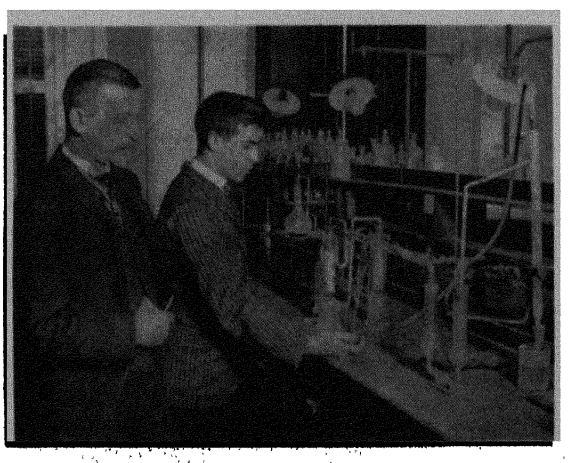
uno Works laboratory, was one of the first in
for the Du Pont Co. A year earlier Remsen
In 1882 the first by-product sulfuric acid was
Hegeler Zinc Co., La Salle, Ill.



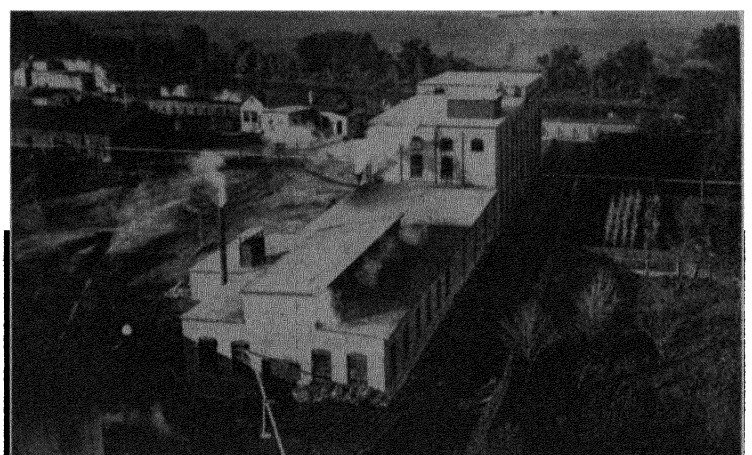
In this laboratory (from model at Museum of Science and Industry, Chicago) Acheson produced carborundum in 1891 and artificial graphite in 1896. Earlier, in 1890 Herman Frasch patented his hot-water process for mining sulfur



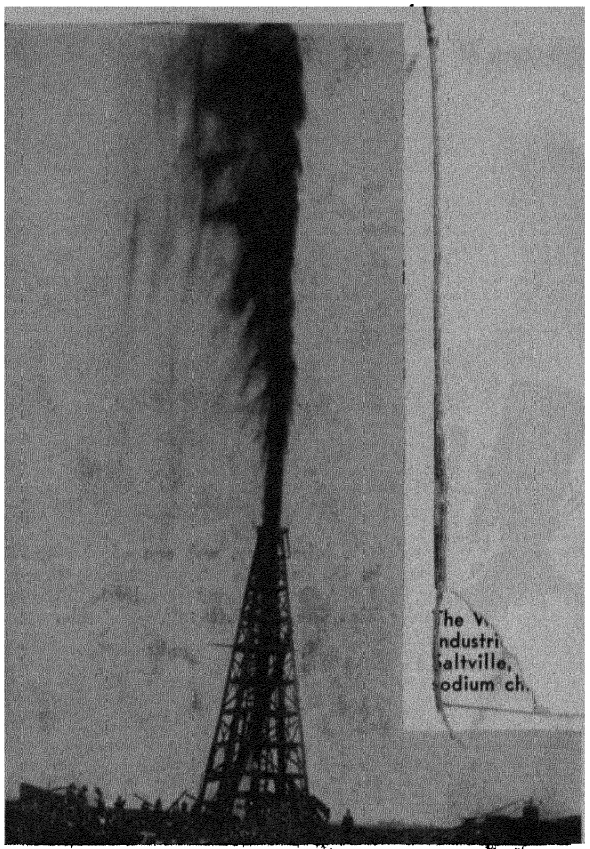
In 1884 the Solvay Process Co. opened this alkali plant near Syracuse, N. Y. In the same year Augustus Schultz perfected chrome tanning, and a year later James Gayley inaugurated the use of a dry air blast in iron manufacture



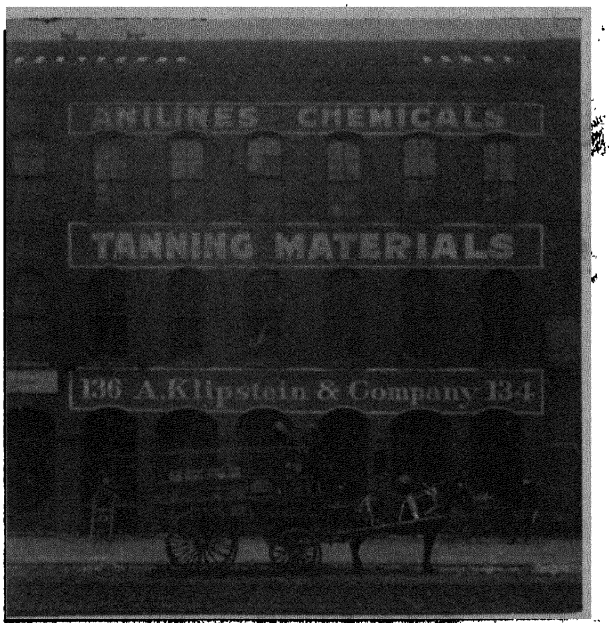
At the University of Pennsylvania in 1893 Edgar Fahs Smith was already instilling in his pupils the principles of basic research



Bromine was the first chemical produced by Dow Chemical Co. when it opened its plant at Midland, Mich., in 1889. The year previous, T. L. Wilson succeeded in making calcium carbide by an electric process, and phosphate deposits were found in Florida



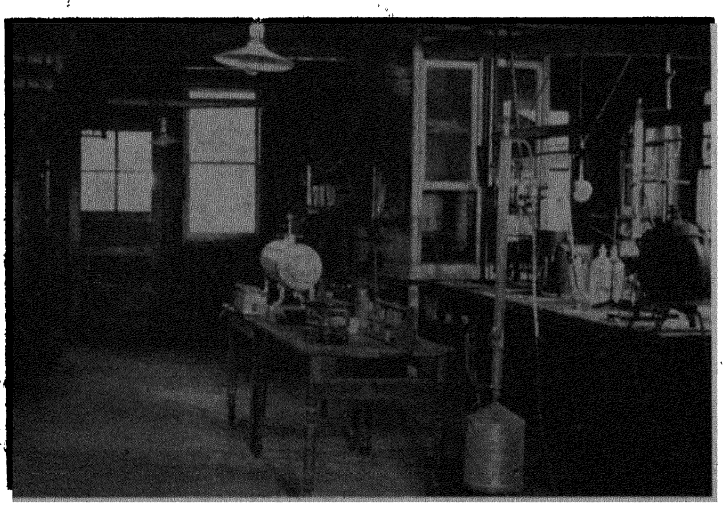
In 1901 the blowing in of the Lucas Gusher, at Spindletop, Tex., heralded the coming of the great petroleum and petrochemical industry in the Southwest. Two years earlier, 12 firms had formed the General Chemical Co. in one of the first great chemical mergers in this country



Old Chicago offices of A. Klipstein & Co., one of the pioneers of the American chemical industry, in 1928 became a part of the American Cyanamid Co. When the picture was taken around 1901, J. F. Queeny had started the Monsanto Chemical Co. in St. Louis; Abbott Alkaloidal Works (now Abbott Laboratories) was founded in Chicago, and in Washington the U. S. Bureau of Standards was established. Right, Baekeland here prepared his first phenol-formaldehyde condensation products in 1905. A year later Cottrell developed his system for electrical precipitation of suspended particles

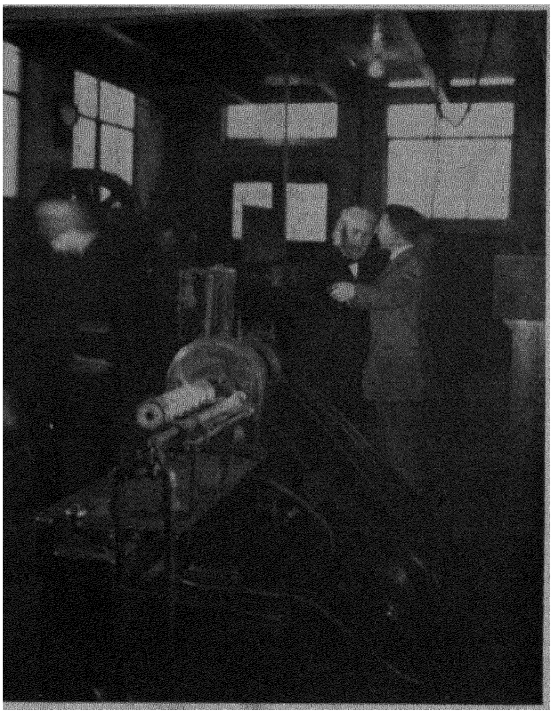


Col. Theodore Roosevelt and his "Rough Riders" at San Juan Hill in 1898 could not foresee the important role the chemical industry was to play in future wars. By this time F. W. Clarke had issued his first annual report on atomic weights (1894), Roentgen had discovered x-rays (1895), and the steel industry had installed its first by-product coke ovens

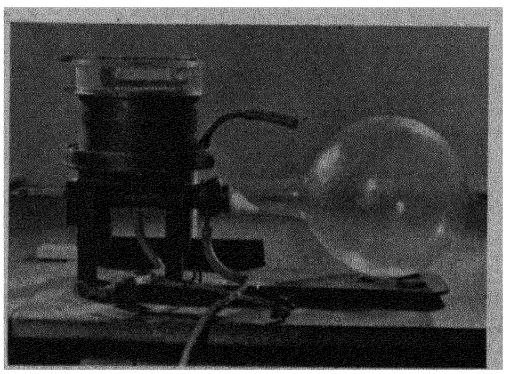




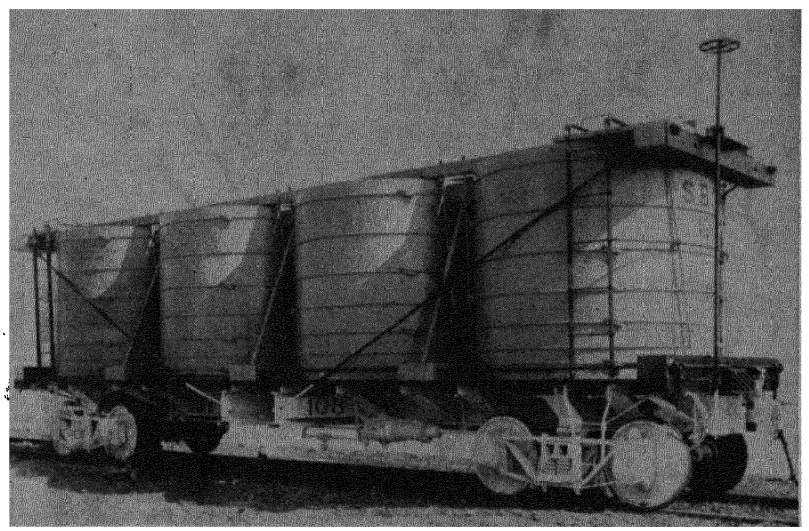
This laboratory was used by Eimer & Amend for the preparation of standard solutions for the chemists of 1906. This year, as a division of the Fisher Scientific Co., Eimer & Amend celebrates its 100th anniversary



Right. W. D. Coolidge of the General Electric Co. explains to Thomas A. Edison how he produced ductile tungsten filaments (1910). In the same year the American Viscose Corp. began making viscose rayon. It was also the year in which Procter & Gamble began the hydrogenation of vegetable oils

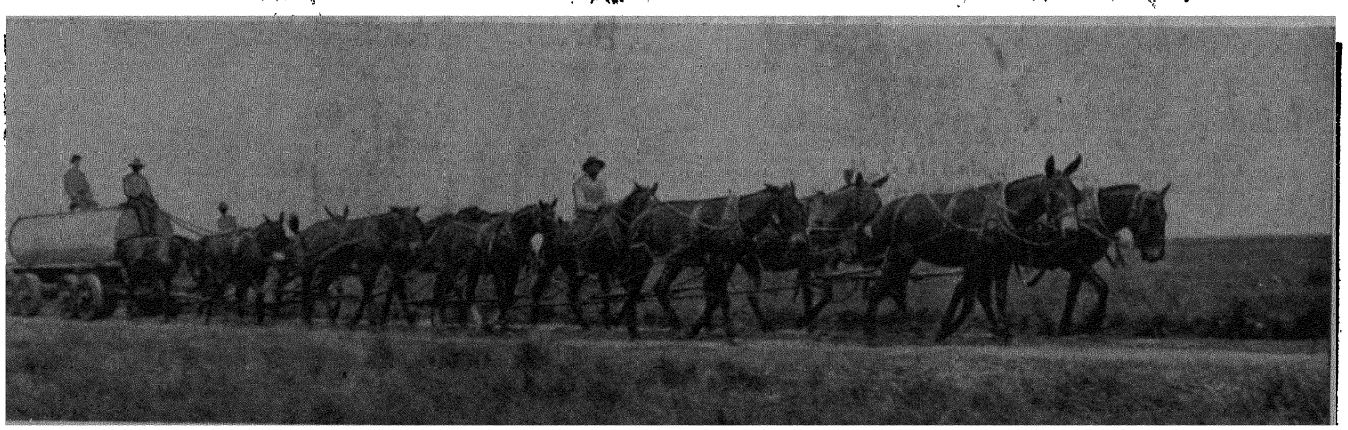


An important tool in the developments leading to the atomic era was the cloud chamber of C. T. R. Wilson in 1912. The chamber made it possible to detect the path of sub-atomic particles



A mule train hauls boiler equipment to Bryanmound, Tex., for early sulfur operations of Freeport Sulphur Co. in 1913. Four years earlier Texas Gulf Sulphur Co. had begun operations in Matagorda County, Texas

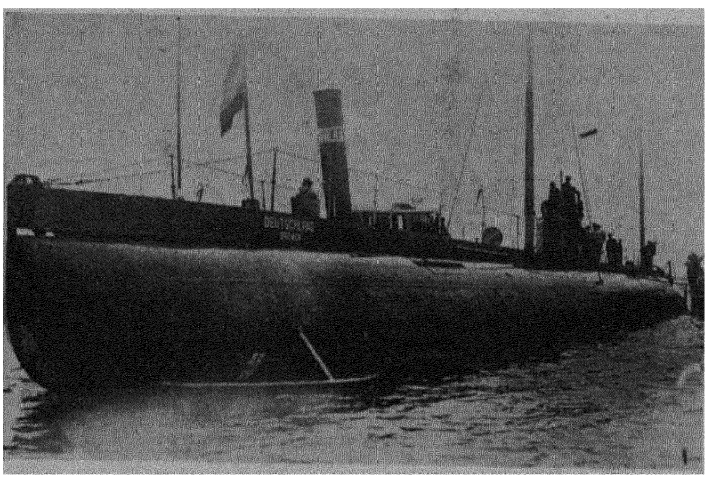
An early type of tank car built about 1913 for the Kalbfleisch Corp., now a unit of American Cyanamid Co. About this time W. M. Burton was making progress on petroleum cracking and the Haber-Bosch nitrogen fixation process was explained at the VIIIth International Congress of Pure and Applied Chemistry in New York

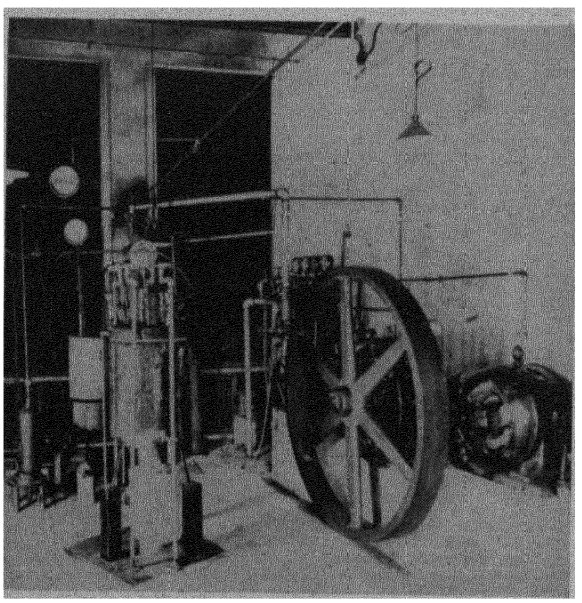


1914 . . . World War I

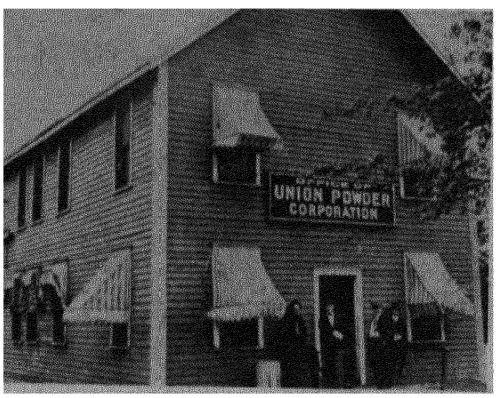
With the outbreak of war in Europe and the German embargo on coal tar dyes, the country found itself short of phenol, potash, cyanides, mercury, coal tar dyes, and medicinals. In the efforts of the chemical industry to meet new demands the foundations of our present great chemical and chemical processing industries were laid. Right. The first shipment of indigo leaves Midland in 1917. Dow was the first company to succeed in the production of synthetic indigo. Below. Shortages were eased somewhat when the submarine Deutschland succeeded in running the British blockade in 1916, carrying 700 tons of dyes





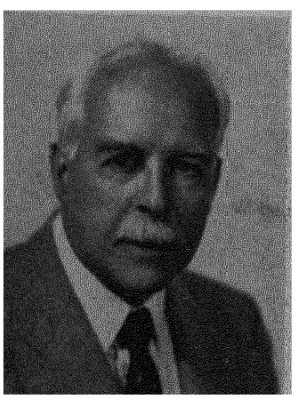


In 1916–17 this experimental unit was constructed by the U. S. Department of Agriculture to study the manufacture of synthetic ammonia by the Haber process

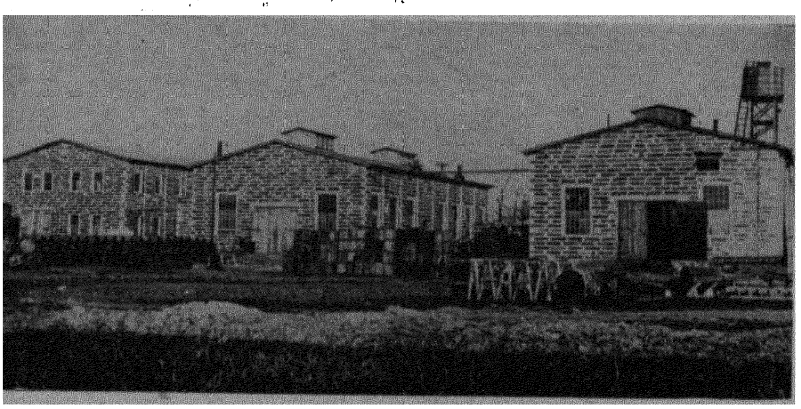


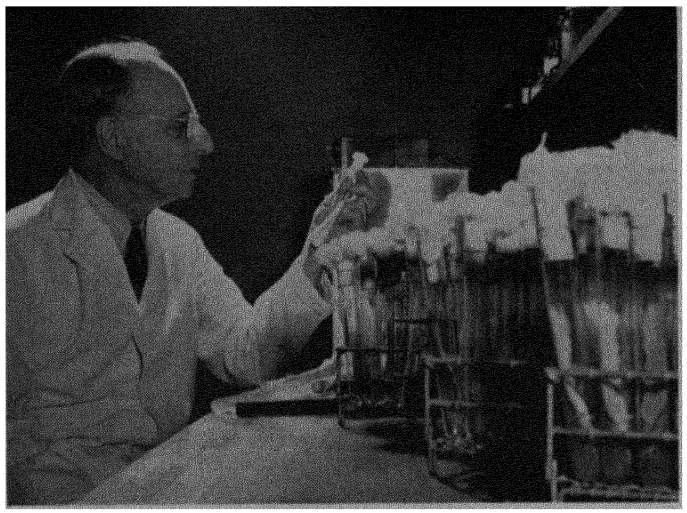
The Old Union Powder Co., at Perlin, N. J., purchased by the Hercules Powder Co. in 1915, is now one of the large plants of the 23 run by Hercules all over the country. One year earlier the Corning Glass Co. had begun the production of Pyrex brand glass

Start of the Calco Chemical Co., now a division of American Cyanamid Co. Ground was broken for these buildings in July 1915 at Bound Brook, N. J. It was also the year of the first chemical exposition in New York. By now the U. S. coal tar industry had grown to six producers of crudes, 17 of intermediates, and 12 of dyes. One year later IG Farben was organized

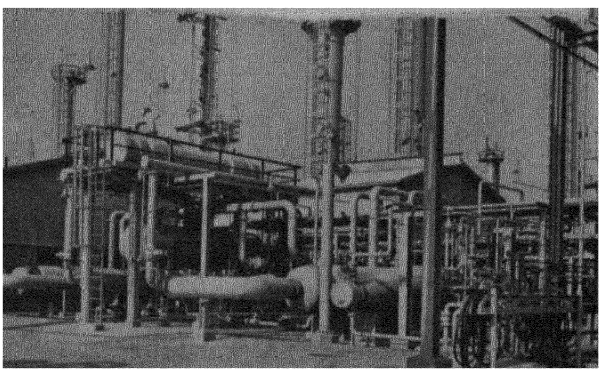


Left. In 1916 G. N. Lewis postulated his concept of the atom, while W. M. Clark had reported his hydrogen ion studies one year earlier and gas black was first used in rubber tires

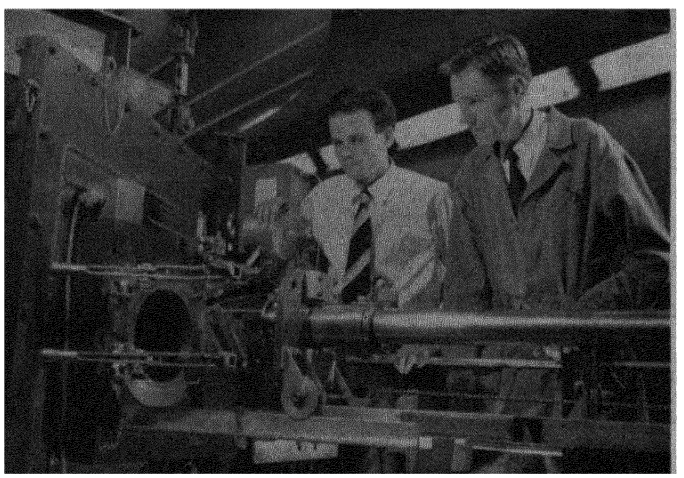




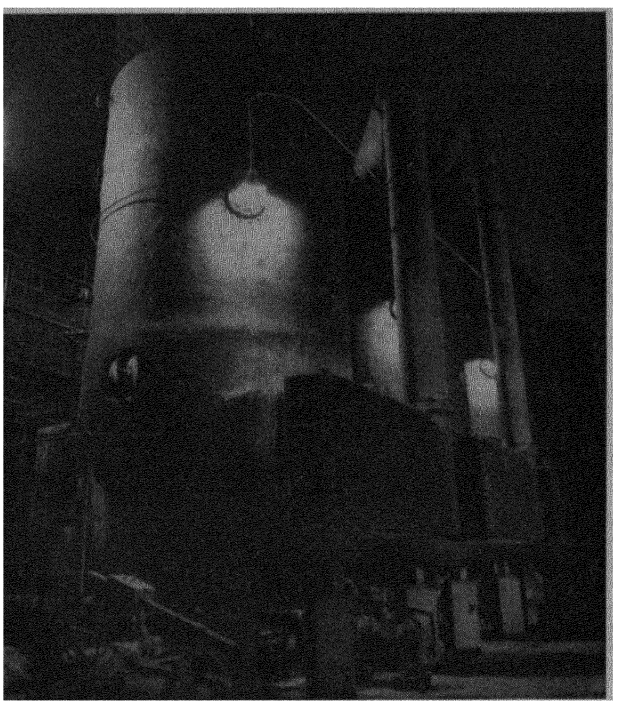
The postwar period was truly an antibiotic age. Here is B. M. Dugger of the Lederle Laboratories who discovered aureomycin in 1947. The synthesis of penicillin was announced in 1946 and terramycin was announced in 1950 by Pfizer. Other developments in the field of chemical therapy included the isolation of vitamin B_{12} by Folkers and coworkers at Merck in 1948, and the first clinical tests with cortisone began the same year



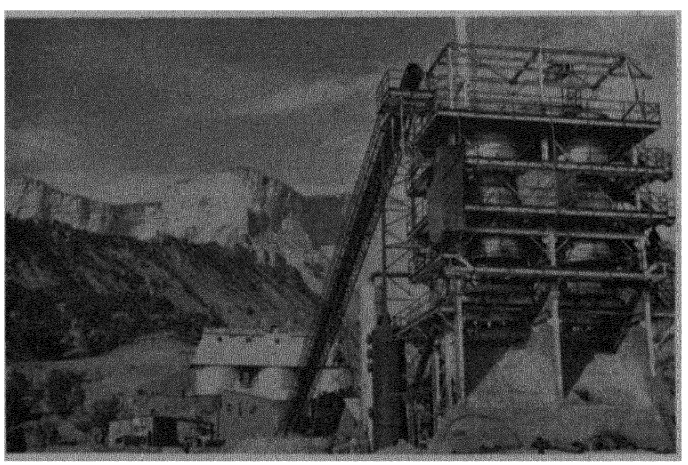
Freedom from the vagaries of natural glycerol prices and supply seemed in the offing when Shell Chemical Co. began large-scale production of synthetic glycerol at its Deer Park, Tex., plant



Left. Many of the problems of the nuclear age were far from solved. A step toward an understanding of the binding forces of the atom was made by the discovery of artificial mesons by C. M. G. Lattes and the late Eugene Gardner of the University of California

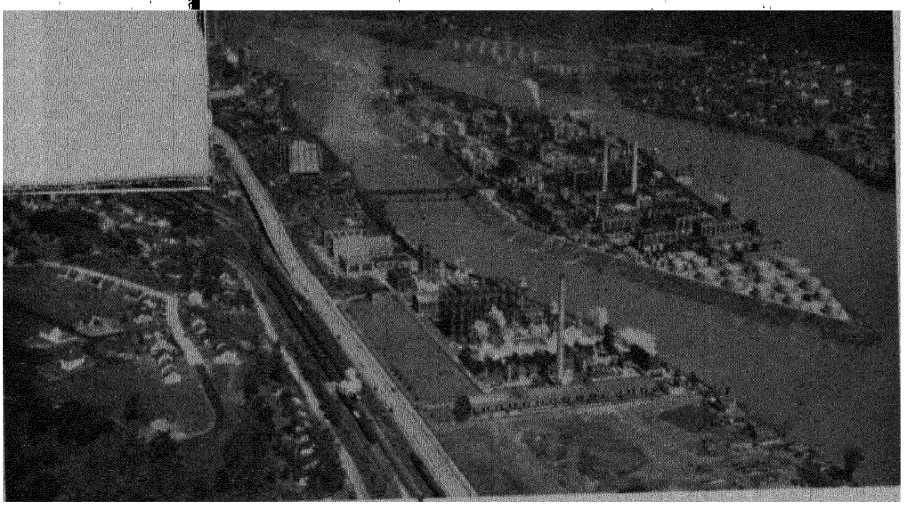


The oil-from-shale demonstration plant of the U. S. Bureau of Mines was another effort to cope with the vast petroleum needs of the world. To help meet this need the petroleum industry invested over $10 billion in new facilities and improvements in the postwar period



Another co-celebrant with ACS of a diamond jubilee is the Foote Mineral Co., one of the leaders in the lithium chemicals field. These triple-effect evaporator tanks are used in the production of lithium hydroxide at the Exton, Pa., plant

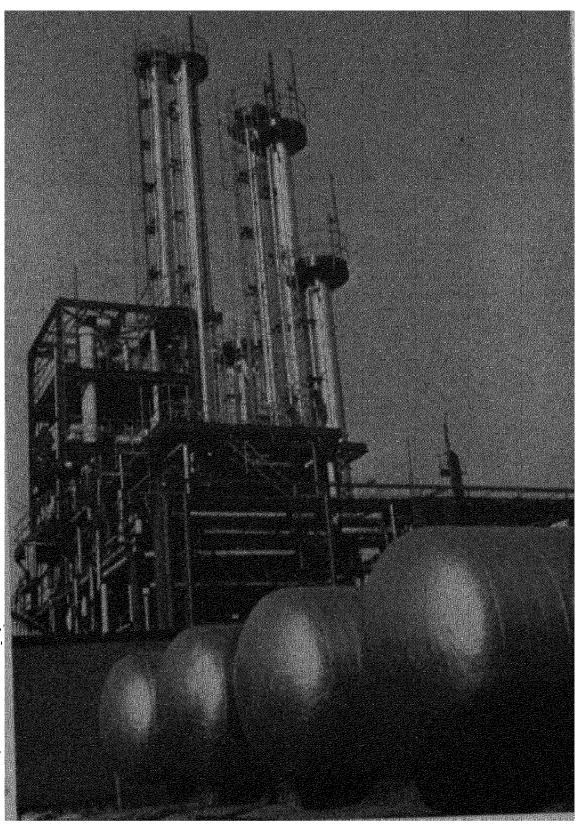
A typical example of the growth and progress of the American chemical and chemical processing industries is the then (1921) and now view of the Blaine Island plant of Carbide and Carbon Chemicals Co.

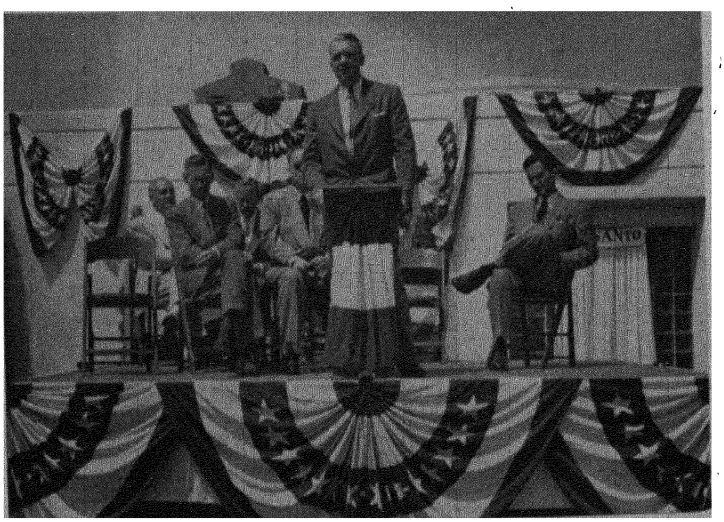


Below. Leonard T. Beale, chairman of the board of directors of the Pennsylvania Salt Mfg. Co., points to clock presented by the King of Denmark to the company, on the occasion of its 100th birthday in 1950



One of the most notable developments of the postwar years has been the rapid advance in plastics technology and production. Pictured are the ethylene finishing towers of the Dow Chemical Co., a step in the production of styrene and saran





Nor has the chemical industry confined its activities to the East and Southwest. Pictured here are officials of the Monsanto Chemical Co. at the dedication of the company's styrene plant at Long Beach, Calif. It is the first such plant west of the Mississippi and is designed to help fill the needs of California's fast-growing plastics industry

appendix

American Chemical Society Councilors, Committees, Division Officers, Local Section Officers

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Connor, Ralph
Conrad, Carl M.
Cooke, Lloyd M.
Cope, Arthur C.
Corwin, Alsoph
Cox, Edward H.
Craig, Lyman C.
Cramer, Archie B.
Crane, F. J.
Crawford, H. Marjorie
Crittenden, Eugene D.
Cronheim, George E.
Croxton, Frank C.
Cummings, Ross

Dahm, H. L.
Daniels, Farrington
Davis, Donald W.
De Atley, L. S.
Deaton, W. M.
Dermer, Otis C.
Dewey, Bradley
Diehl, Harvey
Dittmer, Karl
Dodge, Barnett F.
Doheny, James J.
Donlan, Theodore R.
Doolittle, Dortha B.
Doumani, Thomas F.
Drake, Nathan L.
Dunbar, Ralph E.
Dunkelberger, T. H.
Dunlap, L. H.
Durham, Edward J.
Dutcher, R. Adams
du Vigneaud, Vincent

Edsell, John T.
Edwards, H. L.
Eilerts, Kenneth
Elder, Albert L.
Elvehjem, Conrad A.
Embree, Norris D.
English, J. P.
Esselen, Gustavus J.
Evans, William L.
Ewell, Raymond H.
Eyring, Henry

Fall, Paul H.
Farber, Eduard
Fernandez-Garcia, Rafael
Fernelius, W. Conard
Ferris, S. W.
Fisher, C. H.
Flory, Paul J.
Folkers, Karl A.
Frahm, Elmer E.
Free, Alfred H.
Frey, Charles N.
Frey, Fred E.
Frolich, Per K.
Frost, Harvey N.
Fugassi, J. P.
Furman, N. Howell

Gabbard, James L.
Gaffin, Fisher
Gale, William A.
Gardner, Leo R.
Garlock, Neil B.
Gassmann, Albert G.
Gensler, Walter J.
Gibb, Thomas R. P., Jr.
Gibson, John A.
Gilbert, Frederick A.
Glockler, George
Goos, Arthur W.
Gordy, Edward L.
Gortner, Willis A.
Graham, Carl F.
Granara, Ina M.
Gross, Paul M.
Grummitt, Oliver J.
Gruse, W. A.
Gucker, Frank T., Jr.

Hanson, William J.
Hardy, Edgar E.
Haring, Malcolm Morrison
Harlan, William Robert
Harrisson, Joseph W. E.
Hasche, Rudolph L.
Hassid, W. Z.
Hatch, Lewis Frederic
Heineman, H. C.
Heinemann, Gustave
Heinrich, Herbert
Hersberger, Arthur B.
Hill, Lyle O.
Hilty, Wayne W.
Holbert, J. M.
Holmes, Harry N
Holtzclaw, Charles R.
Homeyer, August H.
Hooker, Albert H.
Hoppert, Carl A.
Huber, Francis C.
Huffman, E. W. D.
Humphreys, W. H.
Hunt, Charles H.
Hunt, Charles K.
Hunter, Howard L.

Ingersoll, Arthur W.

Jacobs, Thomas L.
Johnson, Julius E.
Jolley, J. I.
Juve, Arthur E.
Juve, R. D.

Kalichevsky, Vladimir A.
Kauffman, F. Leo
Kauzmann, Walter
Kenny, Christopher L.
Keyes, Donald B.
Kirby, T. W.
Kirk, Raymond E.
Kirkpatrick, Sidney D.
Kirkpatrick, W. H.
Kirst, William E.
Kleinberg, Jacob
Kneen, Eric
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Krause, Ellis L.
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Leroy, R. H.
Levens, Ernest
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Lind, Samuel C.
Lippert, Arnold L.
Little, Julian R.
Livingston, H. K.
Lollar, Robert M.
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Love, S. Kenneth
Lovell, Edwin L.
Lowe, H. Burton
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Lynch, Cecil C., Jr.

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MacRae, Duncan
Major, R. T.
Mark, Herman F.
Marschner, Robert F.
Marshall, A. L.
Marshall, C. E.
Martin, Jerome L.
Martin, Robert W.
Marvel, C. S.
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McPherson, William
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Patnode, Winton I.
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Ray, Frederick E.
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Rogers, L. N.
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Roseveare, William E.
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Schmidt, Walter A.
Schoene, Dwight L.
Schoonover, Irl C.
Schultz, Harold W.
Scofield, Francis
Scott, Arthur F.
Scudder, Eugene D.
Seaborg, Glenn T.
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Setterstrom, Carl
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Shaffer, Sherman S.
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Simon, H.
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Sparks, William J.
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Tapp, William J.
Taylor, Maurice C.
Taylor, T. Ivan
Thomas, Charles A.
Thomas, Charles L.
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Truitt, Price
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Vernon, Arthur A.
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von Fischer, William
Voter, P. Conant

Wakefield, Harold F.
Wall, Frederick T.
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Weidlein, Edward R.
Wertheim Edgar
Weymouth, Harold D.
White, Charles E.
Whitney, Willis R.
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Winstein, Saul
Winter, Lester L.
Wolff, William A.
Woodburn, H. Milton
Woods, Auburn, Jr.
Work, Lincoln T.

Yoe, John H.
Yohe, G. Robert
Young, Hoylande D.
Young, William G.

Zscheile, Frederick P., Jr.

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Committees of the Council

Council Policy (established 1923). *Chairman*, *N. Howell Furman (President ACS), *Vice-Chairman*, Clifford F. Rassweiler, *Secretary*, *Alden H. Emery (Executive Secretary ACS), *Edgar C. Britton (President-Elect ACS); M. H. Arveson, C. H. Fisher, C. C. Price, W. G. Young (1949–51); N. L. Drake, G. J. Esselen, F. D. Snell, H. F. Wakefield (1950–52), H. E. Bent, W. W. Hilty, J. H. Nair, C. F. Rassweiler (1951–53).

**Ex Officio.*

Nominations and Elections (established 1948). *Chairman*, Ralph Connor; *Secretary*, Arthur C. Cope, A. O. Beckman, H. E. Longenecker, W. O. Milligan (1949–51); Ralph Connor, W. A. Noyes, Jr., P. K. Frolich (1950–52), A. C. Cope, C. S. Marvel, J. H. Yoe (1951–53).

Standing Committees

Chemical Education (established 1948). *Chairman*, Albert F. McGuinn, S. J.; *Secretary*, S. E. Q. Ashley, P. H. Fall, Ina M. Granara, F. T. Gucker, Jr.; A. F. McGuinn, S.J. (1949–51); S. E. Q. Ashley, O. R. Quayle, Price Truitt, William von Fischer (1950–52), L. C. Atchison, L. R. Brantley, A. D. Ludden, Byron Riegel (1951–53).

Constitution and Bylaws (established 1948). *Chairman*, Preston L. Brandt, *Secretary*, Erich Kneen; A. W. Ingersoll, W. I. Patnode, Karl Dittmer, C. L. Thomas (1949–51); P. L. Brandt, A. L. Moxon, W. E. Sohl, W. A. Stanton (1950–52), A. H. Brunner, Jr., F. E. Frey, Eric Kneen, N. W. Rakestraw (1951–53).

Local Sectional Activities (established 1948). *Chairman*, Carl F. Graham; *Secretary*, Jules D. Porsche; C. F. Graham, J. D. Porsche, S. S. Shaffer, W. J. Tapp (1949–51); W. E. Baier, W. R. Harlan, R. D. Juve, A. C. Nixon (1950–52), E. J. Durham, H. K. Livingston, H. G. Oddy, Edgar Wertheim (1951–53).

Membership Affairs (established 1948). *Chairman*, Frank E. Brown; *Secretary*, Belle Otto; F. E. Brown, R. E. Kirk, W. G. Parks, G. T. Packham, Jr. (1949–51); A. O. Bradley, E. L. Lovell, Belle Otto, R. B. Reynolds (1950–52), Gustave Heinemann, L. H. Reyerson, B. A. Shippy, L. T. Work (1951–53).

National Meetings and Divisional Activities (established 1948). *Chairman*, E. E. McSweeney, *Secretary*, Harry E. Outcault; K. A. Folkers, W. E. Kuhn, H. E. Outcault, G. R. Yohe (1949–51); Harvey Diehl, J. T. Edsall, W. A. Pardee, R. O. Robin, Jr. (1950–52), Milton Burton, L. E. Clifcorn, E. E. McSweeney, Herman Mark (1951–53).

Professional Regulations (established 1951). *Chairman*, Arthur C. Cope; G. A. Alles, H. E. Bent, A. G. Bowers, E. C. Britton, N. L. Drake.

Professional Relations and Status (established 1948). *Chairman*, Gordon A. Alles, *Secretary*, Paul C. Condit; H. F. Beeghly, A. G. Bowers, C. F. Metz, G. L. Royer (1949–51); E. H. Brown, A. H. Homeyer, W. M. Sperry, E. D. Wilson (1950–52), G. A. Alles, H. S. Bloch, P. C. Condit, L. H. Rogers (1951–53).

Publications (established 1948). *Chairman*, A. L. Marshall; A. L. Marshall, J. L. Oncley, B. L. Oser (1949–51); H. S. Nutting, Arthur Rose, F. T. Wall (1950–52), O. C. Dermer, W. T. Miller, Jr., G. T. Seaborg, Saul Winstein, (1951–53).

Other Committees

(All appointments for 1951 unless otherwise noted.)

Analysis of Divided Meeting Results (established 1949). *Chairman*, Chester M. Alter; L. W. Bass, O. C. Dermer, N. L. Drake, C. S. Fuller, A. E. Sidwell, Jr.

Analytical Reagents (established 1917). *Chairman*, Edward Wichers; S. E. Q. Ashley, A. Q. Butler, B. L. Clarke, W. D. Collins, F. S. Eisenhauer, R. A. Osborn, J. F. Ross, John Wolf.

Annual Report on Atomic Weights (established 1891). *Chairman*, Edward Wichers.

Hazardous Chemicals and Explosives (established 1923). *Chairman*, George W. Jones; L. E. Cheyney, G. B. Kistiakowsky, A. F. Matson, H. A. Pace, C. E. Silk.

International Relations (established 1947). *Chairman*, Norman W. Krase, C. M. Alter, T. R. Donlan, J. C. Elgin, J. G. Kern, R. M. Noyes, C. C. Price, F. T. Tyson, H. C. Urey.

Membership (established 1876). *Chairman*, Benjamin D. Van Evera; Norman Bekkedahl, Milton Harris.

Nomenclature, Spelling, and Pronunciation (established 1912). *Chairman*, E. J. Crane; L. T. Capell, W. C. Fernelius, H. R. Henze, R. C. Hockett, Mary A. Magill, M. G. Mellon, W. J. Murphy, W. A. Noyes, Jr., H. S. Nutting, A. M. Patterson, Byron Riegel, Janet D. Scott, H. B. Vickery, T. F. Young.

Patent and Related Legislation (established 1899). *Chairman*, Earl P. Stevenson; R. T. Baldwin, W. A. Gibbons, Henry Howard, M. W. Levy, N. A. Shepard, O. W. Storey, P. H. Sullivan.

Professional Training (established 1936). *Chairman*, William G. Young, *Executive Secretary*, John H. Howard (member *ex officio*); A. C. Cope, E. O. Wiig (1949–51); R. A. Beebe, W. C. Young (1950–52), W. C. Johnson, Byron Riegel (1951–53).

Standard Apparatus (established 1924). *Chairman*, W. D. Collins; W. S. Clabaugh, W. A. Kirklin, E. N. Luce, W. I. Patterson, L. E. Pitzer, Lyon Southworth.

Standard Methods for the Examination of Water and Sewage (established 1920). *Chairman*, Edward S. Hopkins; R. C. Bardwell, G. P. Edwards, S. K. Love, C. C. Ruchhoft.

Women's Service (established 1927). *Chairman*, H. Marjorie Crawford; Mary

L. Alexander, Gladys A. Emerson, Eunice V. Flock, Thelma Hoffman, Desiree S. Le Beau, Eby N. McElrath, Elisabeth M. Osman, Elsie Louise Schulze.

Committees of the Board of Directors

Executive Committee (established 1931). *Chairman*, Charles A. Thomas; N. Howell Furman, E. H. Volwiler, J. C. Warner.

Standing Committees

Finance (established 1893). *Chairman*, Robert T. Baldwin; L. W. Bass, R. E. Zimmerman (1949–51); N. C. Babcock, W. C. Callan (1950–52); R. T. Baldwin, C. R. DeLong, R. V. Mellefonte (1951–53); *Ex officio*, Charles A. Thomas.

Member and Public Relations (established 1949). *Chairman*, Walter A. Schmidt; R. W. Bost (1949–51); E. C. Britton (1950–52); W. A. Schmidt (1951–53).

Publications (established 1948). *Chairman*, J. C. Warner; W. C. Fernelius, R. E. Kirk (1951); E. C. Britton, Farrington Daniels, J. C. Warner (1950–52); A. C. Cope, E. H. Volwiler (1951-53).

Other Committees

(All appointments for 1951 unless otherwise noted.)

Advisory Committee: *Younger Chemists International Project* (established 1951). *Chairman*, Erwin Brand; *Vice Chairman*, Frank Howard; Erwin Chargoff, R. J. Dahl, A. H. Emery, H. M. Miller, W. A. Noyes, Jr., P. B. Pearson, C. E. Sunderlin, J. C. Warner, R. R. Williams.

Advisory to the Chemical Corps (established 1947). *Chairman*, H. F. Johnstone, *Vice Chairman*, Edwin R. Baker, Roger Adams, E. K. Carver, A. C. Cope, Joseph Dec, L. F. Fieser, P. K. Frolich, R. L. Jenkins, S. D. Kirkpatrick, W. R. Kirner, Stanford Moore, R. L. Murray, C. C. Price, G. T. Seaborg, H. C. Weber, J. W. Williams.

Clinical Chemistry (established 1945). *Chairman*, Warren M. Sperry; R. N. Harger, R. M. Hill, J. G. Reinhold, H. H. Sobotka, W. A. Wolff.

Exchanges (established 1907). *Chairman*, E. J. Crane; A. D. Bliss, J. M. Crowe.

Foreign Compendia (established 1946). *Chairman*, A. V. Grosse; Roger Adams, M. T. Bogert, W. C. Fernelius, Henry Gilman, H. B. Hass, E. H. Huntress, C. S. Marvel, W. A. Noyes, Jr., G. T. Seaborg, F. T. Tyson.

Frasch Foundation Awards (established 1929). *Chairman*, Bernard E. Proctor; F. C. Blanck, Victor Conquest, C. N. Frey, P. C. Wilbur.

Liaison with the Department of Defense (established 1948). *Chairman*, Farrington Daniels, *Secretary*, Walter R. Kirner; P. I. Bowman, E. K. Carver, A. C. Cope, Ralph Connor, L. P. Hammett, W. C. Johnson, W. E. Lawson, L. A. Sweet.

Merck Graduate Fellowship in Analytical Chemistry (established 1949). *Chairman*, Frank H. Hurley, (1950–51); Philip W. West (1950–52); J. J. Lingane (1951–53).

Paper (established 1908). *Chairman*, Byron L. Wehmhoff; B. W. Scribner, H. J. Skinner.

Scientific Aids for Literature Searching established 1946). *Chairman*, J. Whitney Perry; Paul Arthur, Jr., C. L. Bernier, C. A. Burkhard, R. S. Casey, E. J. Crane, J. H. Fletcher, C. S. Grove, Jr., Karl Heumann, Williamina Himwich, I. B. Johns, W. R. Kirner, B. E. Lanhan, A. M. Patterson, J. H. Pomeroy, E. W. Scott, F. L. Taylor, C. S. Wise, W. J. Wiswesser.

Seventy-Fifth Anniversary (established 1949). *Chairman*, John H. Nair, *Secretary*, R. M. Warren; Mrs. L. W. Bass, H. L. Fisher, R. E. Kirk, H. G. Lindwall, Herman Mark, W. J. Murphy, Norman Shepard, F. D. Snell, W. J. Sparks, A. W. Thomas, E. R. Weidlein.

Testimonial Scrolls (established 1950). *Chairman*, Roger Adams; A. B. Lamb, C. L. Parsons.

Awards

American Chemical Society Award in Pure Chemistry (established 1931). Canvassing Committee for Award Nominations: *Chairman*, W. M. Latimer (1949-51); R. T. Arnold (1950 52); George Glockler (1951–53).

Borden Award in the Chemistry of Milk (established 1938). Canvassing Committee for Award Nominations: *Chairman*, W. H. Griffith (1949–51); G. R. Greenbank (1950-52); B. L. Oser (1951–53).

Eli Lilly & Co. Award in Biological Chemistry (established 1934). Canvassing Committee for Awards Nominations: *Chairman*, H. B. Lewis (1949-51); I. M. Klotz (1950–52); Max Tishler (1951–53).

Fisher Award in Analytical Chemistry (established 1947). Canvassing Committee for Award Nominations: *Chairman*, Edward Wichers (1949–51); W. A. Kirklin (1950–52); G. F. Smith (1951–53).

Fritzsche Award (established 1948). Canvassing Committee for Award Nominations: *Chairman*, E. C. Crocker (1949–51); W. S. Guthmann (1950 52); L. C. King (1951-53).

Ipatieff Prize (established 1947). Canvassing Committee for Award Nominations: *Chairman*, Robert E. Vivian (May 1, 1947–Dec. 31, 1952); Herbert C. Brown (Jan. 1, 1949 -Dec. 31, 1955).

Paul-Lewis Laboratories Award in Enzyme Chemistry (established 1945). Canvassing Committee for Award Nominations: *Chairman*, C. V. Smythe (1949–51); H. A. Lardy (1950–52); J. P. Greenstein (1951–53).

Precision Scientific Co. Award in Petroleum Chemistry (established 1948). Canvassing Committee for Award Nominations: *Chairman*, T. A. Boyd (1949 51); R. H. Sage (1950–52); H. H. Storch (1951-53).

Scientific Apparatus Makers Award in Chemical Education (established 1950). Canvassing Committee for Award Nominations: *Chairman*, Leigh C. Anderson (1951); R. E. Connick (1951–52); J. A. Campbell (1951-53).

Representatives of ACS in Other Organizations

American Association for the Advancement of Science. Cooperative Committee on Science and Mathematics Teaching: C. H. Sorum. Council: E. T. McBee (1950–51); F. D. Rossini (1951-52).

American Documentation Institute. E. J. Crane (1949–51).

American Society of Mechanical Engineers. Air Pollution Control Committee: H. F. Johnstone.

American Standards Association. Sectional Committee Z10: R. B. Sosman; *Sectional Committee Y1*: E. J. Crane; Sectional Committee Z15: L. S. Bonnell; Sectional Committee Z23; R. P. Allen; Sectional Committee P.H.4: C. V. Otis.

American Year Book. Advisory Council: M. T. Bogert.

Biological Stain Commission. Elmer H. Stotz.

Chemical Corps Advisory Board. President-Elect and Executive Secretary of ACS, *ex officio*.

Chemical Engineering Catalog. Norman A. Shepard; *ex officio*, N. Howell Furman.

General Electric Co. Charles A. Coffin and Gerard Swope Fellowship Committee: P. H. Emmett.

National Association of Corrosion Engineers. Inter-Society Corrosion Committee: George H. Young (1950–51); Norman Hackerman (1951–52).

National Research Council. Advisory Panel to the Committee on Food Protection: L. E. Clifcorn, C. G. King. Division of Chemistry and Chemical Technology: A. B. Lamb, W. J. Sparks (July 1, 1949 June 30, 1952), A. H. Emery, H. F. Johnstone (July 1, 1950-June 30, 1953).

Office of Civil Defense Planning, Technical Division: Harry A. Kuhn.

Patent Office Society. General Steering Committee: J. P. Wetherill.

U. S. National Commission for the United Nations Educational, Scientific, and Cultural Organization. W. A. Noyes, Jr.

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National Cylinder Gas Co., Chicago, Ill.
Nepera Chemical Co., Inc., Yonkers, N. Y.
The Neville Co., Pittsburgh, Pa.
Newport Industries, Inc., Pensacola, Fla.
Niagara Alkali Co., Niagara Falls, N. Y.
Nopco Chemical Co., Harrison, N. J.
North American Solvay, Inc., New York, N. Y.
Nova Chemical Corp., New York, N. Y.
Nuodex Products Co., Inc., Elizabeth, N. J.
Oakite Products, Inc., New York, N. Y.
Ohio-Apex, Inc., Nitro, West Va.
Oldbury Electro-Chemical Co., Niagara Falls, N. Y.
Olin Industries, Inc., East Alton, Ill.
Onyx Oil & Chemical Co., Jersey City, N. J.
Penick & Ford, Ltd., Inc., New York, N. Y.
Pennsylvania Industrial Chemical Corp., Clairton, Pa.
Pennsylvania Salt Mfg. Co., Philadelphia, Pa.
Permutit Co., New York, N. Y.
Pharma Chemical Corp., New York, N. Y.
Philadelphia Quartz Co., Philadelphia, Pa.
Pittsburgh Coke & Chemical Co., Pittsburgh, Pa.
Potash Co. of America, Carlsbad, N. M.
Rohm & Haas, Philadelphia, Pa.
Salvo Chemical Corp., Rothschild, Wis.
Sandoz Chemical Works, Inc., Hanover, N. J.
Scholler Brothers, Inc., Philadelphia, Pa.
Sharples Chemicals, Inc., Philadelphia, Pa.
Shawinigan Products Corp., New York, N. Y.
Sinclair and Valentine Co., New York, N. Y.
Spencer Chemical Co., Kansas City, Mo.
Stauffer Chemical Co., New York, N. Y.
Takamine Laboratory, Inc., Clifton, N. J.
Texas Gulf Sulphur Co., New York, N. Y.
Thiokol Corp., Trenton, N. J.
The Trubek Laboratories, Inc., East Rutherford, N. J.
Union Carbide and Carbon Corp. and Subsidiaries, New York, N. Y.
United Carbon Co., Charleston, West Va.
U. S. Industrial Chemicals, Inc., New York, N. Y.
U. S. Potash Co., New York, N. Y.
U. S. Radium Corp., New York, N. Y.
R. T. Vanderbilt Co., Inc., New York, N. Y.
Verona Chemical Co., Newark, N. J
Victor Chemical Works, Chicago, Ill.
Wallerstein Co., Inc., New York, N. Y.
Witco Chemical Co., New York, N. Y.
Jacques Wolf & Co., Passaic, N. J.
Wyandotte Chemicals Corp., Wyandotte, Mich.
Zinsser & Co., Inc., Hastings-on-Hudson, N. J.

Consultants

Burgess Battery Co., Freeport, Ill.
The Dorr Co., New York, N. Y.
Economics Laboratory, Inc., St. Paul, Minn.
Evans Research & Development Corp., New York, N. Y.
Food Research Laboratories, Inc., Long Island City, N. Y.
W. M. Grosvenor Laboratories, Inc., New York, N. Y.
Hydrocarbon Research, Inc., New York, N. Y.
The M. W. Kellogg Co., New York, N. Y.
Knowles Associates, New York, N. Y.
Laboratory of Industrial Hygiene, Inc., New York, N. Y.
Arthur D. Little, Inc., Cambridge, Mass.
Lummus Co., New York, N. Y.
Singmaster & Breyer, New York, N. Y.
Foster D. Snell, Inc., New York, N. Y.
Stone & Webster Engineering Corp., Boston, Mass.
U. S. Testing Co., Inc., Hoboken, N. J.

Fertilizers

Virginia-Carolina Chemical Corp., Richmond, Va.

Food and Kindred Products

American Can Co., New York, N. Y.
American Chicle Co., Long Island City, N. Y.
American Sugar Refining Co., New York, N. Y.
Armour and Co., Chicago, Ill.
Beech-Nut Packing Co., Canajoharie, N. Y.
The Borden Co., New York, N. Y.
California and Hawaiian Sugar Refining Corp., Ltd., San Francisco, Calif.
Clinton Foods, Inc., Clinton, Iowa.
Coca Cola Co., Atlanta, Ga.
Continental Baking Co., New York, N. Y.
Continental Can Co., Inc., New York 17, N. Y.
Continental Foods, Inc., Hoboken, N. J. (Subsidiary of Thos. J. Lipton, Inc.)
Corn Industries Research Foundation, New York 17, N. Y.
Corn Products Refining Co., New York, N. Y.
Cudahy Packing Co., South Omaha Station, Neb.
Drake Bakeries, Inc., Brooklyn, N. Y. (Subsidiary to Borden Co.)
General Foods Corp., New York, N. Y.
General Mills, Inc., Minneapolis, Minn.
Hawaiian Pineapple Co., Ltd., Honolulu, Hawaii.
H. J. Heinz Co., Pittsburgh, Pa.
Hershey Chocolate Corp., Hershey, Pa.
Imperial Sugar Co., Sugar Land, Texas.
Kind & Knox Gelatin Co., Camden, N. J.
Thomas J. Lipton, Inc., Hoboken, N. J.
Morton Salt Co., Chicago, Ill.
National Biscuit Co., New York, N. Y.
National Dairy Research Laboratories, Inc., Long Island City, N. Y.
Pillsbury Mills, Inc., Minneapolis, Minn.
Quaker Oats Co., Chicago, Ill.
Ralston Purina Co., St. Louis, Mo.
Red Star Yeast and Products Co., Milwaukee, Wis.
Refined Syrups & Sugars, Inc., Yonkers, N. Y.
Staley Manufacturing Co., Decatur, Ill.
Standard Brands, Inc., New York, N. Y.
Swift & Co., Chicago, Ill.
United Fruit Co., Boston, Mass.
Ward Baking Co., New York, N. Y.

Glass and Fiber Products

Corning Glass Works, Corning, N. Y.
Libbey-Owens-Ford Glass Co., Toledo, Ohio.
Minnesota Mining & Mfg. Co., St. Paul, Minn.
Owens-Corning Fiberglas Corp., Newark, Ohio.
Owens-Illinois Glass Co., Toledo, Ohio.
Pittsburgh Plate Glass Co., Pittsburgh, Pa.
Raybestos-Manhattan, Inc., Passaic, N. J.
Rayonier, Inc., New York, N. Y.
Willson Products, Inc., Reading, Pa.

Individuals

Lt. Franklin H. Branin, Jr., Silver Springs, Md.
Andrew Fletcher, President, St. Joseph Lead Co., New York, N. Y.
H. Burton Lowe, New York, N. Y.

Laboratory Equipment

The American Platinum Works, Newark, N. J.
Baker & Co., Inc., Newark, N. J.
Barnstead Still & Sterilizer Co., Boston, Mass.
Beckman Instruments, Inc., South Pasadena, Calif.
Fisher Scientific Co., Pittsburgh, Pa.
International Equipment Co., Boston, Mass.
Kewaunee Mfg. Co., Adrian, Mich.
Leeds & Northrup Co., Philadelphia, Pa.
The Pfaudler Co., Rochester, N. Y.
Arthur H. Thomas Co., Philadelphia, Pa.
T. C. Wheaton Co., Millville, N. J.

Machinery and Electrical Equipment

Bell Telephone Laboratories, New York, N. Y.
Blaw-Knox Co., Pittsburgh, Pa.
Food Machinery and Chemical Corp., San Jose, Calif.
Foster Wheeler Corp., New York, N. Y.
General Electric Corp., Schenectady, N. Y.
Infilco, Inc., Chicago, Ill.
Philco Corp., Philadelphia, Pa.
Radio Corp. of America, Princeton, N. J.
Remington Rand, Inc., So. Norwalk, Conn.
Research Construction Co., Inc., New York, N. Y.
Sylvania Electric Products, Inc., New York, N. Y.
United Shoe Machinery Corp., Boston, Mass.
Wagner Electric Corp., St. Louis, Mo.
Western Precipitation Corp., Los Angeles, Calif.
Westinghouse Electric Corp., Pittsburgh, Pa.

Metals and Mining

Iron and Steel

Allegheny Ludlum Steel Corp., Pittsburgh, Pa.
Arco Steel Corp., Middletown, Ohio.
Crucible Steel Co. of America, Pittsburgh, Pa.
Downingtown Iron Works, Inc., Downingtown, Pa.
Inland Steel Co., Chicago, Ill.
Jones & Laughlin Steel Corp., Pittsburgh, Pa.
Molybdenum Corp. of America, New York, N. Y.
U. S. Steel Corp., Pittsburgh, Pa. (of Delaware)

Nonferrous Metals

Aluminum Co. of America, Pittsburgh, Pa.
American Brass Co., Waterbury, Conn.
American Zinc, Lead and Smelting Co., St. Louis, Mo.
The Eagle-Picher Co., Cincinnati, Ohio.
The Indium Corp. of America, Utica, N. Y.
International Nickel Co., Inc., New York, N. Y.
Kennecott Copper Corp., New York, N. Y.
Metal Hydrides, Inc., Beverly, Mass.
The Vulcan Copper & Supply Co., Cincinnati, Ohio.
The Vulcan Detinning Co., Sewaren, N. J.

Mining

The M. A. Hanna Co., Cleveland, Ohio.

Pittsburgh Consolidation Coal Co., Pittsburgh, Pa.

Paints and Varnishes

Lilly Co., High Point, N. C.
Lilly Varnish Co., Indianapolis, Ind.
National Lead Co., New York, N. Y.
The Sherwin-Williams Co., Cleveland, Ohio.
Stoner-Mudge Co., Pittsburgh, Pa.
Thompson & Co., Oakmont, Pa.
Titanium Alloy Manufacturing Division, National Lead Co., New York, N. Y.
Titanium Pigment Corp., New York, N. Y. (Subsidiary of National Lead Co.)

Paper Products

Behr-Manning Corp., Troy, N. Y.
The Gardner Board and Carton Co., Middletown, Ohio.
Marathon Corp., Rothschild, Wis.
The Mead Corp., Chillicothe, Ohio.
West Virginia Pulp & Paper Co., New York, N. Y.

Petroleum

Anglo-Iranian Oil Co., Ltd., New York, N. Y
Atlantic Refining Co., Philadelphia, Pa.
Continental Oil Co., Ponca City, Okla.
Fluor Corp., Ltd., Los Angeles, Calif.
Gulf Oil Corp., Pittsburgh, Pa.
W. D. Heath Eves (USA representative of Anglo-Iranian Oil Company, Ltd.), New York, N. Y.
Humble Oil & Refining Co., Houston, Tex.
Lion Oil Co., El Dorado, Ark.
The Lubisol Corp., Cleveland, Ohio.
Pan American Refining Co., Houston, Tex.
Phillips Petroleum Co., Bartlesville, Okla.
The Pure Oil Co., Chicago, Ill.
Richfield Oil Corp., Los Angeles, Calif.
Shell Chemical Corp., New York, N. Y. (Associate of Shell Oil Co.)
Shell Development Co., Emeryville, Calif. (Associate of Shell Oil Co.)
Shell Oil Co., New York, N. Y.
Sinclair Refining Co., New York, N. Y.
Socony-Vacuum Laboratories, Socony-Vacuum Oil Co., Inc., New York, N. Y.
Standard Oil Co. of California (and its subsidiaries), San Francisco, Calif.
Standard Oil Co. (Ind.), Chicago, Ill.
Standard Oil Co. (the Ohio Corp.), Cleveland, Ohio.
Standard Oil Development Co. (N. J.), New York, N. Y.
Sun Oil Co., Philadelphia, Pa.
The Texas Co., New York, N. Y.
Union Oil Co. of California, Wilmington, Calif.
Universal Oil Products Co., Chicago, Ill.

Pharmaceuticals, Cosmetics, and Soap

Abbott Laboratories, North Chicago, Ill.
Bristol-Myers Co., Hillside, N. J.
Burroughs Wellcome & Co., Inc., Tuckahoe, N. Y.
Chesebrough Manufacturing Co., New York, N. Y.
Ciba Co., Inc., New York, N. Y.
Ciba Pharmaceutical Products, Inc., Summit, N. J.
Colgate-Palmolive-Peet Co., Jersey City, N. J.
Dodge & Olcott, Inc., New York, N. Y.
Heyden Chemical Corp., New York, N. Y.
Hoffmann-La Roche, Inc., Nutley, N. J.
Johnson & Johnson, New Brunswick, N. J.
Lambert Pharmacal Co., St. Louis, Mo.
Lehn & Fink Products Corp., Bloomfield, N. J.
Lever Brothers Co., Cambridge, Mass.
Eli Lilly & Co., Indianapolis, Ind.
Merck & Co., Inc., Rahway, N. J.
Wm. S. Merrell Co., Cincinnati, Ohio.
Northam Warren Corp., Stamford, Conn.
Parke, Davis & Co., Detroit, Mich
S. B. Penick & Co., New York, N. Y.
Charles Pfizer & Co., Inc., Brooklyn, N. J.
The Procter & Gamble Co., Cincinnati, Ohio.
Schieffelin & Co., New York, N. Y.
G. D. Searle & Co., Chicago, Ill.
Smith, Kline & French Laboratories, Philadelphia, Pa.
E. R. Squibb & Sons, New York, N. Y.
Sterling Drug, Inc., New York, N. Y.
U. S. Vitamin Corp., New York, N. Y.
Upjohn Co., Kalamazoo, Mich.
Winthrop-Stearns, Inc., New York, N. Y.
Zonite Products Corp., New York, N. Y.

Publishers

Interscience Publishers, Inc., New York, N. Y.
McGraw-Hill Publishing Co., Inc., New York, N. Y.
Reinhold Publishing Co., New York, N. Y.

Research Institutions

Battelle Memorial Institute, Columbus, Ohio.
Mellon Institute of Industrial Research, Pittsburgh, Pa.
Southwest Research Institute, San Antonio, Tex.
Southern Research Institute, Birmingham, Ala.
Stanford Research Institute, Stanford, Calif.

Rubber Products

Connecticut Hard Rubber Co., New Haven, Conn.
Firestone Tire & Rubber Co., Akron, Ohio.
B. F. Goodrich Co., Brecksville, Ohio.
Goodyear Tire & Rubber Co., Akron, Ohio.
Hewitt-Robins, Inc., New York, N. Y.
Lee Tire & Rubber Co. of New York, Inc., Conschohocken, Pa.
Rubber Corp. of America, Brooklyn, N. Y.
U. S. Rubber Co., Passaic, N. J.

Textiles

American Viscose Corp., Philadelphia, Pa.
Celanese Corp. of America, New York, N. Y.
The Clark Thread Co., Inc., and affiliated companies, New York, N. Y.
Collins & Aikman Corp., Philadelphia, Pa.
Industrial Rayon Corp., Cleveland, Ohio.
Mohawk Carpet Mills, Inc., Amsterdam, N. Y.
North American Rayon Corp., New York, N. Y.

Tobacco Products

The American Tobacco Co., New York, N. Y.
Liggett & Myers Tobacco Co., Inc., New York, N. Y.
Philip Morris & Co., Ltd., New York, N. Y.
R. J. Reynolds Tobacco Co., Winston-Salem, N. C.

Transportation

Bendix Aviation Corp., Detroit, Mich.
General American Transportation Corp., Chicago, Ill.

Vegetable Oil

Archer-Daniels-Midland Co., Minneapolis, Minn.
Deecy Products Co., Cambridge, Mass.
E. F. Drew & Co., New York, N. Y.
Elbert & Co., Inc., New York, N. Y.
Spencer Kellogg and Sons, Inc., Buffalo, N. Y.

Miscellaneous

The Chemical Foundation, New York, N. Y.
Gillette Safety Razor Co., Boston, Mass.
W. T. Grant Co., New York, N. Y.
Safeway Stores, Inc., San Francisco, Calif.
W. A. Sheaffer Pen Co., Fort Madison, Iowa.
Stanley Home Products, Inc., Easthampton, Mass.
The United Gas Improvement Co., Philadelphia, Pa.
Watson Johnson Leavenworth & Blair, New York, N. Y.


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