TEXT FLY WITHIN THE BOOK ONLY

UNIVERSAL
LIBRARY

OU_156787

UNIVERSAL
LIBRARY

OSMANIA UNIVERSITY LIBRARY

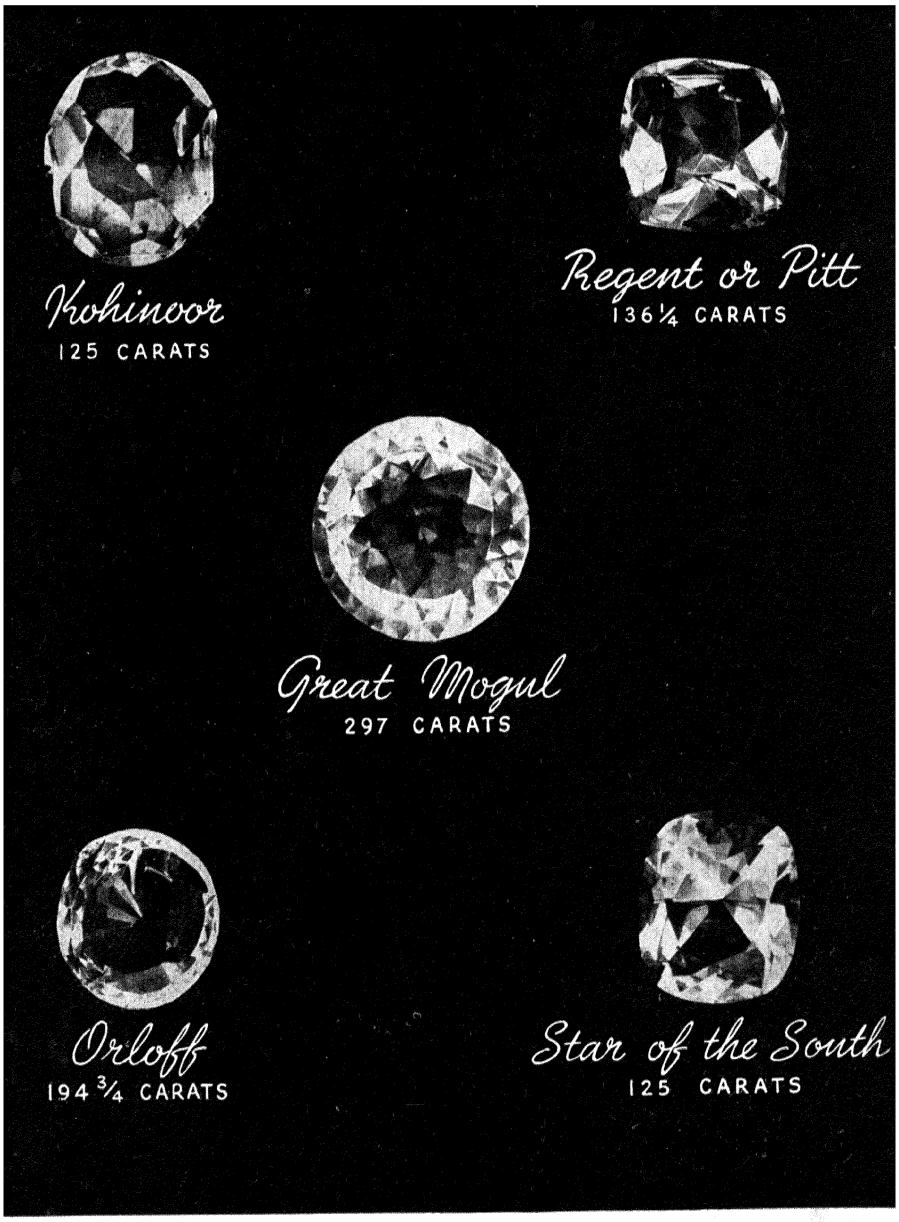
Call No. 551 | M13P Accession No. G

Author McCorkle, Paul.

Title Physical world. 1950.

This book should be returned on or before the date last marked below.

THE PHYSICAL WORLD



Famous Diamonds. (Courtesy, American Museum of Natural History.)

THE PHYSICAL WORLD

by

PAUL McCORKLE, Ph.D.

Head, Department of Physics, Bradley University



THE BLAKISTON COMPANY · 1950

Philadelphia · Toronto

COPYRIGHT, 1950, BY THE BLAKISTON COMPANY

This book is fully protected by copyright, and no part of it, with the exception of short quotations for review, may be reproduced without the written consent of the publisher

PRINTED IN THE UNITED STATES OF AMERICA
BY THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

This text comprises a survey and orientation course in the physical sciences. The material is designed to be a part of a college and university general education program. All educators recognize the importance of some science work in general college curricula and many colleges include several courses in the sciences as a part of the program of students.

In any large number of students beginning their college work there will be found three groups: those who have had little or no science in preparatory schools and who do not intend to pursue intensive work in the scientific field; those who plan to major in science; and those who are potential science teachers in the secondary schools. In this text an earnest effort has been made to provide material which is of value to each of these groups, yet material so chosen that there will be little duplication for students who supplement the course with the traditional courses in astronomy, chemistry, geology, and physics.

The book is the outgrowth of several years of teaching and supervision of physical science courses in various types of colleges. These experiences lead to the belief that such a text will enable those students who will go no farther in the physical sciences to have an appreciation of their scientific environment. Certainly it will make them better educators, ministers, lawyers, or housewives. One of the criticisms which is being directed at the science departments of our colleges is that each department aims to train students intensively in a particular field to the exclusion of the other curricula of the college. Whether or not this criticism is justified, many students avoid courses in the specific sciences and gain little or no knowledge of modern scientific developments.

The proper presentation of science in secondary and elementary schools is one of the most difficult tasks that a teacher can undertake. Because of the breadth of the field it is essential that the teacher have a thorough training in the entire field of science. Realizing this fact, our survey of science has been so built that it provides the necessary physical science background for the general science teacher. To this end numerous elementary demonstrations have been included throughout the text as well as much thought-provoking material. The experimental exercises found at the end of each chapter are suitable either for classroom demonstration or for individual laboratory work. In every instance, simplicity in equipment and in technic has been sought.

The text material has been divided into chapters which, as much as possible, are complete in themselves. This makes it possible for the teacher to change the order of use. Although the book is primarily intended for a year's course, it may be used as a semester course by omitting chapters. The variety of chapters enables each teacher to choose the material best suited to individual needs and interests. It is suggested that the text material be supplemented by extensive reading in books and magazines.

In choosing topics for inclusion in the text, the test in each case has been whether a topic is of general interest. The social and economic aspects have not been emphasized in as much as it is felt that such material is a part of other curricula in the college and that introduction of such topics would involve duplication. Some attention has been paid to the historical backgrounds of the sciences. In no case have scientific principles been sacrificed to attain simplicity of presentation. The ultimate goal has been to present a concise statement of each topic, introduced in a manner to arouse interest and stimulate logical thinking on the part of the student.

PAUL MCCORKLE

Peoria, Illinois

CONTENTS

Preface v

Introduction 1

1. The Sun 7
2. The Stars 21
3. The Moon and Eclipses 38
4. Planets and Other Bodies of the Solar System 49
5. The Earth as a Planet 62
6. The Earth a Clock 74
7. The Earth's Changing Crust 84
8. The Hydrosphere 96
9. Rocks and Minerals 111
10. Products of Rocks and Minerals 128
11. The Atmosphere 143
12. Winds and Weather 160
13. The Atom and Its Radiations 183
14. Matter Associated with Chemical Energy 202
15. Chemistry Associated with Living Things 219
16. Nutrition 230
17. Water and Its Applications in Daily Life 245
18. True and Apparent Solutions 255
19. Cleansing 265
20. Textiles and Plastics 272
21. Energy Applied to Machines 283
22. Heat, a Form of Energy 301
23. Energy and Its Relation to Sound 322
24. Energy Manifested as Light 336
25. Electricity and Magnetism 364
26. Electricity in Our Daily Life 383
27. X-rays and Radioactivity 403
28. The Future of Science 419

Index 439

INTRODUCTION

To science, pilot of industry, conqueror of disease, multiplier of the harvest, explorer of the universe, revealer of nature's laws, eternal guide to truth.

—INSCRIPTION ON THE NATIONAL ACADEMY OF SCIENCE

HISTORY AND AIMS OF A TEXT IN SCIENCE

As we turn back the pages of history, we are amazed at the paucity of scientific achievement in early centuries. Although the Chinese and the Greeks made great progress in mathematics, logic, and art, they accomplished little in the physical sciences. One of the great thinkers in the fields of science and logic was the Greek, Aristotle, 384–322 B.C. This man wrote voluminously in the sciences and in politics. A master of logical thinking, yet he erred in many of his ideas because he did not use the experimental method as a check on his logical arguments.

In this period there is, however, one exception in the person of Archimedes, who lived in Syracuse about 250 B.C. This great mathematician also worked in the realm of science. He stated the principles of flotation and of levers so clearly that we cannot improve upon his arguments.

During the period from 200 B.C. to A.D. 1200 there was a long interval during which little scientific work was done. It is true that the Arabs, taking up the torch of learning dropped by the Greeks, did some work in mathematics and alchemy. During this long interval, most of the learning was concentrated in the religious bodies in Europe. It is, therefore, not surprising that these bodies became the centers of intellectual advancement. Consequently, when Copernicus and Galileo appeared upon the scene, their revolutionary ideas in science had to confront the fixed ideas of the religious leaders. Many persons have criticized these leaders severely for their refusal to accept quickly these new concepts of the physical world. Perhaps such criticism is not altogether justified. When ideas have been prevalent for centuries, it is difficult for men to throw aside these ideas overnight. Even today, men change their opinions very slowly.

However that may be, we have in the work of these men examples of the triumph of experiment over pure logic. Galileo is rightly called the "father of experimentation." Whether or not he actually dropped objects from the leaning tower of Pisa, he was the first actually to test his

ideas by his sensory impressions. After his time, science became a prominent part of human knowledge.

In the very year of Galileo's death, Sir Isaac Newton was born. One of the greatest of thinkers, this man was destined to carry forward both the experimental method formulated by Galileo and the logic of the type used by Aristotle. By careful observation, he formulated laws of the universe which are amazing because of the clarity and brevity of their language. Unfortunately, it often happens that the ideas of a great thinker hinder progress in later generations. This was the case with both Aristotle and Newton. Some of Newton's statements, especially in the field of light, were incorrect. But such was his prestige that not until 1801 were they successfully challenged. When Thomas Young in that year proposed the wave theory in contradiction to the corpuscular one of Newton, men at first ridiculed his suggestion. But again experiment had its way and thus was opened a great new field of investigation.

Other scientists of this period were Franklin, Hutton, Volta, Laplace, Lavoisier, and Davy.

After 1800, the progress of science was rapid and extensive. We must be content to mention merely a few of the great investigators of the nineteenth century. Some of the outstanding names are Foucault, Michelson, Herschel, Kirchoff, Priestley, Fraunhofer, Dalton, Tyndall, Wöhler, Maxwell, Mendeléeff, Hertz, Helmholtz, Kelvin, Faraday, Arrhenius, Agassiz, and Darwin. Many of these men will be introduced to the reader in later pages as we proceed in our study of science. A sincere student of the scientific method will feel impelled to read the biographies of these great men in which are revealed the scientific methods of approach to the great problems of the universe.

Today the progress of science is so rapid and its achievements so vast that we dare not be dogmatic in our thinking. The accepted theory of today may be outmoded by the experiments of tomorrow. In the hands of such men as Roentgen, Richards, Thomson, Rutherford, Millikan, Urey, Einstein, Compton, Bohr, Sommerfeld, Nieuwland, and Fermi, to name only a few, our world of science has been rapidly expanding. No one can foresee the progress of the next generation.

This is an age of science. We are masters of machines. The man on the street ridicules the routine laboratory man and the theorist, but at the same time holds up to reverence an Edison or an Einstein. Such is the fame of Einstein that any item concerning him is important news. The entire text of the paper presented by Einstein in 1926 to the Prussian Academy of Science was cabled to the New York *Herald Tribune*, and was published in its entirety, including mathematical equations so complicated that only a few mathematical specialists could read them intelligently.

Although he is disdainful of the methods of the scientist, the layman

is quick to capitalize on the results of his achievements. Many a man has invested his fortune in a new wireless gadget, or a dreamer's method of television. Newspapers will still give space for an announcement of a "fuelless" motor, a "perpetual motion" machine, or "creation of life" in a test tube. Texts on popular science are best sellers. (One wonders just how much the layman understands of a popular description of the theory of relativity even when written by a master.)

Ignorance of science leads intelligent people into ridiculous decisions. Some years ago a great hubbub was created by a principle called "technocracy." One fallacious idea which came out of the principle was that science should stop making new discoveries of labor-saving machines lest mankind perish from economic bankruptcy. On the medical side, witness the millions of magnetic belts and other worthless contrivances and "patent" medicines which man buys to cure his ills.

For generations, men have accepted the doctrine of cause and effect, and only in the last decade has the principle been called into question. During some periods in the world's history, the doctrine produced curious conclusions. The Greeks believed that a man's life was charted at birth. If, for example, the individual was destined to die by drowning, it was beyond his power to prevent the accident. Such ideas were carried over into religious beliefs by Calvin and others, and led to the doctrine of predestination as opposed to that of free will. In science, men believed that if one could discover all the laws which govern a certain phenomenon, one would be able to understand the course of the experiment, be it the eruption of a volcano, a radio broadcast, or the flash of a lightning discharge. Perhaps one might state the position as that of law and order. Men believed that the universe was originally "wound up" and started on its path according to a set of physical laws. To know these laws would be to know truth. Today, many thinkers believe in a doctrine of free will (chance) in the field of physics and other sciences.

The thinking individual sees the world about him and speculates about its reality. Science attempts to describe and interpret the universe for him. It makes known that the universe has had a long period of evolution; it has gone through great changes in form and character of life. Most men are content to enjoy the benefits of science and they make no attempt to advance its boundaries. Occasionally there arises a mental giant who, with one vital principle, takes science ahead to great new discoveries. As these men come upon the stage of human progress, science advances by great strides.

Many persons have seized upon this realization of a scientific age to insist that the scientist must come down from his pedestal and scatter his knowledge to all men. To this end some educators insist that courses in the sciences must be superficial in character. Their viewpoint is that most

persons are merely "tourists in the forest of science and not hewers of wood." This type of argument has won many friends among those to whom concentrated thinking is abhorrent. As long as a beautiful word picture is drawn concerning an atom, they do not wish to be compelled to search underneath the painting for the artistry of the painter. We read in our newspapers about such apparently unrelated items as x-rays, radium, cosmic rays, and atomic bombs. It is the goal of science to coördinate such experiences, so that the intelligent man may be able to have a logical understanding of the underlying principles. This idea has been well stated by Einstein when he says, "The object of all science is to coördinate our experiences and bring them into a logical system."

In order to accomplish this end, one must strive to integrate the sciences to such an extent that the student sees the interrelation of all knowledge. In accomplishing such integration, however, we must be careful not to substitute slipshod thinking for exact logical processes. Clear thinking is always more satisfactory than half truths. In early times there was only natural philosophy. Man had not set up the arbitrary subdivisions of physics, geology, astronomy, biology, and chemistry. Although our scientific knowledge has increased greatly during the past century, it is still possible and wise to continue to introduce science by teaching natural philosophy.

There is also to be considered the use of science courses as cultural subjects. Many a college graduate has a thorough knowledge of the works of Shakespeare, but no intelligent information concerning the method of lighting the home. Moreover, such students have acquired no information or appreciation of the technics and skills which the scientist has developed over a long period of years. It should be the function of the course to give all students some cultural information. A natural result of such presentation is a desire on the part of the student to continue his studies along scientific lines. To appreciate science one must have a background of scientific knowledge.

The student may forget much of the factual material learned in his science courses, but, if he is an intelligent thinker, he will acquire from his science training the ability to judge values both in people and in material things. He will not be led astray by half-developed theories. He will be prone to sift ideas and to reserve judgment concerning questionable proposals. He will have learned to think logically and accurately. Modern industrial life is a complex and intricate network. Today, each of us is a link in a great chain, and the trained mind is essential to success.

Any one who attempts to present any field of science is faced with certain fundamental problems. During the past century, the world has seen a tremendous output of new marvels which have had their origin

in the work of some scientist. The scientific world is in a state of flux. The astronomer has penetrated far beyond the limits of the universe of our ancestors and is speculating about the size of the universe of stars and nebulae. The chemist is building up synthetic products at such a rate that the whole world of human affairs seems to be dependent upon the laboratory. Within the past 50 years, scientific discovery has awakened the mind of man to the realization that we live in a complex universe of which our world is only a tiny but complicated fragment. Despite this advancement, there is not one single branch, or even a minor subdivision, of which we can write a compilation of all that is known and say "this is the final record." Science has made and will continue to make for us a better and more comfortable world. It remains to be seen whether man can adjust his social structure to avail himself of the great advances offered as a result of scientific research.

The student who begins the study of the physical sciences may be appalled by the size of the task before him. He must remember, however, that in science, as in all other fields of knowledge, it is necessary to acquire a vocabulary of technical terms. Only by repeated use of these technical terms can he hope to acquire the vocabulary necessary for scientific development. Moreover, this is an age of experimentation and research. It is to be hoped that the student will, if possible, avail himself of considerable laboratory experimentation. Only by such methods can he really appreciate the scientific method.

The educational value of a study of science consists not so much in remembering the statements of others as in forming individual opinions through study and experimentation. The student who is satisfied to fill his mind with facts in order to pass an examination will not progress far in scientific thinking. He should learn to read and write intelligently on scientific topics. A good teacher of science will rely less on memorized facts than on a careful interpretation of the physical phenomena which the student experiences in daily life. An understanding of the principle of the doorbell is far more important than a memory drill on the Laws of Motion.

The student must always remember that the field of science is too vast to be covered adequately in any elementary textbook. What is learned there is only a stepping stone to a fuller realization of the tremendous activities of scientific investigators. Although much of the material in this book is well established, many statements made at present will need revision in the light of later study. Above all, the student of science must not be content with slipshod statements. It is just as easy and far more satisfactory to state principles accurately as to make vague statements which mean nothing.

References

Coith: "So You Want to Be a Chemist," New York, The McGraw-Hill Book Co.
Haldane: "Science and Everyday Life," New York, The Macmillan Co.
Joffe: "Men of Science in America," New York, Simon and Schuster.
Kaempffert: "Science Today and Tomorrow," New York, The Viking Press.
Lee: "Backgrounds and Foundations of Modern Science," Baltimore, Williams and Wilkins Co.
Loeb and Adams: "The Development of Physical Thought," New York, John Wiley and Sons.
Mees: "The Path of Science," New York, John Wiley and Sons.
Russell: "The Scientific Outlook," New York, W. W. Norton and Co.
Yates: "Young Men and Machines," New York, Dodd, Mead and Co.

1. THE SUN

Girt with his mantle of tempestuous flame glares in midheaven; but to his noontide blaze
The slender violet lifts its lidless eyes and from his splendour steals its fairest blue
Its sweetest perfume from his scorching fire.

—HOLMES

Man has always wished to understand the reasons for the phenomena of nature which he noticed about him. Those things which he did not understand he often made a part of his religious worship. The eclipses of the sun were thought by the Chinese to be caused by a dragon swallowing that "life-giving" object. The priests beat drums to drive away the dragon. Many people, such as the Mayas, sacrificed human lives in sun worship. Early man was a hunter and a fisherman, and he wove the animals around him into his religion and into his ideas of the sky. Later he became a herdsman, and his religion contained a worship of pastoral things.

At a very early time, the idea took root that the stars and the planets were controlling factors in man's life. Because of this, the subject of astrology became important in the minds of ancient peoples. Much of our knowledge of early races is due to the fact that they recorded eclipses and other happenings in the heavens as a part of their study of astrology.

Perhaps the most reverenced of all bodies was the sun, the "day star." This was most natural, inasmuch as life itself depends on the sun. The Egyptians and the Chaldeans made the sun one of the supreme gods. Consequently, in beginning a study of physical phenomena, it is natural to consider first the sun, for our sun is certainly to us the most important of all heavenly bodies. We, too, are dependent upon it for life itself. It provides light, heat, and ultraviolet rays, and makes possible the rainfall and the photochemical process necessary for the growth of plants. The variations in solar energy cause aurorae (see p. 376) and magnetic storms.

Our sun is an intensely hot ball of highly compressed gas that shines by its own light, as contrasted to the planets, such as Mars, which shine by reflected light. It is a star of average size and temperature. The star Betelgeuse, in the constellation of Orion, is 400 times the diameter of the sun.

Since, compared to other stars, the sun is close to the earth, it ap-

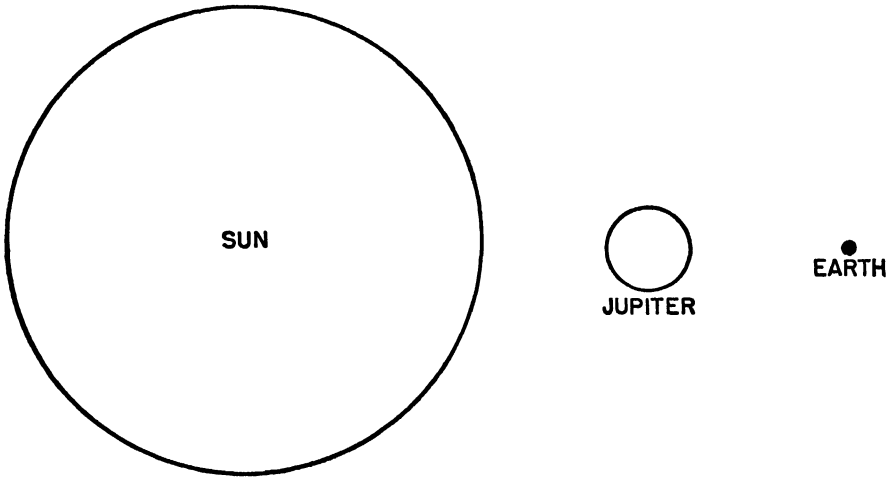


FIG. 1. Comparative sizes of sun, Jupiter, and earth.

pears to us to be a very large body. Actually, the sun is about 93,000,000 miles from the earth. To form a concept of this distance, imagine an aviator flying toward the sun at a speed of 300 miles per hour. He would need nearly 40 years to travel the distance. The diameter of the sun is 866,000 miles, which means that it is about 100 times the diameter of the earth. Over a million spheres of earth size could be packed into the sun if it were a hollow ball (Fig. 1). It requires 8 minutes for sunlight, at a speed of about 186,000 miles per second,[1] to travel from the sun to the earth.

The outermost part of the sun is called the *corona* (Fig. 2). This is visible only during a total eclipse, at which time it appears to be a great glob of pearly white color, its light being polarized (see p. 359). It apparently consists of a very much rarefied gas having a thickness of several hundred thousand miles. The exact constitution of the corona is still in dispute, but it is quite certain that it contains no unknown elements. There is some evidence that the corona lines seen in the spectroscope are due to the gas, helium.

Within the corona lies the *chromosphere* (color layer), a mass of gas mostly hydrogen, helium, and calcium, 5,000 miles thick. It is in violent motion and at times shoots out great prominences (Fig. 3) of glowing gas as much as a million miles high. The gases of the innermost part of the chromosphere (the reversing layer) are responsible for the Fraunhofer lines (see p. 16).

The central part of the sun, the visible disk, is named the *photosphere* (light-giving sphere). The temperature of this photosphere is believed to

[1] The exact value is $186{,}284 \pm 7$.

be several million degrees and the temperature of the surface is known to be about 10,000 degrees Fahrenheit.

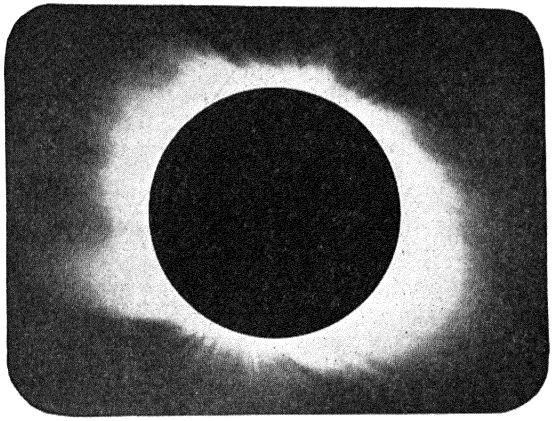


FIG. 2. The corona (Courtesy, Weld and Palmer "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

Because of the enormous pull of gravity on the sun, the material is compressed greatly; this results in the mass of the central part being very

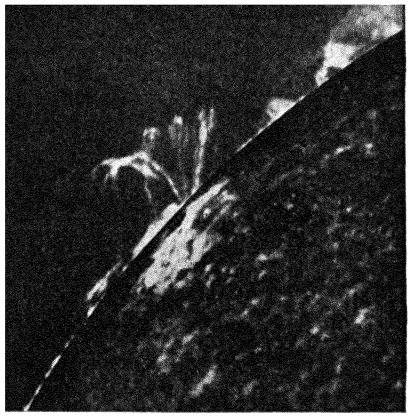


FIG. 3. Solar prominences. (A reprint of Yerkes Observatory negative S95. By permission of the University of Chicago Press.)

compact. In fact, it somewhat resembles a liquid in that it does not obey the gas laws. (See p. 148.)

ROTATION

The sun rotates on an axis in the same direction as the earth rotates. The time of rotation varies at different points, being 25 days at the equa-

tor and 33 days near the poles. Such a motion indicates that the sun is a fluid. (A fluid is a gas or a liquid.) One proof of this rotation is based on the Doppler Principle. Every one has noticed that the pitch of the sounding horn of an automobile seems to rise as the car approaches, and to fall as the car recedes. The principle as applied to light states that: If a luminous body moves toward us, the color of the light seems to shift slightly toward the violet end of the spectrum, the shift depending upon the speed. If the light source is moving away from us, the color shifts toward the red. By examining the light from the two sides of the sun's disk with a spectroscope (see p. 15), the rotation may be detected.

The position of a line in the spectrum is indicated by its wave length. For example, the red line of hydrogen under normal conditions has a wave length of 0.00006563 cm. If the light of a receding body containing hydrogen is examined, the wave length of the red line seems to be slightly longer. If the body is approaching, the wave length seems to be slightly shorter. The apparent change in wave lengths is due to the body's motion and not to any change in the state of the substance emitting the light.

Sun-spots

The movement of sun-spots also aids in proving that the sun rotates. These spots are really dark areas (Fig. 4), some more than 50,000 miles in diameter and perhaps 1,000 miles deep. They are saucer-shaped valleys on the surface consisting of whirling masses or spinning funnels of cooler gas which constitute cyclonic storms on the sun. They are probably much like tornadoes on the earth. A vortex or whirlpool in water, such as is caused by a canoe paddle, is a good illustration. George Hale, an astrono-

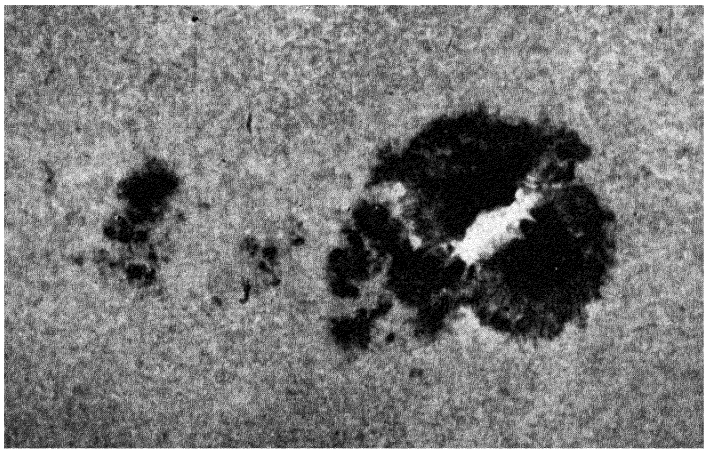


Fig. 4. Sun-spots. (Courtesy, Mt. Wilson Observatory.)

mer at Mt. Wilson Observatory, in 1903 discovered that these sun-spots produce intense magnetic fields, and that the Zeeman effect (the splitting of spectral lines by a magnetic field) was visible in the whirling spots. A sun-spot has some of the properties of a magnet.

These sun-spots become numerous at intervals of about 11 years. They were numerous in 1926, and again in the years 1937–1939. At the beginning of a sun-spot cycle, the spots are concentrated in the higher latitudes of the sun, about 40 degrees north and south of the sun's equator. As the cycle progresses, the spots approach the equator of the sun and disappear in low latitudes. Many of the spots occur in pairs, one in the northern hemisphere and one in the southern hemisphere. Because of their magnetic properties, at a period of sun-spot activity, we have "magnetic storms" due to a change in the *ionosphere* (see p. 400), which disturb radio and telegraph service. At such times the aurora borealis (see p. 376) and the aurora australis are very prominent. There is at present no satisfactory explanation of the cause of the spots.

Appearance

The casual observer will not find much of interest in the sun. It appears to be a ball of yellow light, too bright to be gazed at directly. We notice that it is high in the sky at noon in the summer, and that it is low during the winter months. We are also aware that it gives us long days in summer and short ones in winter. Most people also know that an exposure

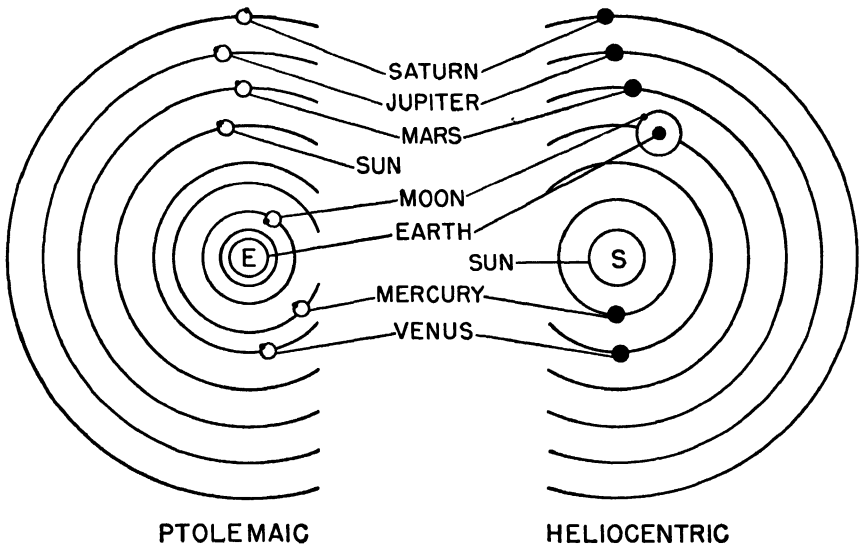


Fig. 5. (A) A diagram of the Ptolemaic universe. (B) A diagram of the heliocentric universe.

for a photograph is short when the sun is shining. The sun *apparently* rises in the east and sets in the west as a reddish ball. During most of the day it has a yellow color. Because of this apparent rising and setting, ancient peoples believed that the sun revolved about the earth. (A *revolution* refers to the motion of one body about another. A *rotation* refers to the turning of a body on its axis.)

Early Astronomers

Perhaps the most important scientist of early days was Aristotle (384–322 B.C.). This investigator studied biology, astronomy, and many other related fields. His ideas were prevalent until the fifteenth century. Another representative of the period was the astronomer, Ptolemy (about 100 B.C.). Both of these scientists believed that the earth was the center of the universe and that all other bodies revolved about the earth (Fig. 5, A). In the sixteenth century, Nikolaus Copernicus and Galileo Galilei (Fig. 6) advanced the heliocentric theory that the sun was the center of the solar system, and that the earth and the other planets revolved about it. Galileo, who is often called the "father of experimentation," made a small telescope, and by its use discovered the moons of Jupiter, the phases of Venus, mountains on the moon, and sun-spots. After the time of Galileo, the idea of a heliocentric system of planets became a fixed principle in science (Fig. 5, B).

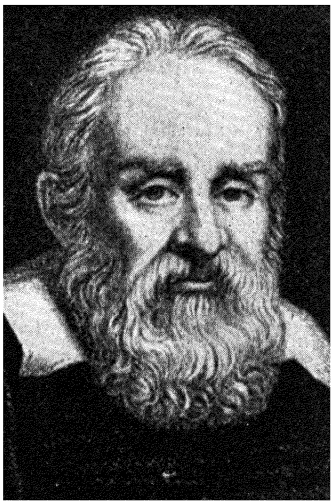


Fig. 6. Galileo Galilei (1564–1642). Discovered the moons of Jupiter; made one of the first telescopes; discovered the laws of the pendulum; founder of experimental physics.

Galileo (1564–1642) was a famous Italian, a professor at the University of Padua. He advocated the heliocentric theory of Copernicus but, because of his irascible attitude, was challenged by various religious groups. Because of his attitude, he suffered many hardships in his later life. Some of his discoveries in other fields were the laws of falling bodies and the laws of the pendulum.

It is interesting for us to try to understand the attitude of the people of that time toward science. An astronomer of the time of Galileo expressed himself as follows: "There are seven windows in the head—two nostrils, two eyes, two ears, and a mouth; so in the heavens there are two favorable stars (Venus and Jupiter), two unpropitious (Mars and Saturn), two luminaries (sun and moon), and Mercury alone undecided and in-

different. From which we gather that the number of planets is necessarily seven. Moreover, the satellites of Jupiter are invisible to the naked eye, and can have no influence on the earth, and are consequently useless, and therefore do not exist."

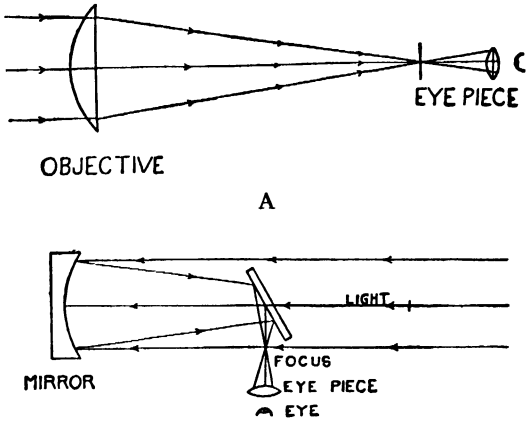


FIG. 7. (A) A refractor. (B) A reflector.

ASTRONOMICAL INSTRUMENTS

THE TELESCOPE. A telescope contains a lens or mirror of large diameter which forms an image of a distant object. It also contains an eyepiece to enable the observer to examine the details of the image. In the case of an astronomical refracting telescope, there are two convex lenses (thicker

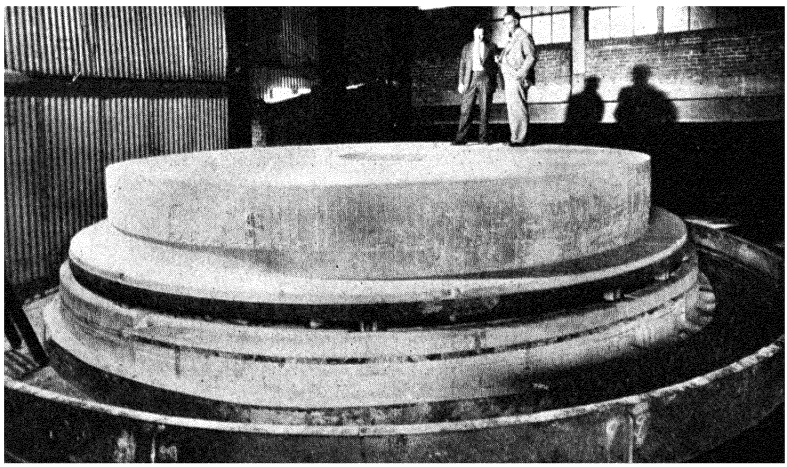


FIG. 8 .The casting for the 200-inch telescope mirror. (Courtesy, The Corning Glass Co.)

at the center than at the edge) (see p. 346) (Fig. 7, A). The objectives lens has a large diameter, that of the Yerkes telescope being 40 inches in diameter. In the reflecting telescope, the objective lens is replaced by a mirror with a concave surface (Fig. 7, B). The "100-inch" mirror at Mt. Wilson is of this type. There has now been set up at Mt. Palomar a telescope having a mirror 200 inches in diameter, which is a part of the most powerful telescope in existence (Fig. 8).

The 200-inch telescope was designed by George Ellery Hale of the Mt. Wilson Observatory, near Pasadena, California. The great mirror was cast from a special pyrex glass by the Corning Glass Works. The mirror has been ground to the proper curvature and is now in use. It is located on Mt. Palomar. The mirror is coated with aluminum instead of silver in order to secure better reflecting power for the ultraviolet. There are about 60 large telescopes located in various observatories of the world. Fig. 9 shows the reflector and the refractor at the Franklin Institute in Philadelphia.

If one wishes to study faint objects in the sky, the large lens or mirror is valuable in that it gathers considerable light from the object and brings the light to a focus for use by the eyepiece or by the spectroscope. Few persons have a clear understanding of the true value of a telescope. The largest telescopes give our eyes the effect of pupils several feet in diameter. If one remembers that the eye pupil has an area of about 0.03 square inch, it is evident that the "200-inch" mirror with an area of 31,400 square inches gathers several hundred thousand times the light that the unaided eye can gather. The light-gathering power depends on the area of the objective. In this way, stars too faint to be seen by the unaided eye become visible.

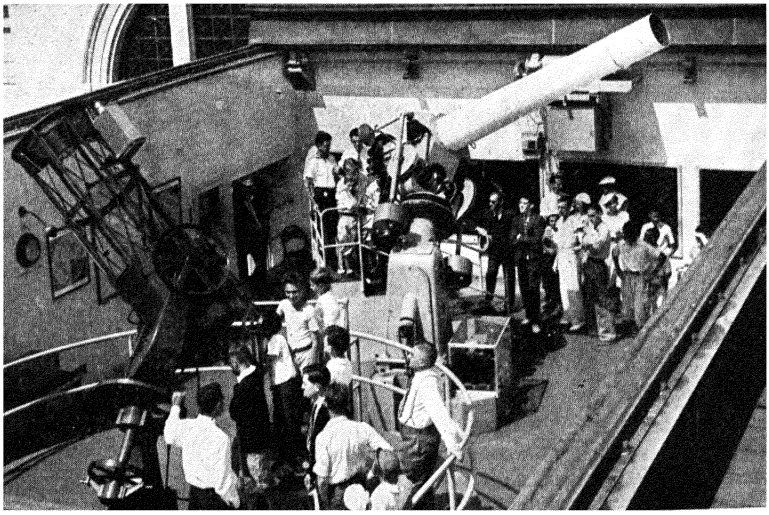


FIG. 9. Telescopes at the Franklin Institute, Philadelphia, Pa. (Photo Gladys Muller.)

In addition, the eyepiece has the property of making objects such as planets appear larger. A star is always a point of light. In order to produce clear vision, the "200-inch" mirror has been ground to an accuracy of one millionth of an inch.

THE SPECTROSCOPE. The principle underlying this instrument was discovered in 1666 by Sir Isaac Newton (Fig. 10), who formed a spectrum by passing white light through a prism. This spectrum is similar to the rainbow formed by water drops in the atmosphere. A simple type of the instrument consists essentially of a triangular glass prism (Fig. 11). When a narrow beam of white light such as that coming from an electric lamp filament or from the photosphere of the sun falls on the prism, the emergent light spreads outward into a continuous spectrum. To improve the spectrum we use a narrow slit and a system of lenses. If, instead of white light, the light from sodium vapor or the light of a helium tube enters the prism through a slit (Fig. 13), the emergent light will consist of lines of discrete colors called a bright line spectrum (Fig. 12). There will be no "rainbow." We find that every element in *the gaseous state can* produce a group of lines which serves to identify the element, and that *no two elements ever produce lines at exactly the same place in the spectrum.* For example, sodium



FIG. 10. Sir Isaac Newton (1642–1727). Invented the calculus, discovered many of the laws of light; stated the Law of Gravitation. One of the greatest scientists of all time.

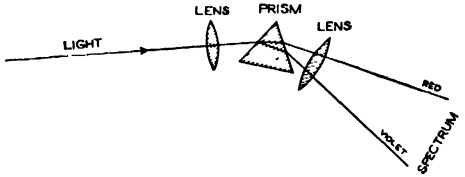


FIG. 11. Diagram of the prism spectroscope.

produces a line which absolutely identifies the element (Fig. 12). If sodium chloride (table salt) is placed in a flame, an amount as little as one-hundred-thousandth of a milligram can be detected, so that the chemist may use the spectroscope for analysis.

The uses of the spectroscope in modern science and industry cover such varied fields as the detection of poisons in foods, measurement of the temperatures and dis-

tances of stars, measurements of the temperatures in motor cylinders, a study of vitamins, investigation of atomic structure, identification of colors of paints, and research in crime detection.

When we use the spectroscope to study the sun, we find a continuous spectrum upon which are superimposed a great many dark lines, called the Fraunhofer lines (Fig. 12) after their discoverer. (At the time of a total eclipse, when the photosphere is covered, the Fraunhofer lines become bright lines called the *flash spectrum.*) By means of the spectroscope, it has been found that 61 of the known elements certainly exist in the chromosphere of the sun. A large part of the sun is hydrogen. However, the most striking result is that no evidence has been found that any element is present which does not exist on the earth. Possibly the reason that some of the other elements have not been found is that they lie deep in the sun and do not occur in its atmosphere (chromosphere).

The spectral lines of 12 of the missing elements are principally in the ultraviolet, and the rays do not penetrate the earth's atmosphere. (The element helium (*helios,* the sun) was first discovered in the sun by means of the spectroscope.) Some important elements which have not been found in the sun are gold, mercury, bismuth, radium, cesium, neon, argon, and chlorine.

The explanation of the appearance of the Fraunhofer lines is that the white light from the photosphere, when passing through the cooler gases of the reversing layer, loses a part of its intensity. Each element—e.g., hydrogen—in the reversing layer absorbs from the white light (composed of a mixture of all the colors) the same spectral colors that the element emits as a bright line spectrum. For example, sodium, which emits the yellow double line, will absorb light in the yellow part of the continuous spectrum. Thus we find dark *D* lines in the sun's spectrum (Fig. 14).

Possible Sources of the Sun's Heat

The sun is pouring out light and heat energy at a tremendous rate. The earth gets only a small fraction, about one two-billionth, of the total amount radiated.[2] From biologic and geologic evidence, we find that the sun has been pouring out this energy in about the same way for several billion years. How can we account for this enormous evolution of energy in the form of heat? Where does the energy go which does not strike the

[2] The solar constant of radiation is defined as the number of calories per minute which 1 square centimeter of the earth would receive from the vertical rays of the sun if there were no atmosphere around the earth. The value is about 2 calories per minute.

Fig. 12. Solar spectrum and bright line spectra of various elements.

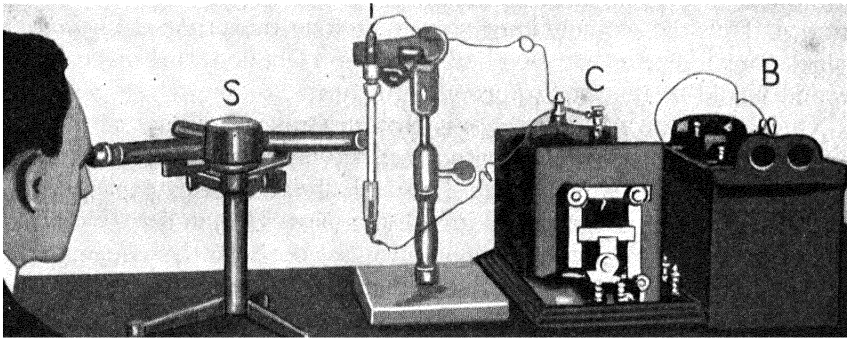


FIG. 13. Viewing the bright line spectrum of helium by means of a spectroscope. C is an induction coil which supplies current for lighting the helium tube (T) which contains helium gas at low pressure. S is the spectroscope. B is a storage battery.

earth? Men in all ages have speculated on these questions, but as yet they have not been answered to our satisfaction. We may immediately dismiss such ideas as that of a furnace burning coal. Were the sun made of pure carbon and giving out heat at its present rate, it would burn up in about 2,000 years. Moreover, the sun is too hot to burn! The carbon dioxide

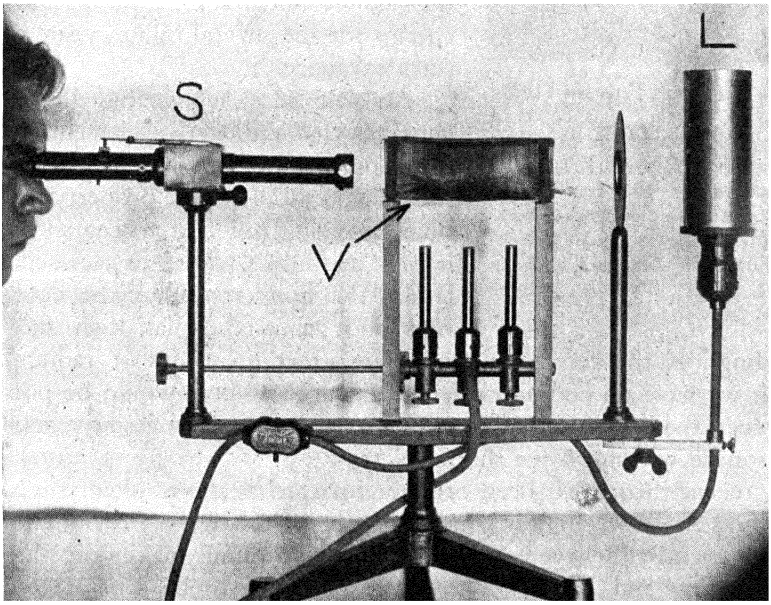


FIG. 14. An apparatus which illustrates the principle of the Fraunhofer lines. L is a tungsten lamp which represents the photosphere; V contains sodium vapor, representing the chromosphere. The sodium lines are viewed by the spectroscope (S).

produced by the oxidation of carbon would dissociate as fast as it was formed. Thus the sun could not give up heat by this process. Theoretical calculations indicate that the combustion of 15 billion tons of coal each second would be required to produce the heat.

One of the earliest guesses was that meteors (shooting stars) were continually falling into the sun and that the heat developed by the collisions kept up the temperature. The difficulty with this explanation is that the sun would continuously increase in mass. This, in time, would increase the attraction of gravitation and upset the solar system, with the result that the planets would approach the sun. Apparently, nothing of this sort is happening.

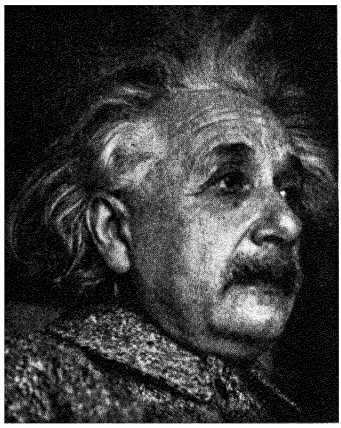


FIG. 15. Albert Einstein (1879–). A great mathematical physicist. He stated the principle of relativity. His work laid the foundation for the recent discoveries in atomic energy. A resident of Princeton, N.J. (Courtesy, Shapley: "Galaxies," Philadelphia, The Blakiston Company.)

Hermann von Helmholtz (1821–1894), a German physicist (see p. 344), advanced the theory that the sun was getting smaller, and that as it contracted the temperature was increasing due to the great compression of the gaseous photosphere. Although a good theory, there are serious difficulties with it; therefore it has been practically abandoned. Such a contraction could not have supplied sufficient energy for the several billion years of the sun's existence.

Another idea which has been suggested is that radioactive elements in the sun supply the heat. The element radium (see Chapter 27) has the property of continually giving out heat to the surroundings. If radium is placed in a closed container, the temperature of the container rises and remains higher than the surroundings. If the sun were to contain great quantities of radium, for which we have no certain evidence, a source of heat would be possible. However, the life of radium is too short—only a few thousand years. This heat source will not solve the problem.

A recent theory has been brought forward as the result of the work of *Albert Einstein* (Fig. 15) in his theory of relativity. Previous to this theory, scientists believed that there were two things making up the universe, *matter* and *energy*. These were believed to be separate entities which could be neither created nor destroyed. Einstein predicted that matter under certain conditions can be transformed into kinetic energy, and that energy can be changed into matter. From the theory we may calcu-

late that the conversion of 1 Gm. of material (for example, a few grains of sugar) into energy is equivalent to the burning of several thousand tons of coal. In 150 billion years, the sun's mass would need to decrease by only one one-hundredth of its original amount in providing the energy which it has emitted up to the present time.

Since the speed of atoms depends on the temperature, at 30,000,000 degrees Centigrade (the probable temperature of the core of the sun), a change of mass into energy may take place. This theory assumes that the mass of the sun is decreasing at the rate of 4,000,000 tons per second. But even at this rate most of the sun's mass still remains. Such a theory does predict an eventual disappearance of the sun at some future time.

Another possible source of the heat of the sun has been proposed recently by H. A. Bethe. He suggests that, as a result of a complicated set of nuclear reactions in the sun, four atoms of hydrogen combine to form one atom of helium. Since the mass of the four hydrogen atoms is nearly 1 per cent greater than the mass of the helium atom, this loss of mass when changed into energy may be the source of the heat emitted by the sun. The theory assumes that the carbon atoms in the sun act as a catalyst in the reaction.

If four hydrogen atoms of atomic weight 1.008 are changed into one helium atom of atomic weight 4.003, there will be a mass loss of 0.029 or 4.6×10^{-26} Gm. The energy produced from this mass loss may supply part of the heat of the sun (Chapter 27).

References

Abbott: "The Earth and the Stars," New York, D. Van Nostrand Co.
Duncan: "Astronomy," New York, Harper and Brothers.
Eddington: "Stars and Atoms," New York, Oxford University Press.
Ingalls: Amateur telescope making, *The Scientific American.*
Jeans: "The Universe Around Us," New York, The Macmillan Co.
McKready: "A Beginner's Star Book," New York, G. P. Putnam's Sons.
Menzel: "Stars and Planets," New York, The University Society.
Menzel: "Our Sun," Philadelphia, The Blakiston Company.
Moulton: "Astronomy," New York, The Macmillan Co.
Olcott: "Sun Lore of the Ages," New York, G. P. Putnam's Sons.
Stetson: "Sun-Spots," New York, The McGraw-Hill Book Co.

Questions and Problems

1. Describe the various layers of the sun.
2. Describe the principles of reflectors and refractors.
3. What evidence is there for a rotation of the sun?
4. What is: a star? a Fraunhofer line?
5. Describe sun-spots. Have they any effect on the earth?
6. Give three explanations for the cause of the sun's heat.
7. Describe a spectroscope.
8. Why are some elements not found in the sun?
9. If the sun were to become cooler, what effect would it have on the earth?

10. What is astrology?
11. How do we determine that the sun rotates counter-clockwise?
12. How could you determine whether carbon is present in the sun?
13. How can we prove that the earth revolves about the sun?

Topics for Discussion

Sun-spots	The Doppler Effect	The "200-inch" Telescope
Telescopes	Albert Einstein	Sir Isaac Newton

Possible Sources of the Sun's Heat

Experiments

1. Using a spectroscope of the type shown in Fig. 13, study the line spectra of sodium, lithium, and hydrogen. To produce the yellow lines of sodium, use a piece of glass rod in a Bunsen flame or a roll of asbestos soaked in salt water and placed on the Bunsen burner tube.
2. Use lithium chloride in a flame to produce the red line of lithium.
3. For hydrogen, use a hydrogen discharge tube, which can be purchased at any of the instrument companies. Connect it to an induction coil as shown in Fig. 13.
4. If a direct vision spectroscope is available, view the Fraunhofer lines in the sun's spectrum. There are several inexpensive types of this instrument that can be secured from the apparatus companies.
5. Using a piece of glass coated with lamp black, examine the sun to see if any sun-spots are visible. Be certain that the glass is well coated in order to protect the eyes.

2. THE STARS

The quenchless stars, so eloquently bright
Untroubled sentries of the shadow'y night.
—ROBERT MONTGOMERY

The starry heavens have been a source of amazing wonder to people of all times. Shepherds and astrologers, peasants and princes, alike have felt a sense of awe when gazing at the night-carpeted sky. Ancient peoples imagined that shapes of various animals were set among the stars. There are dogs (Canis Major and Minor), bears (Ursa Major and Minor), a lion (Leo), a bull (Taurus), a dragon (Draco), and various birds, but no elephants or tigers. Probably Babylonia and Persia furnished the names of many groups of stars. Later, other constellations were named from the heroes and heroines of Greek and Roman mythology. We have Cepheus, Perseus, Andromeda, Pegasus, and Cassiopeia. Other constellations are Auriga the charioteer, Bootes the herdsman, and Orion the hunter. It must be emphasized that, as a rule, stars in a constellation do not have the same distances from the earth. Their grouping is fortuitous.

The entire myth of Andromeda is recorded in the heavens. King Cepheus and Queen Cassiopeia had a daughter Andromeda, who was condemned by the gods to be sacrificed to the sea monster Cetus. The hero, Perseus, mounted on the winged horse, Pegasus, rescued the maiden. The entire group is found in the northern constellations.

Another interesting story concerns Orion, the mighty hunter, who had the misfortune to be loved by the goddess Diana. The sky shows Orion accompanied by his dogs, Canis Major and Canis Minor, hunting the bull Taurus. On the shoulders of Orion we find the great star Betelgeuse, and at his feet the star Rigel. In Canis Major is Sirius, and in Canis Minor is Procyon. The teacher of young children will do well to use some of these myths as stories to arouse interest in the stars and in their positions.

The names of some stars in the constellations come from Arabia, such as Betelgeuse, Rigel, Alcor, Mizar, Deneb, Aldebaran. Others are of Roman origin: Capella, Vega, Spica, Sirius. Stars having names are those which are very bright (first or second magnitude). There are 20 first-magnitude and 65 second-magnitude stars. The unaided eye can see under the best conditions only about 5,000 stars. Because of its light-gathering power, however, one could photograph by means of the "100-inch" telescope about one billion stars (Fig. 16). Because of the enormous num-

ber of stars, thousands are known only by a number or a Greek letter, and millions have not even a number. Some of the bright stars are described in Table 1.

Each of these stars is a sun like our own. Each radiates light and heat energy into the surrounding space. With the exception of our sun, all the stars are very remote. The nearest star, Proxima, in the constellation Centaurus, is 4.3 *light years* (25 million million miles) distant. This star is not visible in northern United States. Many of the stars are far larger than the sun, while others are smaller. Some are very hot, others comparatively cool. Blue stars such as Sirius (the brightest star in the sky) in the constellation Canis Major have surface temperatures of about 18,000° F., while red stars such as Aldebaran in the constellation Taurus are rather cool, 5,000° F. Moreover, it is quite certain that there are dark



FIG. 16. The North America Nebula. A star field. From a photograph by Barnard at Mount Wilson with the 10-inch Bruce camera of the Yerkes Observatory. (Courtesy, Bok and Bok: "The Milky Way," Philadelphia, The Blakiston Company.)

Table 1

THE STARS

Name	*Constellation*	*Apparent Magnitude*	*Type*	*Distance (Light Years)*	*Diameter (Sun = 1)*	*Density (Water = 1)*	*R.A. (hrs.)*	*Declination (Degrees)*
Sirius .	Canis Major	−1 6	A	8 8	1 8	0.4	6.7	−16 6
Canopus. .	Argo	−0 86	F	540	. .	. .	6 4	−52 6
Alpha Centauri.....	Centaurus	+0 05	G	4	1.1	10	14.5	−60.5
Vega.....	Lyra	+0.14	A	27	3	0.1	18.6	38.7
Arcturus...	Bootes	+0.25	K	40	160	3×10^{-4}	14.2	19.6
Betelgeuse.	Orion	1.0	M	270	400	5×10^{-7}	5.9	7.4
Aldebaran..	Taurus	1.05	K	57	38	5×10^{-5}	4.5	15.0
Antares .	Scorpius	1.2	M	250	450	4×10^{-7}	16 4	−26.3
Deneb..	Cygnus	1 33	A	400	0 7	1 3	20 6	45 0

bodies in the sky which were once luminous but have now cooled. The Coal Sack in the southern sky is probably a mass of dark material about 300 light years away that obstructs our view into outer space. There are also star clusters (Fig. 17).

STAR SPECTRA

Although the sun and the planets have been studied by astronomers for centuries, it is only within the last one hundred years that the stars have received special attention. In 1824, Fraunhofer was able to study the spectra of some of the bright stars. In 1885, W. H. Pickering and his associates at Harvard set out to photograph and classify star spectra. After 60 years of intensive work, there are recorded measurements of over 200,000 stars. A few of these stars have the curious property of flaring up to intense brightness and then slowly fading. Such stars are called *novae*. No explanation for such behavior has been found. Two famous novae are one in Aquila which was very bright in 1918, and one in Hercules which flared up in 1934.

Fig. 18 shows various types of star spectra. Most of the lines are dark Fraunhofer lines. A few stars show bright line spectra.

The stars show great differences in the type of absorption (Fraunhofer) lines produced by their atmospheres, and, for convenience, have been divided into classes. Class *A* stars, of which a good example is Sirius in Canis Major, show strong hydrogen lines and lines of some metals. They are fairly hot, having a surface temperature of about 10,000° C. Class *G* stars, of which the sun and Capella in Auriga are examples, show evidence of many metals such as sodium and calcium. The surface temperature is about 6,000° C. Class *M* stars have a surface temperature of about 3,000° C. and

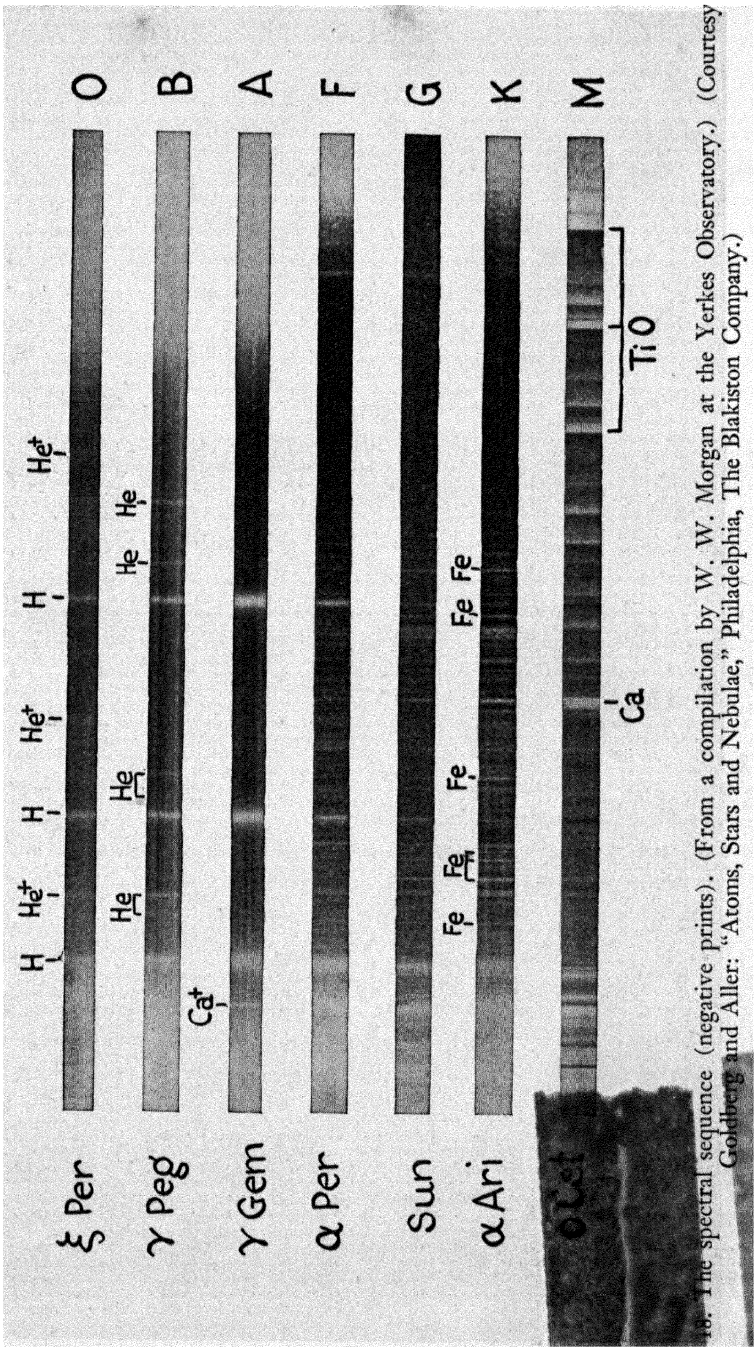
are distinctly reddish. Their atmospheres contain vapors of such metals as titanium. Betelgeuse is an example. There are a few stars which seem to have temperatures as high as 100,000° C. These are called Class *O*. Star temperatures are measured by the thermocouple (see p. 306). It is interesting that there are no evidences for unknown elements in any star. This is a great aid in explanations of the origins of stars.

Location of Celestial Objects

In order to locate a star in the sky it is necessary to have some reference lines. Let us imagine ourselves at the center of a great rotating hollow ball (the celestial sphere) whose surface is studded with stars. The axis of the earth points toward a star in this ball which is called Polaris (the North Pole Star). A circle drawn around this ball over our Equator is the *Celes-*



Fig. 17. The Pleiades Cluster. From a photograph by Barnard. The Pleiades are embedded in nebulosity. (Courtesy, Bok and Bok: "The Milky Way," Philadelphia, The Blakiston Company.)



18. The spectral sequence (negative prints). (From a compilation by W. W. Morgan at the Yerkes Observatory.) (Courtesy Goldberg and Aller: "Atoms, Stars and Nebulae," Philadelphia, The Blakiston Company.)

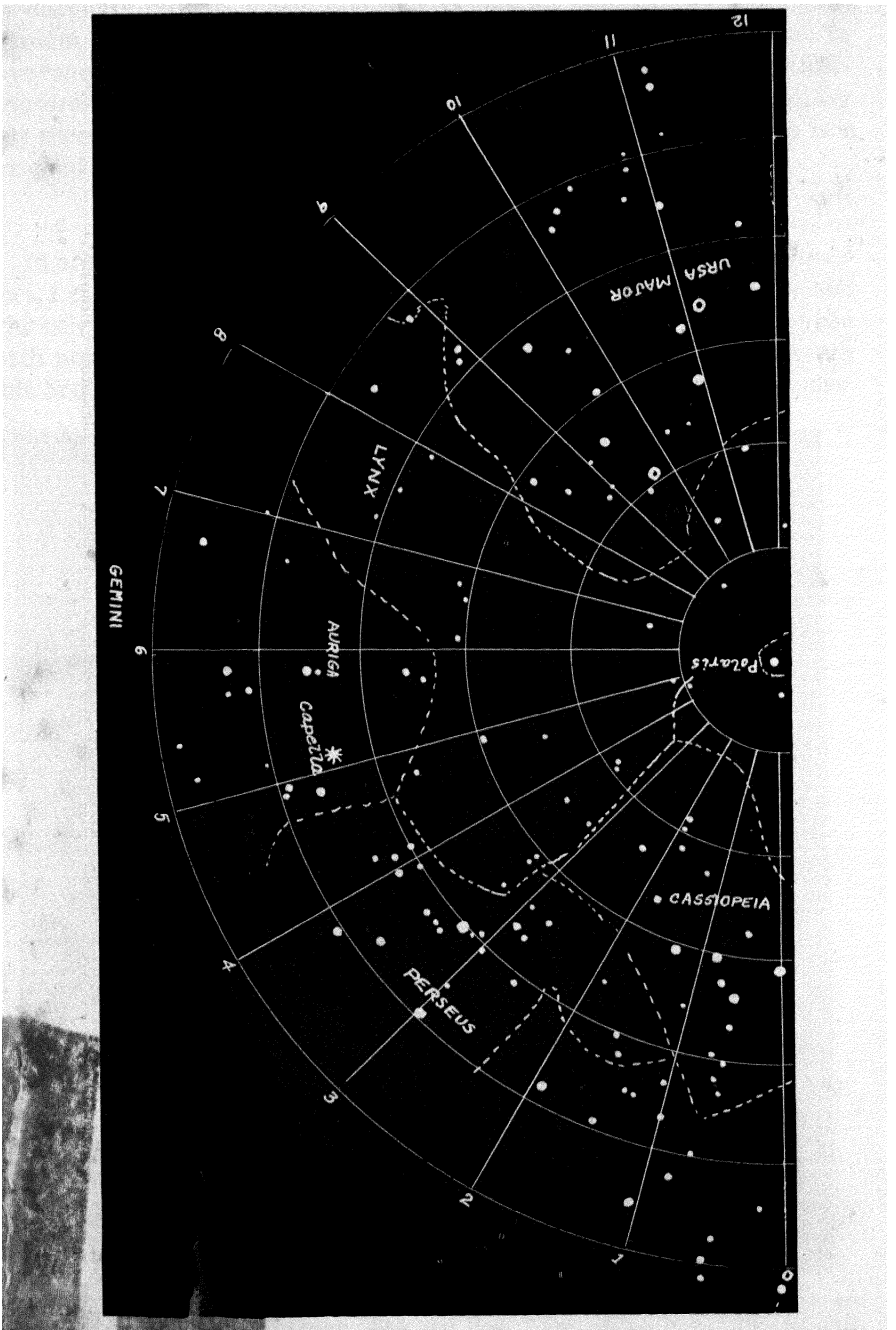
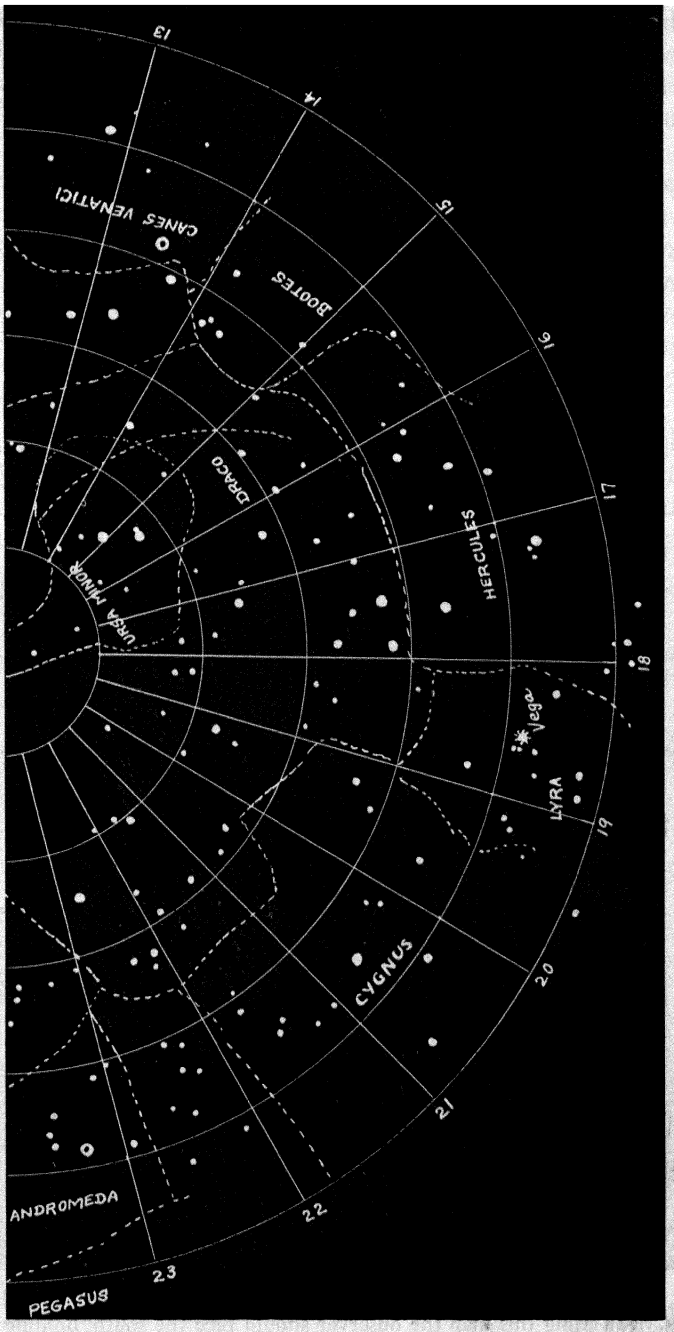


FIG. 19. The Northern Circumpolar region. Declinations 90° to 30°. The center of the



map is 90°. * First magnitude. ○ Nebulae. In using the map the observer faces north.

tial Equator. The point directly overhead is the *Zenith.* Just as latitude on the earth is measured from the equator to the pole, so *declination* is the term used to measure angular distance from the celestial equator to the pole. (The elevation of Polaris above the horizon at any location equals the latitude of the place. At 40° North Latitude, the altitude of Polaris is 40°.)

Instead of the term longitude we use the term *right ascension* (R.A.) for star mapping. *Right ascension* is measured eastward from the point in the sky where the sun meets the celestial equator at the beginning of spring (vernal equinox). The *vernal equinox* is a point on the celestial equator with the coördinates, R.A. zero hours, declination zero degrees. It is located just south of the constellation Pegasus. By use of the coördinates, right ascension and declination, we may locate stars in any part of the sky. In this system, Vega in the constellation Lyra is located as follows: Right Ascension 18 hrs., 30 min.; Declination North 38.7 degrees. (Table 1 gives the right ascension and declination for a number of the bright stars.) For convenience, the sky is usually divided into sections. The stars in the region north of 40 degrees North Declination are included

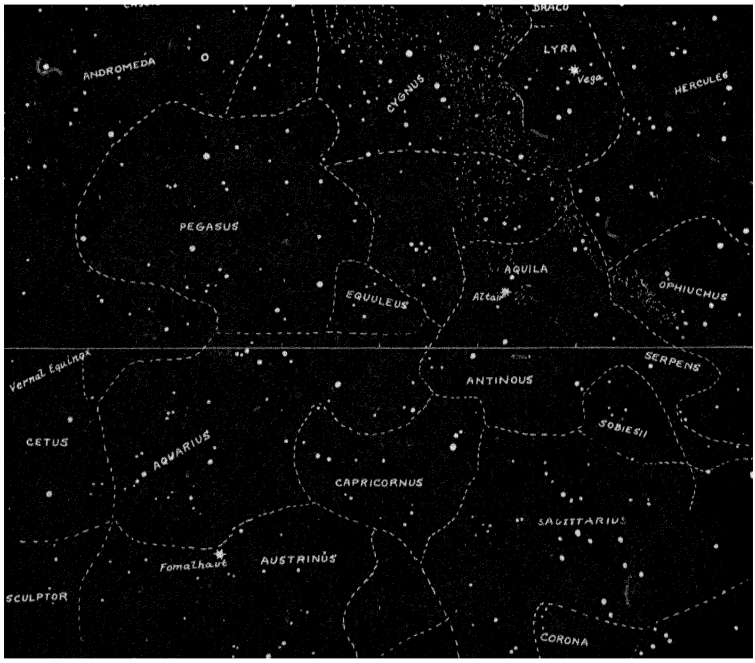


FIG. 20. Constellations visible in the United States, October 1, 8 P.M. and September 15, 9 P.M. In using this map the observer should face the south, holding the map in a position such that Cygnus is directly overhead. The line passing through the center of the map is the celestial equator. This map shows the position of the vernal equinox. Note the Milky Way.

in the North Circumpolar group (Fig. 19). The stars in the region south of 40 degrees South Declination comprise the South Circumpolar group. The balance of the stars in the sky are included in the Equatorial group.

To observers in latitude 40° North, the stars of the North Circumpolar group do not rise and set as do stars in the Equatorial group. Instead, they appear to revolve around Polaris once every 24 hours. The center of the map is nearly at the position of the star Polaris. The circles indicate *declination.* The radial lines mark the zones of right ascension.[1]

For example, the star Alpha Aurigae (Capella) has a declination of 47° North and a right ascension of 5 hrs. 10 min. (These numbers are only approximate, being read directly from the chart (see p. 26). Figs. 19–22 represent the brighter stars visible in the United States at various times of the year.)

STAR MAGNITUDES

The casual observer is aware that some stars are much brighter than others. On any clear night, some stars of Ursa Major, the star Vega in

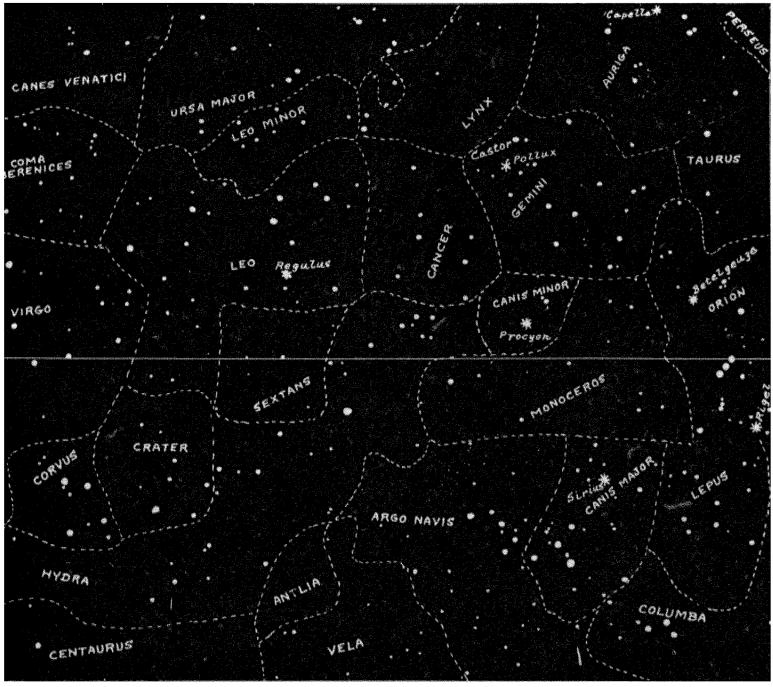


FIG. 21. Looking south April 1, 8 P.M. and March 1, 10 P.M. In this part of the year Capella will be nearly overhead. In the sky will be found Orion, Leo, and Canis Major.

[1] The declination circles are spaced at 10-degree intervals. Each right ascension line represents one hour.

Lyra, and the star Capella in Auriga stand out as bright dots in the northern sky. The astronomer uses the word *magnitude* to measure the relative brightness of stars. A star of first magnitude is 100 times as bright as a star of fifth magnitude, or 2.512 times as bright as a second-magnitude star. Thus it follows that a first-magnitude star is $(2.512)^2 = 6.31$ times as bright as one of third magnitude. From Table 1 we note that Betelgeuse in Orion is a typical first-magnitude star. The brighter stars in Cassiopeia are of second magnitude. However, there are objects in the sky still brighter, and for them we use zero and negative magnitudes. We note that Sirius is —1.6 magnitude. The moon, sun, and some planets (e.g., Venus —4) are still brighter and these also are given negative magnitudes.

Unfortunately, this *apparent* magnitude is of little scientific importance, because of the fact that the stars are at different distances from the earth. A much more important unit for scientific work is the *absolute magnitude*.

Let us suppose that all the stars are on the surface of a great sphere so that all are at the *same* distance, 32.6 light years, from the earth. The points of light will appear in their true relative brightness.

It is of interest to compare the magnitude of our sun with that of



FIG. 22. Looking south June 1, 10 P.M. and July 1, 8 P.M. This part of the sky contains Vega, Arcturus and Spica.

other stars, assuming all at the distance of 32.6 light years from the earth. Table 2 indicates that the sun under this condition is a very faint star.

Table 2

STAR MAGNITUDES

	Apparent Magnitude	*Absolute Magnitude*
Sun . .	−26 7	4 85
Sirius .	−1 58	1 27
Polaris	2 12	−3.65
Rigel	0 34	−5 77

DISTANCES OF CELESTIAL OBJECTS

Star distances are so enormous that it is inconvenient to indicate these distances in miles. Instead, the term *light year*, is used in popular language. This term means the number of miles that light travels in a year. Arcturus, in Bootes, is about 40 light years distant, an expression meaning that the light which reaches the earth tonight from Arcturus left that star 40 years ago. Perhaps it is more startling to make the equivalent statement: If Arcturus were to become dark today, we would still receive light for 40 years. Light travels in free space at a rate of 186,274 miles per second. (This means that the light comes from the moon in about one second, from the sun in eight minutes, and from distant planets in intervals of hours.) Since there are about 31,500,000 seconds in a year, this means that a light year is about 6 million million miles.

SPEED OF LIGHT

The speed of light has been determined by many observers, one of these being Abraham Michelson of the University of Chicago. By using a rotating mirror on one mountain and reflecting the light from a mirror on another mountain 22 miles distant, he was able to make an accurate calculation of the speed of light. Fig. 23 illustrates the method. Light from the arc is reflected from the face "a" of the rotating mirror. Upon reflection from the mirror M, the light returns and is viewed by the eye as it is reflected from "a'." Since the distance between mirrors was known accurately, Michelson needed only to determine the speed of rotation of the spinning mirror in order to calculate the speed of light through the atmosphere.

It is of interest to remark that the light which left Arcturus during the time of the Columbian Exposition in 1893 was used to turn on the lights at the Chicago Century of Progress in 1933, 40 years later. This was made possible by focusing a telescope on Arcturus and placing a photocell (see p. 195) at the eyepiece. The

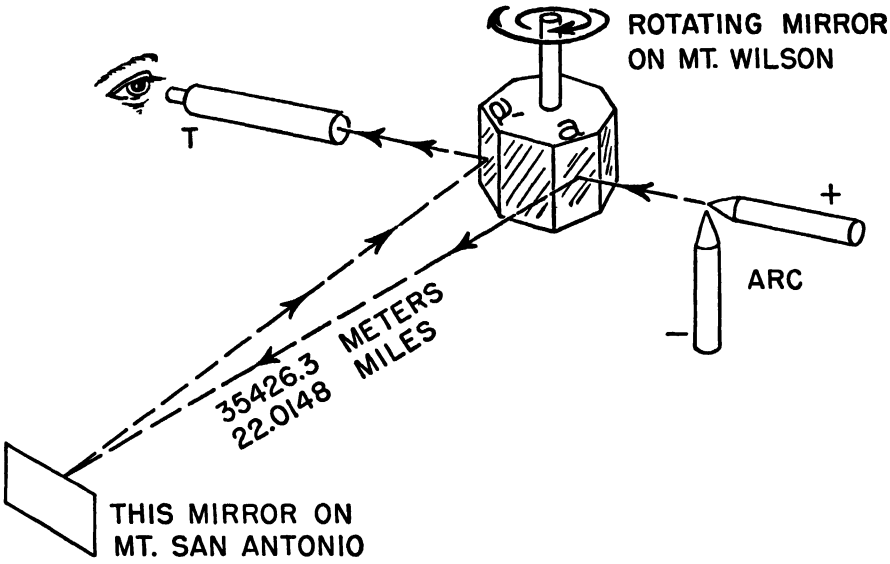


FIG. 23. Michelson's method of measuring the velocity of light.

electric current produced in the photocell operated the light switch which turned on the lights at the exposition grounds.

STAR DISTANCES

It is beyond the scope of this text to explain all the methods by which the enormous star distances are measured. The distances of nearby objects can be determined by the method of parallax. The reader may best understand parallax by performing the following simple experiment. Keeping one eye closed, hold a forefinger so that it is in line with some object on a rather distant wall. If, now, the other eye is opened and the first one closed, the finger will no longer be in line with the object. The finger has not shifted but the line of sight has changed.

In determining the distance of a body in the solar system, such as the moon, two observers at observatories A and B, several thousand miles apart (Fig. 24), may determine the apparent position of the object relative to the distant stars and thus measure the angle of parallax. This is the method that is used by the surveyor. In determining the width of a lake, a base line is measured along one bank. At both ends of this line the surveyor sights a tree on the opposite shore. From these measurements he has determined one side and the opposite angle of a triangle. It is then a simple problem in geometry to determine the distance across the body of water.

Similarly, in determining star distances, the astronomer at A (Fig. 25) observes the position of the star B relative to a background of distant

stars. Six months later, when the earth is on the other side of the sun at the position C, the astronomer observes the new position of the star B. The star has not shifted but the astronomer has. The base of his triangle is 186,000,000 miles, the diameter of the earth's orbit. One-half of the angle between the two directions is called the parallax of the star. This is

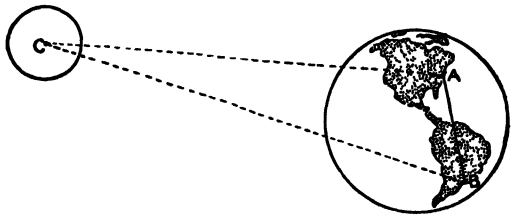


FIG. 24. The diagram illustrates how the astronomer measures the distance to the moon and sun. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

called the method of *Heliocentric Parallax* and is useful only for stars which are less than 200 light years distant.

One of the recent methods which is of great importance is the variable star method. There are stars in all parts of the sky which are brighter on some nights than on others. Some of these stars, the Cepheid Variables (so called because one of the type stars, Delta Cephei with a period of 5¼ days, is in the constellation Cepheus) flare up at regular intervals in the same manner that a fire brightens when fuel is added at regular intervals. These variables repeat exactly an increasing brightness followed by a decrease. They seem to be pulsating. Moreover, *the brightest of the Cepheids change their brightness most slowly*. All Cepheids with the same time of fluctuation have the same *absolute brightness*. The reason for the peculiar behavior of these stars is not known.

Miss Leavitt of the Harvard Observatory discovered some of these variables in one of the Magellanic Star Clouds, in the South Circumpolar

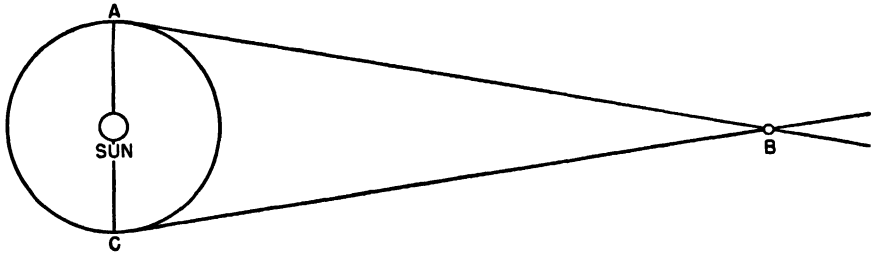


FIG. 25. The diagram shows how star distances are measured. The line AC is the diameter of the earth's orbit. This line is the base line of the triangle ABC. B represents the star whose distance is to be determined.

group. Since the distance of this star cloud was known already, the true brightness (absolute magnitude of the variables could be determined. Miss Leavitt found that the pulsation rates of these variables depended on their absolute magnitudes. As a result, the apparent brightness and true brightness of any Cepheid wherever found could be established and the distance of the star determined.

Most of the nebular distances have been determined by means of the Leavitt-Shapley Law. When a Cepheid variable has been found in a distant nebula—there are at least 40 in Andromeda—it is necessary only to determine its period of variation and its apparent brightness. The absolute magnitude can be determined and thus the distance can be calculated.

The Galaxies

Most of the great groups of stars and star clusters that we observe seem to belong to a closed system or *galaxy*. We observe the "Milky Way" as a cloud of distant stars forming a band about the sky, having a diameter of about 100,000 light years. Modern investigation leads us to believe that our galaxy is shaped like a flattened biscuit, not a sphere, and that the rim of our "Milky Way" Galaxy is the cloud of stars which we call the "Milky Way." Perhaps this galaxy is rotating like a pinwheel. It seems that the sun is one of the stars of the galaxy. It may be that the spin of the galaxy keeps the stars in position.



Fig. 26. Spiral nebula (M81). (Courtesy, Mt. Wilson Observatory.)

Outside this galaxy there are millions of other galaxies, many of which are of a spiral type (see Fig. 26). The best known of these outer galaxies is the "Nebula in Andromeda" (Fig. 27) which can be seen by the unaided eye on clear nights. It must be emphasized that the Andromeda Nebula is much more remote than any of the stars of the constellation Andromeda. The nearest outer galaxy is nearly 1,000,000 light years from the "Milky Way" Galaxy. Some of these nebulae are as remote as 500,000,000 light years. What is the limit of the universe? We do not know, but the suggestion of Einstein that his space-time system is a closed one has attracted much study. Perhaps the whole of space is composed of millions of galaxies.

The Evolution of the Universe

At the outset, it must be emphasized that any definite information concerning the method of formation of our present universe is lacking. We can only speculate, having as our basis the fragmentary information gained from the heavens by powerful telescopes.

For a long time men have conjectured that the universe was originally filled with a gas without form (chaos). As time went on, this gas tended to coagulate, forming separate bodies. These enormous bodies we call *nebulae* (Fig. 28). In these nebulae the process of the formation of the stars, which coagulated out of the formless gas, went on during countless years. By studying the nebulae it may be possible to form some



Fig. 27. The nebula in Andromeda. (A reprint of Yerkes Observatory negative N 101. By permission of the University of Chicago Press.)

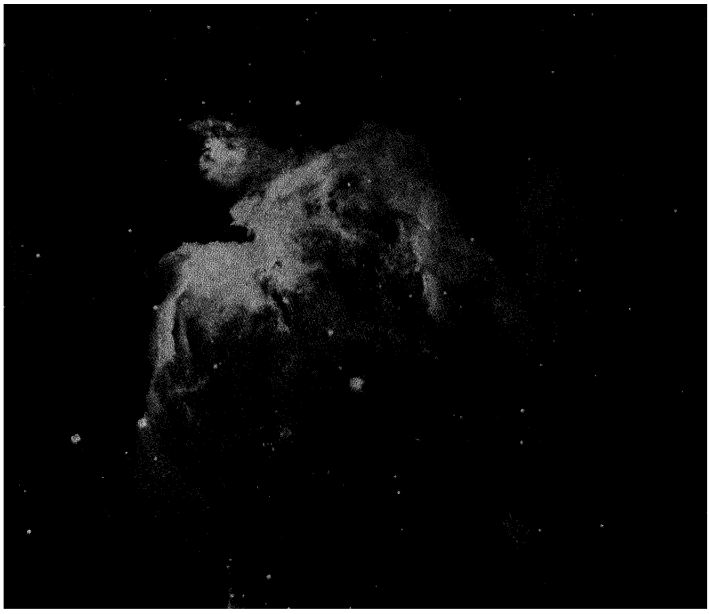


FIG. 28. The Orion nebula. (Courtesy, Mt. Wilson Observatory.)

better ideas of star evolution and to determine the size of the stellar universe.

REFERENCES

Abbott: "The Earth and the Stars," New York, D. Van Nostrand Co.
Collins: "The Book of the Stars," New York, Appleton-Century Co.
Fath: "Through the Telescope," New York, The McGraw-Hill Book Co.
Fisher and Lockwood: "Astronomy," New York, John Wiley and Sons.
Golberg: "Atoms, Stars, and Nebulae," Philadelphia, The Blakiston Company.
Grondal: "The Music of the Spheres," New York, The Macmillan Co.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
Jeans: "Astronomy and Cosmogony," New York, The Macmillan Co. (An advanced text.)
Jeans: "The Stars in their Courses," New York, The McGraw-Hill Book Co.
Jeans: "The Universe Around Us," New York, The Macmillan Co.
Luckeish: "The Book of the Sky," New York, E. P. Dutton and Co.
Menzel: "Stars and Planets," New York, The University Society.
Moulton: "Astronomy," New York, The Macmillan Co.
Russell, Dugan and Stewart: "Astronomy," Boston, Ginn and Co.
Shapley: "Galaxies," Philadelphia, The Blakiston Company.
Stetson: "Man and the Stars," New York, The McGraw-Hill Book Co.

QUESTIONS AND PROBLEMS

1. Describe the appearance of a nebula.
2. What is: a star? a constellation?

3. What is a Cepheid Variable? Why are they important?
4. How can we measure the distance to a planet?
5. What is meant by a class *G* star?
6. How many miles in 10 light years? Answer: 59×10^{12}
7. What is: right ascension? declination?
8. It requires 40 years for light to reach us from Arcturus. What is the distance to the star in miles? Answer: 236×10^{12}
9. What is the difference between a spiral nebula and a galactic nebula?
10. What is meant by the "Milky Way"?
11. If you were at the equator, could you see Polaris?
12. What is meant by a second-magnitude star?
13. How was the speed of light measured by Michelson?
14. For what is Arcturus famous?
15. For what is Miss Leavitt noted?

Visual Aid

"Exploring the Universe," University of Chicago Film

Topics for Discussion

Nebulae
Novae
Variable Stars
Star Distances
Star Diameters
Origin of the Universe
Star Types

Experiments

1. Plot the various constellations in the North Circumpolar group (Fig. 19). Use polar coördinate paper. This paper consists of concentric circles and radial lines. The circles are used for declination and the lines for right ascension. Special coordinate paper is procurable.
2. Using a test star chart such as those furnished by the Eastern Science Supply Co., write in the names of the principal stars from Fig. 19 of the text.
3. If desired, special sheets can be secured for the equatorial group, making it possible to plot the entire sky.
4. Choose the maps which correspond to the seasons of the year and learn to identify some of the important constellations. (Charts 1 and 2, pp. 432–433, will be found useful in plotting constellations.)

3. THE MOON AND ECLIPSES

O Lady Moon, your horns point toward the east,
Shine, shine, be increased, be increased.
O Lady Moon, your horns point toward the west,
Wane, wane, be at rest, Lady Moon, Lady Moon.
—CHRISTINE ROSSETTI

Next to the sun, the best-known object in the heavens is the moon. This bright object, varying in shape from a crescent to a complete disk of spotted appearance, is a frequent night visitor. Unfortunately, it is in the night sky for only part of the month and is seldom at full brightness so that its light is not dependable. As in the case of the sun, from earliest times man has endowed the moon with supernatural powers. The light of the moon was believed capable of producing moon madness, hence *lunacy*. Even today many farmers insist that unless they plant potatoes in the dark of the moon the crop will be poor. A ring about the moon is believed to predict wet weather. There is a basis of truth in this last idea since the ring is due to high humidity in the atmosphere of the earth, and for this reason rain may be imminent.

GENERAL DESCRIPTION OF THE MOON

The moon is the closest celestial object, the distance from the earth varying from 221,463 miles (perigee) to 252,710 miles (apogee). Its diameter is 2,160 miles and it is about $\frac{1}{64}$ the size of the earth. It is a dead body having, as far as can be observed, no atmosphere and no internal heat. This lack of atmosphere can be determined by viewing the edge of the moon (Fig. 29). The rim is very sharp, whereas it would be hazy if gases were around the body. When a star moves across the edge of the moon, it is suddenly eclipsed. If an atmosphere were present, the disappearance would be gradual. At the time of a total eclipse of the sun, the light shines between the jagged mountains of the moon, causing the "Baily's Beads." These various phenomena indicate that no atmosphere exists on the moon. The spectroscope indicates that no water is there. Any possible atmosphere may have been lost because the pull of gravity on the moon was not sufficient to prevent the escape of the rapidly moving gases and vapors (see p. 148). The force of gravity on the moon is much less than on the earth. It is believed that most of the hydrogen and helium on the earth have escaped into outer space because the pull of gravity

was not sufficient to retain these light gases. On the moon, it is possible that even the heavy gases, such as oxygen, carbon dioxide, and water vapor, have escaped, leaving no atmosphere. On earth, the velocity of escape is 7 miles per second, while on the moon the velocity of escape is only 1.5 miles per second. (It is of interest that the distance to the moon was determined in 1945 by radar wave propagation.)

TELESCOPIC APPEARANCE

As a contrast to the sun, the appearance of the moon in a telescope is very interesting. One finds mountain ranges, sharp peaks, and deep craters. There are other areas called *seas* because the early observers thought that they contained some liquid. These seas are rock areas. Some of them have interesting names such as the Sea of Tranquillity, the Sea of Nectar, and the Sea of Dreams.

In contrast to the earth, where the peaks are rounded off by the action of weathering, the mountains on the moon consist of jagged peaks, which show no evidence of climatic action. There are several mountain chains, among which are the Apennines, the Alps, and the Caucasus mountains. The Apennines alone have several thousand jagged peaks. Were we able to make a trip to the moon we would find walking very difficult. The rocks are probably like rough lava.

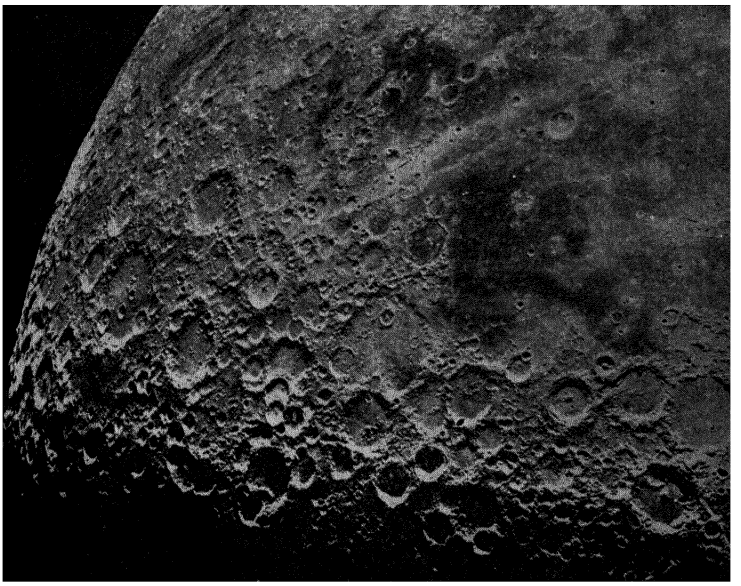


FIG. 29. Craters on the moon. (Courtesy, Mt. Wilson Observatory.)

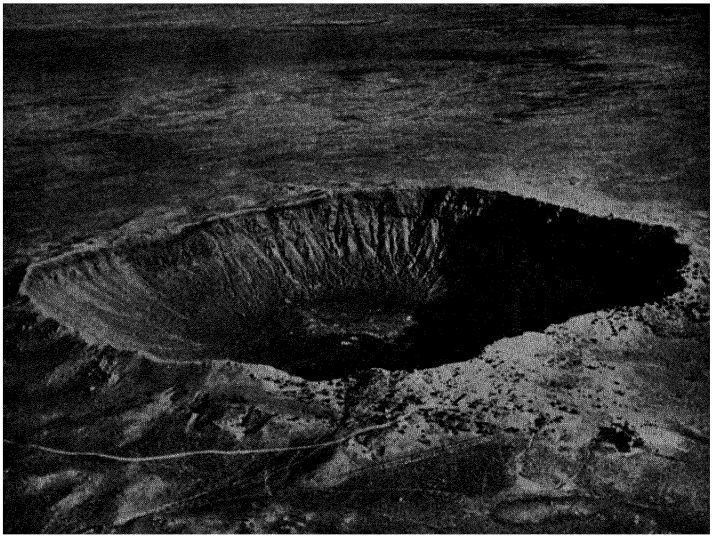


FIG. 30. Meteor Crater in Arizona. (Courtesy, Trans World Airline.)

The crater-like depressions have been the subject of much study. There are about 100,000 on the side visible to us. One of the largest craters is named Theophilus. The floor of this crater is 64 miles wide and contains three mountain peaks. It resembles a cup with cones at the bottom. Probably the best explanation of these holes, some as large as 100 miles in diameter and several miles deep, is that they are the result of volcanic action. However, no direct evidence of such action has ever been observed. Another explanation is based on the fact that the moon is doubtless continually being bombarded by meteors (see p. 56) and these holes may be the result of the collisions. Several examples of such action exist on the earth. In northern Arizona near the village of Winslow there is a crater called Meteor Crater. This hole is about one mile in diameter (Fig. 30). Many pieces of meteoric material have been found around it. It is believed to have been caused by the fall of a great meteorite in prehistoric times.

On June 30, 1908, a catastrophe happened in the province of Yenisei in Siberia. Although no one saw the event, many trees were mowed down and thousands of reindeer were killed. Because of the inaccessibility of the region, only after a lapse of several years were scientists able to penetrate into the locality. It seems fairly certain that a great meteorite fell in the region but up to the present it has not been found.

Unfortunately for the meteor theory as applied to the moon, the craters are not distributed evenly over the surface of the moon and it is

difficult to understand how meteor showers could be concentrated only in certain parts of the surface.

TEMPERATURE

The temperature of the moon is subject to great changes. On the earth the temperature is made rather uniform because the oceans and the atmosphere retain the heat and prevent rapid changes of temperature at night. In the daytime the atmosphere acts as a shield to prevent too high a temperature. But since a lunar day is 29.5 earth days in length, one side of the moon is exposed for a long time to the sun, and, because of the lack of atmosphere, the daytime temperature is above the boiling point of water. At night the temperature falls to a value lower than the lowest temperatures on earth.

MOTIONS

The moon moves about the earth while the earth revolves about the sun. Consequently the combined motions are somewhat complex. The time for the moon to move about the earth with respect to the sun—the synodic month—is about 29½ days.

During this time, the moon also turns on its axis so that, as the moon revolves once about the earth, it turns once on its axis. Fig. 31, B, represents revolution with rotation, and Fig. 31, A, represents revolution without rotation. Because of this fact, the moon always presents the same face to the earth and man has never seen the other face of the moon. Actually, due to small vibrations called librations, 59 per cent of the surface is seen.

PHASES

During the month, varying sections of the moon are seen, ranging from a narrow disk to a full moon. In the drawing (Fig. 32), the inside circles indicate the corresponding phases as seen from the earth.

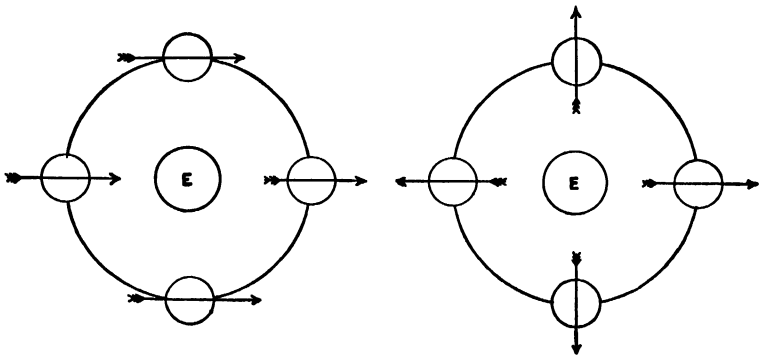


FIG. 31. (A) Represents revolution without rotation. (B) Represents revolution with rotation. In this case an observer on the earth sees only one face of the moon.

When the moon is in position A (conjunction) and we are at position "a" on the earth, the moon is in the sky with the sun in the daytime. We do not see it since the lighted face is invisible. This is the new moon or dark of the moon. A week later the moon is at position B (quadrature). Since we are at "b" we see one-half the face (first quarter). During this phase the moon is overhead at sunset. When the moon is in position C (opposition) and is above or below the plane of the earth's orbit, we have full moon at position "c" on the earth. Finally, if the moon is at position D and we are at "d," the moon is in the sky at sunrise.

Between these positions we have the crescent moons beginning with the new moon and increasing in size (waxing) until the full moon is reached. The moon then wanes until new moon is reached.

An easy method for the demonstration of the peculiar rotation and revolution of the moon is to mark a spot on a ball which will represent the moon and to carry this ball around another ball representing the earth, always keeping the spotted side facing the earthball. If an electric lamp is used to represent the sun, the phases can be seen in a darkened room.

Eclipses

Should the moon when at position C (Fig. 32) be in the plane of the orbit, so that the sun, moon, and earth are in line, the earth would cast a shadow over the moon and we would have a lunar eclipse. Obviously, this

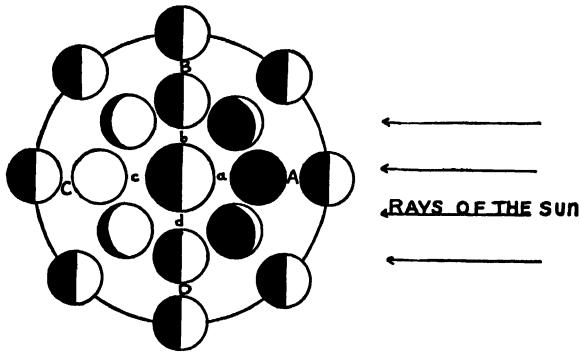


Fig. 32. Phases of the moon.

cannot occur in the middle of the day. Since the moon does not often get into the plane of the earth's orbit, both solar and lunar eclipses are infrequent at any one part of the earth. A lunar eclipse lasts much longer than a solar one, because the earth casts a much larger shadow on the moon than the moon casts on the earth. Although eclipses of the moon are interesting, they are of little scientific importance (Fig. 33).

In order for a solar eclipse to occur, not only must the moon be in

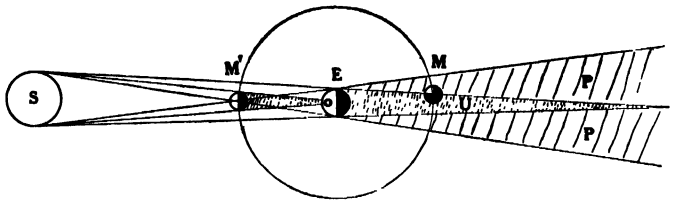


FIG. 33. Moon at M' produces an eclipse of the sun (S) on the earth (E). The moon at M produces a lunar eclipse. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

conjunction (A), but it must also cross the plane of the earth's orbit at the same time. Because the moon is very small compared to the sun, the exact conditions are not often fulfilled. If the moon is at its greatest distance from the earth, the moon's disk is not large enough to completely cover the sun's photosphere. In this case we have a ring or annular eclipse. These eclipses are of little interest to the astronomer. There may be as few as two solar eclipses in a year, or as many as five. Since most of these are either partial or annular, and since, in the event of a total eclipse, the path of totality is very narrow (about 100 miles wide), a total eclipse at any one location occurs very infrequently. As an illustration, an eclipse occurred in the eastern United States in 1932. The next eclipse in that section will not occur until 1963.

A solar eclipse is a magnificent spectacle. As the moon begins to touch the face of the sun, there is at first no noticeable change. After about one-half of the sun's disk has been covered, objects begin to cast strange shadows. During the few seconds which precede totality, the sky has a strange appearance somewhat like a smoky atmosphere. At the instant before totality, the moon's shadow comes rushing across the western horizon like a storm; the sky is dark violet in color; the observer has the sensation of approaching disaster. As the observer gazes at the sun he may see brilliant beads of light ("Baily's Beads") as the sun shines between the mountains of the moon. During the period of totality the corona flashes out brilliantly; the bright stars appear; Mercury is visible. The appearance is that of a peculiar twilight. It is not surprising that early peoples were terrified by the spectacle. Probably no spectacle of nature is more awe-inspiring. Ancient peoples believed that the eclipse was sent by the gods as a punishment. The Scandinavians made a great noise to chase away the animals who were devouring the sun.

The solar eclipse is of vital importance to the astronomer because at such a time he can study the corona, check some of the principles of the theory of relativity, and search for new planets close to the sun. Unfortunately, eclipses are not always conveniently located for observation. On June 8, 1937, an eclipse occurred in a region of the Pacific Ocean

where there were only two small uninhabited islands. The importance of this eclipse was its length—about 5 minutes of totality.

Earth Shine

One of the curious phenomena that we observe in connection with a narrow crescent moon is called the "old moon in the new moon's arms." As one carefully observes the lighted crescent, he may see faintly the



Fig. 34. Earth shine. (A reprint of Yerkes Observatory negative M45. By permission of the University of Chicago Press.)

rest of the face. The faint illumination on the dark part of the face is due to light reflected from the lighted side of the earth to the moon and reflected back from the moon to the dark part of the earth. This is earth shine (Fig. 34).

Tides

An important effect of the moon on the earth is its gravitational force causing the tides. Every day, in most parts of the world, there occur two high tides along the seacoast, coming at intervals of about 12½ hours. Between these high tides there are periods of low tides. The sun also produces tidal effects at 12-hour intervals, but these are less important since the tide-producing force of the sun is much less than that of the moon. Although the sun has a much greater mass than the moon, its distance is so great that its tide-producing force is small. When the sun and the moon are in conjunction (both on the same side of the earth) or in opposition

(on opposite sides of the earth) the combined forces produce exceptionally high tides called *spring tides*. When the moon is in quadrature (halfway between conjunction and opposition) we have the *neap tides*.

CAUSE OF TIDES. Not until the time of Newton was there an adequate explanation of the causes of tidal action. The Law of Gravitation teaches us that between any two objects in the universe there is an attraction which depends directly upon the masses of the bodies and inversely on the square of the distance between their centers of gravity. If M_1 and M_2 represent the masses of the earth and moon, and D the distance between their centers, the force of the attraction can be expressed by the relation $F = G\frac{M_1M_2}{D^2}$, in which G is the constant of gravitation (see p. 288).

If the earth were smooth and entirely covered by water, the tides would follow the moon in a simple manner, but owing to the varying depth of the sea and the irregularities of the land masses, the prediction of the time of high tide at any location requires many records of previous tides.

In order to give a simple explanation of tidal action we shall assume the moon to revolve about the equator of an earth which is entirely covered by water. The water at points A and B (Fig. 35) is attracted toward the moon by the gravitational forces represented by the lines AA′ and BB′. These forces cause the water to flow in the directions to produce a tidal bulge. On the other side of the earth at D and E it can be easily shown that, since the gravitational attraction at these points is less than at the center C, the forces produce a tidal bulge here as well. If the moon were at rest, these tides would occur every 12 hours, since the earth makes one rotation from west to east in 24 hours. However, the moon is also moving about the earth, completing one revolution eastward in 29½ days. As a result of these two actions, the average intervals between tides due to the moon is 12 hours and 25 minutes, while the tides due to the sun occur each 12 hours.

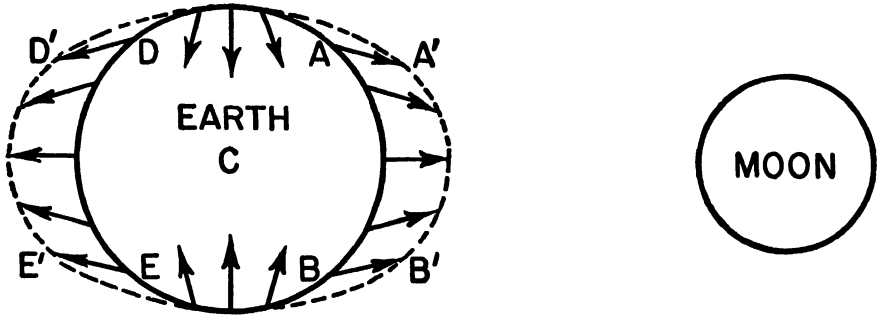


FIG. 35. The two tidal bulges.

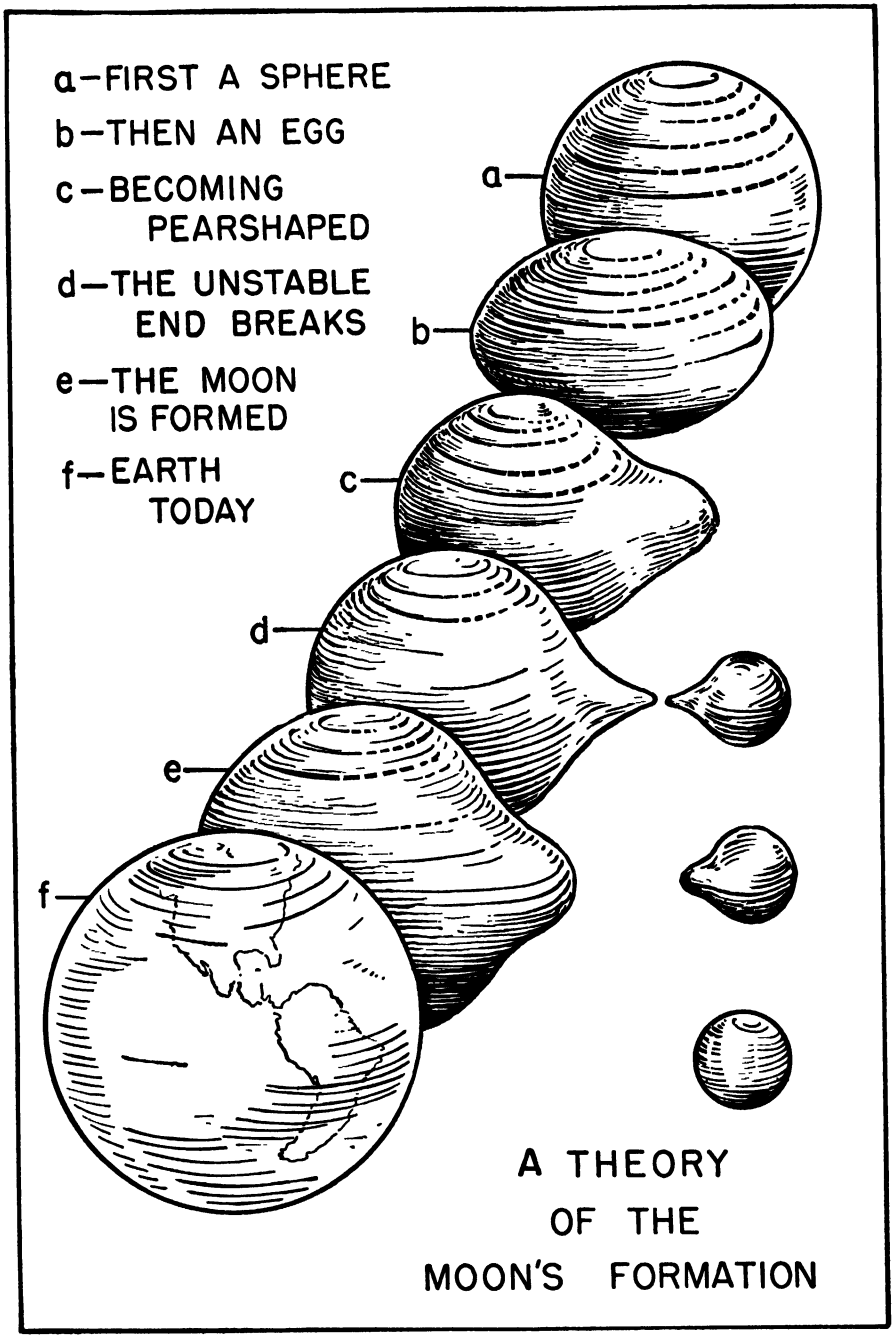


FIG. 36. A theory of the formation of the moon. (Redrawn from Stetson: "Man and the Stars," after Jeans and Darwin, New York, McGraw-Hill Book Co., Inc.)

The height of the tide varies from 2 feet in midocean to a maximum of 50 feet in the Bay of Fundy. At Boston, the maximum height is 11 feet, at New York 8 feet. The high tide in the Bay of Fundy has been studied with a view to producing electric energy from the rise and fall of the water at Passamaquoddy. One of the most unusual of the tidal phenomena is the Pororoca of the lower Amazon at Para, where the water may rise to a height of 20 feet in a few minutes' time.

Origin of the Moon

When a body is started into revolution about another and there is no force to slow it down, it will continue to revolve under the action of the force of gravitation. Thus the moon having been started at some time in the past continues to revolve at a practically constant rate and probably will continue to do so for a long time to come. There is no certain explanation of the origin of the moon. Fig. 36 illustrates the theory that the moon was separated from the earth in early geologic time. However, there are grave objections to such an explanation.

References

Darwin: "The Tides," Boston, Houghton Mifflin Co.
Duncan: "Astronomy," New York, Harper and Brothers.
Fisher: "The Story of the Moon," New York, Doubleday, Doran and Co.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
Menzel· "Stars and Planets," New York, The University Society.
Moulton: "Consider the Heavens," New York, Doubleday, Doran and Co.
Naysmith and Carpenter: "The Moon," London, John Murray Co.
Proctor: "The Moon," New York, Longmans, Green and Co.
"The Nautical Almanac," Washington, U.S. Government Printing Office.

Questions and Problems

1. Explain the causes of a total eclipse of the sun.
2. Explain the manner of the moon's rotation.
3. Describe the phases of the moon.
4. What is earth shine?
5. Why has the moon no atmosphere?
6 What are the causes of tides? Describe them.
7. Can a lunar eclipse be seen at noon? Explain.
8. What is the phase when sun, moon, and earth form a right angle?
9. What do the terms apogee and perigee mean?
10. Why does the moon rise at different times of day?

Visual Aid

"The Moon," University of Chicago Film

Topics for Discussion

Phases
Solar Eclipses
Tides
Meteor Crater
The Bay of Fundy

Experiments

1. If you live near the seacoast, predict tides for your locality by use of an almanac.
2. Map the lunar craters. Use lantern slides or moon maps.
3. Using the Nautical Almanac, which can be secured at nominal cost from the Superintendent of Documents at Washington, D.C., find the time of moonrise and moonset for the first day of each month of the year. From this information, predict the various phases of those days.
4. Make a drawing showing the various phases for each day of a month.

4. PLANETS AND OTHER BODIES OF THE SOLAR SYSTEM

Out of the deep, my child, out of the deep,
Where all that was to be, in all that was,
Whirl'd for a million aeons thro' the vast
Waste dawn of multitudinous-eddying light—.
—ALFRED TENNYSON

PLANETS

Of all the celestial bodies that have stirred the imagination of man, probably none is more stimulating than the nine planets, those bodies which wander about in the heavens. Six of these were known in very early times. The word *planet* means *wanderer.* This name arose from the fact that the planets seemingly wandered about, their motion being relative to the fixed stars. The casual observer will note that there are often in the sky bright objects which do not twinkle. These objects will be found in various positions, and at times will disappear entirely. On a certain night Mars may be found in the location of the constellation, Leo; on another night it may be located in Cancer. Or during another part of the year, Mars will be in the sky in the morning. *The planets are continuous bodies which shine by reflected sunlight, and, like the earth, they revolve about the sun in nearly circular orbits.* The motions of the planets are governed by three laws stated by Johannes Kepler (see p. 76).

Because of the revolution of the earth about the sun, the sun seems to move eastward among the stars in a path called the *ecliptic.* All the planets, as well as the moon, will be found within 9 degrees of this path. The ecliptic passes through the locations of 12 constellations, called constellations of the Zodiac. These constellations are Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, and Aquarius (see p. 75).

Any almanac will give the signs of the zodiac as they apply to various parts of the body. For example, Aries was believed to rule the head, Leo the heart, and Gemini the arms.

Within the last few years, planetaria have been constructed which simulate the motions of the heavenly bodies. One such planetarium is illustrated in Fig. 202.

The subject of astrology was based on the different positions of the planets among the stars. Mars and Saturn were believed to have a sinister effect on human affairs. In ancient times, events were based on the relations of planets to the stars. Mars ruled wars; Venus controlled love and beauty; the moon controlled disease; Saturn provided a cold, callous nature; Jupiter was beneficent. When a child was

born, a horoscope was cast which would indicate the course of his life. If the grouping of the heavenly bodies was favorable, the child might lead a fruitful life, free from sorrow and disease. Even today many people avidly follow the prognostications of the astrologers.

Table 3

THE PLANETS

Planet	*Mean Distance from Sun (Miles)*	*Year*	*Number of Moons*	*Sidereal Day*
Mercury	35,950,000	88 days	none	88 days
Venus	67,170,000	225 days	none	uncertain
Earth	93,000,000	365¼ days	one	24 hrs.
Mars	141,500,000	687 days	two	24 hrs., 37 min.
Asteroids	*Various small planets between Mars and Jupiter*			
Jupiter	483,200,000	11 86 yrs.	eleven	10 hrs.
Saturn	885,900,000	29 5 yrs.	nine	10 hrs., 30 min.
Uranus	1,782,000,000	84 yrs.	four	10¾ hrs.
Neptune	2,792,000,000	165 yrs.	one	15 hrs.
Pluto	3,673,000,000	247 yrs.	unknown	unknown

MERCURY (MESSENGER OF THE GODS). This is a small planet very close to the sun. Consequently, it is difficult to see. It is visible at the time of a total eclipse, also at some seasons of the year, when it will be found as a star-like body low on the horizon at sunrise or sunset. It is believed to have no atmosphere, it probably is very hot, and it is of little interest to the amateur astronomer. It is nearly as bright as Sirius and the temperature on the sunlit side is 350° C. Its main interest to the scientifically minded student lies in the fact that the theory of relativity offers an explanation of its perturbed (disturbed) path around the sun.

VENUS (GODDESS OF LOVE). The next planet in order of distance from the sun is Venus (Fig. 37), called both a morning and an evening star. During parts of the year, Venus is "west" of the sun and is visible before sunrise. (A planet is "west" of the sun if it rises before the sun.) But, at other times, it is "east" of the sun and is visible in the west in the early evening. For part of the year it is on the opposite side of the sun from the earth and is not visible. It also presents phases like the moon. It is the brightest object next to the moon in the night sky. In fact, it is so bright that it can often be seen at midday.This gives rise to the statement that "one can see stars in the daytime." (Actually, a powerful telescope will make a few of the brightest stars visible in the daylight.) For various reasons, it is often called the twin of the earth. It has about the same diameter (7,700 miles) and nearly the same mass. Unfortunately, it is one of the most difficult planets to study. Astronomers have tried to penetrate the cloud layer that covers the surface, but as yet no observer has ever seen the

face of the planet. This cloud layer is not fully understood. In 1932, using infrared photographic plates, Adams and Dunham found evidence for immense quantities of carbon dioxide around the planet. So far, no evidence for the presence of oxygen and water has been found. Inasmuch as oxygen and water vapor are necessary for life on earth, this may mean that life has never begun on Venus. On the other hand, life may be abundant under the great cloud layer.

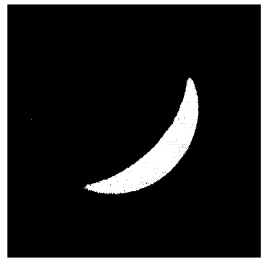


FIG. 37. A crescent Venus. (A reprint of Yerkes Observatory negative P2. By permission of the University of Chicago Press.)

The planet has no moon that can be seen. The poles of Venus are probably as warm as our equatorial regions. No definite evidence for rotation has been found. The Doppler test (see p. 10) fails to show any evidence for rotation.

EARTH. The next in order of planets is the earth. This planet will be discussed in Chapter 5.

MARS. Beyond the earth is Mars, a reddish object (Fig. 38). Although Venus is called the twin of the earth, Mars is very nearly the counterpart of our globe. It has two small moons (Deimos and Phobos), rotates on its axis in about 24 hours, has seasons like the earth, has an atmosphere which probably contains some water vapor, although little if any oxygen, and shows polar caps of white material. Because of the small amount of water on the planet, astronomers believe that the polar caps are atmospheric phenomena (clouds) rather than ice caps.

Both the telescope and the spectroscope are used in the study of the Martian surface and atmosphere. By the use of blue and red filters, the astronomers are able to form impressions concerning Mars. Most of the evidence is still uncertain but it seems that the atmosphere of Mars is very small in amount.

In 1887, Giovanni Schiaparelli, an Italian astronomer, announced that he had seen long, straight, narrow (50 miles wide) streaks on the Martian surface (Fig. 39). Since that time, many observers, including Percival Lowell and E. E. Barnard, have studied the surface. Some agree that the markings exist, while others claim they are optical illusions. At present, it seems certain that the markings do exist. Naturally, this has aroused much discussion as to whether Mars has life on its surface. It is probable that the temperature of the planet (80° F. at the equator) is warm enough to support some form of life. It seems possible that life of some sort, perhaps vegetation, may exist on the planet. Even on the earth, the forms of life are so varied that we can hardly make any speculations as to the forms of life on another planet. The theory of evolution teaches that the more

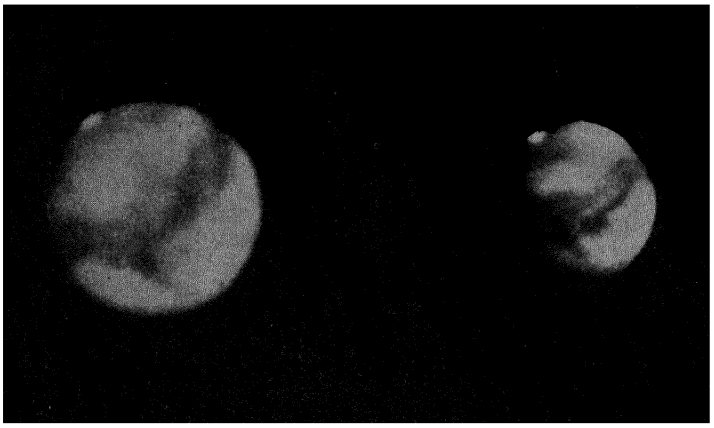


FIG. 38. Telescopic views of Mars, showing polar caps. (Courtesy, Mt. Wilson Observatory.)

complex forms of life have developed from simpler types, and it may be that on Mars the process of evolution took very different paths, and that we would not recognize as familiar any forms of life there. Until we have penetrated the mystery of the origin of life, it is impossible to draw any conclusions regarding other worlds.

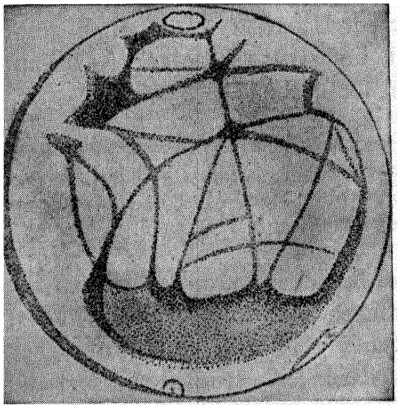


FIG. 39. A drawing of the canals of Mars.
(After Schiaparelli.)

ASTEROIDS. In 1801, the Italian astronomer Piazzi, while searching for another planet between Mars and Jupiter, found a little planet which he named Ceres. Its diameter is less than 500 miles. Since that time more than 1500 of these small planets have been found. Many of them have received fanciful names. Some, such as Achilles, have been named after the Greeks.

The gods are represented; various colleges are honored; feminine and masculine names are used; pet dogs are remembered. One of the most interesting of these small planets, Eros, comes quite near the earth (about 16,000,000 miles in 1931), and it is used as a yardstick in astronomical calculations. It is probable that these tiny bodies are fragments of larger bodies.

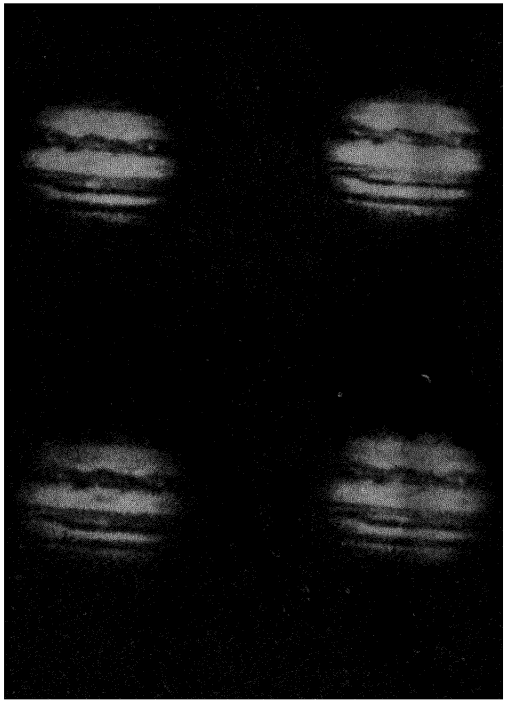


Fig. 40. Telescopic views of Jupiter. (Courtesy, Mt. Wilson Observatory.)

Jupiter (God of the Universe). This great body (Fig. 40), 86,000 miles in diameter, the largest of the planets, is visible in the sky for most of the year and is easily identified by its brilliance. Not much is known concerning the planet. Recently the spectroscope has revealed that the outer layer of Jupiter is composed mainly of liquid ammonia and gaseous methane (natural gas). The temperature is very low. It presents a spheroidal shape owing to its rapid rotation. A most interesting feature of Jupiter is the presence of 11 moons, two of which revolve in a retrograde (backward) direction relative to the others. Galileo found four of these moons by his telescope, thus confirming the theory of Copernicus that the center of the solar system is the sun and not the earth.

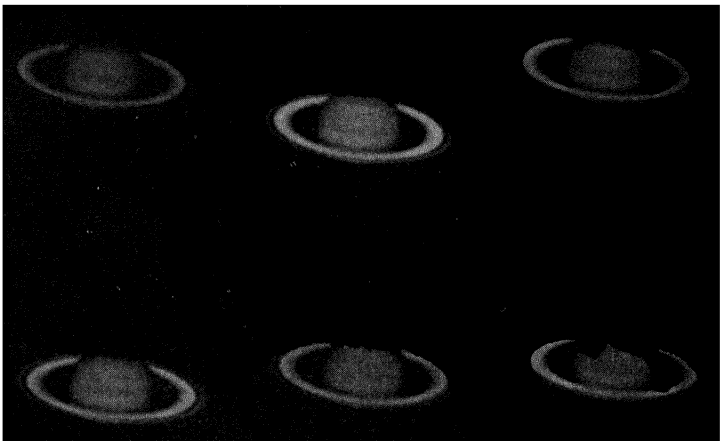


FIG. 41. Telescopic views of Saturn. (Courtesy, Mt. Wilson Observatory.)

SATURN (GOD OF TIME). Far beyond Jupiter lies this most beautiful of all planets (Fig. 41). This planet, almost as large as Jupiter (71,000 miles in diameter) and rotating rapidly, is interesting because it is the only object in the heavens that has rings. Galileo noticed a peculiarity about Saturn, but his telescope was not powerful enough to make the rings clearly visible. The rings are now known to be masses of small stones (meteors), each revolving about the planet in its own path. Perhaps they represent moons "spoiled in the making." The appearance in the telescope is that of three sheets of silver. Saturn has nine moons, one of which, Phoebe, revolves in a retrograde direction, from east to west. These backward motions of satellites prove a serious flaw in the nebular hypothesis of the origin of the solar system (see p. 58).

URANUS. Uranus (32,000 miles in diameter), the next planet in order of distance, was discovered in 1781 by the astronomer William Herschel, and the planet is still called Herschel by some astronomers. He found it accidentally while searching for new comets. The atmosphere of Uranus also contains ammonia and methane. Its surface temperature is about 250° below zero F. Its appearance is very much like a star, and it cannot be seen easily with the unaided eye, being about sixth magnitude (see p. 30). Very little is known concerning Uranus except that it resembles Jupiter in many respects. Uranus *rotates* in a retrograde direction. The planet has four moons, all of which revolve in a backward direction.

NEPTUNE (GOD OF THE SEA). Neptune (31,000 miles in diameter) was made known by one of the most romantic discoveries in science. Two young mathematicians, John Adams in England and Joseph Leverrier in France, had calculated that the disturbed motion of Uranus was caused by the gravitational attraction of another body. This would indicate the

presence of another planet. Leverrier wrote to the German astronomer Johann Galle, telling him exactly where it should be found. Galle turned his telescope to the point of the sky and found the planet less than one degree in declination (see p. 28) from the indicated spot. The planet rotates in the direct way and has *one* satellite which revolves in the *retrograde* direction. (A satellite is the scientific name for moon.) The method of calculation involved the subject of perturbations, which refers to the disturbance of the elliptical path.

Each body in the solar system exerts a gravitational force on every other body. The sun attracts the earth, the moon, and all the other bodies of the solar system. The earth also attracts each of the other bodies. The result of this is that all the paths are irregular in shape. It was found that Uranus differed from the path that it should have pursued. The inference was that an unknown body was exerting a gravitational pull on Uranus. The body was found to be Neptune.

PLUTO (GOD OF THE UNDERWORLD). In 1930, the world was startled by the announcement of a new planet. This planet was given the name Pluto. After the discovery of Neptune, astronomers found the perturbations of Uranus were not completely accounted for. Various investigators set themselves the task of predicting the position of another new planet. Percival Lowell was one of the most constant searchers, and it is a tribute to his memory that, although the discovery was not made until after his death, his calculations made the discovery possible. The image of the planet was found on a photographic plate by a young assistant, C. W. Tombaugh at the Lowell Observatory. Actually the planet is very faint and little is known about it.

COMETS AND METEORS

Any casual observer of the sky is familiar with the meteors ("falling stars") which flash at frequent intervals across the sky. Occasionally, these objects are very large and brilliant, being called "fireballs." Meteors are really small rocks which have entered our atmosphere and have been heated by friction with the air. They are visitors from outside space and are at an average height of about 70 miles.

Millions of meteors enter the earth's atmosphere daily and at certain seasons there are meteoric showers. We have the Perseids in August, the Lyrids in April, the Andromids in November—all named for the part of the sky from which they seem to radiate. Such showers seem to be associated with comets. It is quite probable that every meteor shower represents a disintegrated comet.

Most meteors burn up at heights of perhaps 30 miles, but at rare intervals the large ones fall to the earth as meteorites. At least a thousand of these meteorites are preserved in museums. The largest is the Hoba which

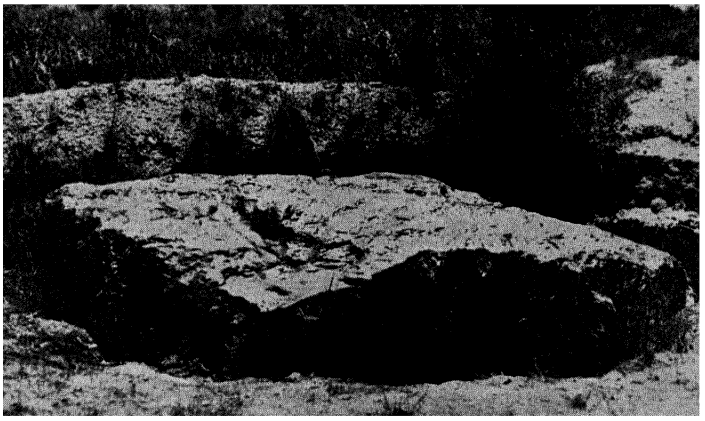


FIG. 42. Iron meteorite—60 tons. (Courtesy, Natural History Magazine.)

fell in Africa (Fig. 42). One from Greenland was brought back by Perry and is now in the Hayden Planetarium in New York City.

Man has always regarded the fall of meteorites with awe. This is natural since they are visitors from outside the earth. It is believed that many ancient images of the gods were cut from meteorites. The Kaaba at Mecca contains a large meteoric relic. The famous statue of Diana was probably of meteoric origin. It is remarkable that, as far as we know, no meteorite has ever killed a human being. As stated in Chapter 3, it is believed generally that Meteor Crater in Arizona was formed by an enormous meteorite which fell about 50,000 years ago. Mention has already been made of a great meteorite which fell in Siberia in the year 1908.

Closely associated with meteors, and perhaps the source of the majority of them, are comets. There are several hundred thousand of these objects in the solar system. Few of them ever become visible to the naked eye. The important ones have always been noted for their long tails (Fig. 43). (The word *comet* means "long-haired.") Comets move in paths which carry them far out in space, but they are all believed to be a part of the solar system. They do not all follow the ecliptic, and the orbits seem to be greatly elongated, perhaps extending far outside the orbit of Pluto. They apparently consist of small rocks and an envelope of gas, principally carbon monoxide, carbon dioxide, and cyanogen. (We obtain this evidence by the spectroscope.) People in all ages have been frightened by the appearance in the sky of these curious objects. The astronomer Edmund Halley found that the bright comets which appeared in 1531, 1607, and 1682 in reality were reappearances of the same body. He correctly predicted the return of this comet in 1758 and as a result the comet has been called Halley's comet. It reappears every

75½ years. It was last visible in 1910 and will return in 1986. Comets shine mostly by their own light.

There are three types of meteorites. Some are composed of metallic iron and nickel (siderites) while others are stony in character. The stony type contains no new elements but has some unusual structures and compounds. These rocks have hydrogen, helium, carbon dioxide, and nitro-

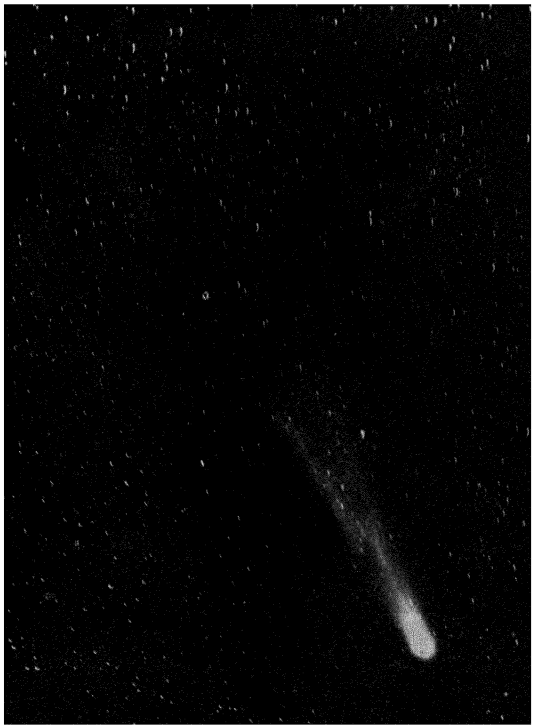


FIG. 43. The Brookes comet. (A reprint of Yerkes Observatory negative C104. By permission of the University of Chicago Press.)

gen, but no free oxygen. About 30 of the known elements have been found in meteorites. Some phosphides and carbides have been found in these mysterious objects.

ORIGIN OF THE SOLAR SYSTEM

The solar system consists of the sun, 9 planets, 26 satellites, 1500 asteroids, and 1,000 comets. Since all the planets are much nearer the sun than is any star, it is practically certain that the sun is in some way responsible for the evolution of the solar system. The most distant planet, Pluto, is less than 4 billion miles from the sun, while the nearest star,

Proxima Centauri, is about 25,000 billion miles distant. It is remarkable that all the planets travel about the sun in the same direction. The sun rotates in the same direction that the planets revolve. The moons, with a few exceptions, revolve about the planets in the same direction as the planets revolve about the sun. Nearly all the planets rotate in the same direction as the sun. Any satisfactory theory of the origin of the solar system must be able to explain the uniformity of motion.

There are several theories which are worthy of consideration. It must be emphasized that no theory rests on any very definite basis of fact and that one must consider each with an open mind. Moreover, no theory offers an explanation of ultimate creation.

THE NEBULAR HYPOTHESIS. This theory was presented in 1796 by the astronomer Pierre Laplace. He reasoned that the sun originally extended out to the limits of the solar system, several billion miles. Perhaps the sun resembled a nebula, hence the name of the theory. The gaseous body was rotating and was very hot. As the mass cooled and lost heat by radiation, it contracted, and, because of the conservation of momentum, began to rotate faster until it lost a ring of matter from its equator.

A simple illustration of the principle of conservation of momentum is to whirl a ball at the end of a string and allow the string to wind around the forefinger. As the length of the string becomes shorter, the ball moves more rapidly.

This ring of material formed a planet. Other rings were formed as time went on, and so the solar system evolved. Theoretically, such gaseous rings could not form spheres, but would remain in a form like the rings of Saturn. The retrograde motions could not be accounted for. Nevertheless, the theory offered a great field for study and was partly responsible for the work of Darwin on "The Origin of Species."

THE PLANETESIMAL HYPOTHESIS. The theory of Laplace conjectured that the sun by its own motions formed the planets. In contrast to this, we have the two star theory of Thomas Chamberlin and F. R. Moulton, two professors at the University of Chicago. In 1900, they advanced the theory that, in the passage of time, our sun came near another star (a star without planets) whose gravitational pull caused many small bodies to be torn away from the sun. In time, these small bodies coalesced into the present planets. This theory is called the Planetesimal Hypothesis.

THE TIDAL THEORY. An improvement on the Planetesimal Hypothesis is the *Tidal Theory* developed by the astronomer James Jeans (Fig. 44). The initial idea is that our sun was aided in the evolution of the solar system by the close approach of another star which has since left the vicinity. Suppose that a few billion years ago such a star approached our sun close enough to be in the range of our present solar system. This star

was very large and our sun was a gaseous body. Because of the enormous gravitational attraction exerted by the star, two long prominences were thrown out from the sun. One of these tidal streamers (A) was raised on the side adjacent to the star, and the other (B) on the opposite side, in a manner similar to the water tides on the earth. As the star moved forward, the streamers were set into revolution and they coagulated into rotating spheres, the planets. The moons were formed subsequently. The larger spheres absorbed the smaller ones and the solar system slowly assumed the present form. Assuming that this hypothesis provides a substantially correct description of the evolution of the planets, the earth

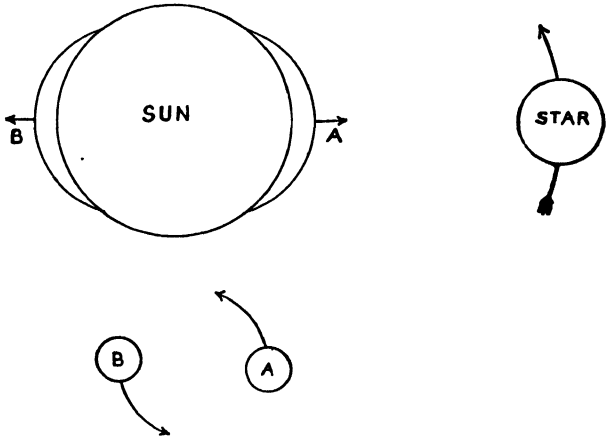


FIG. 44. The tidal theory of the origin of the solar system.

grew around a nucleus by gathering to itself gas and stones. The comets and meteors are bodies which were not absorbed by the larger ones. When the earth became large enough, it began to retain an atmosphere. Some time after this, life appeared.

THREE STAR AND DOUBLE STAR THEORIES. Two other theories worthy of mention are the Three Star Theory and the Double Star Theory. Ross Gunn considers the solar system to have been formed by the fission (division) of a very large star into our sun and another star. Between these two bodies, many little bodies remain which form our planets. Many of the known stars are double and triple stars, a fact that makes this theory a possible solution of the problem of planet origin (Fig. 45).

HOW WILL THE WORLD END?

Most scientists believe that planets are like human beings. They are born; they grow old; they die. Perhaps Venus is young, the earth is mature, and Mars is old.

However, there are certain lines of evidence which lead to the belief

that the earth may be destroyed by some catastrophe before it dies a natural death in the evolutionary process.

Were the moon to approach the earth to a distance of 100,000 miles instead of its present 240,000 miles, the mutual gravitational attractions might pull great meteors from both moon and earth, destroying all life.

All theories of the cause of the sun's heat lead to the conclusion that the sun will become cold at some time in the future or perhaps it will explode as it becomes a nova. In either case, life will disappear. Perhaps a comet will strike the earth head on and destroy life.

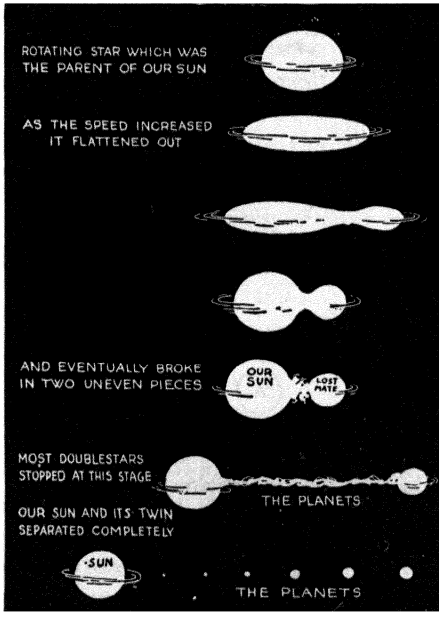


FIG. 45. The fission theory of planet formation. (Courtesy, Science Service.)

Fortunately for our peace of mind, there is no evidence that any of these cataclysms will occur in the near future. We feel certain that the earth, sun, and moon have not materially changed their structures and relative positions in the last billion years.

REFERENCES

Chamberlin: "The Two Solar Families," Chicago, University of Chicago Press.
Duncan: "Astronomy," New York, Harper and Brothers.
Fath: "Astronomy," New York, The McGraw-Hill Book Co.
Jeans: "Through Space and Time," New York, The Macmillan Co.
Jones: "Life on other Worlds" New York, The Macmillan Co.
Lemon: "From Galileo to Cosmic Rays," Chicago, University of Chicago Press.

Menzel: "Stars and Planets," New York, The University Society.
Olivier: "Comets," Baltimore, Williams and Wilkins Co.
Proctor and Crommelin: "Comets," London, Technical Press.
Russell: "The Solar System and Its Origin," New York, The Macmillan Co.
Russell, Dugan, and Stewart: "Astronomy," Boston, Ginn and Co.

Questions and Problems

1. Compare Mars with the earth as to the possibility of the existence of life.
2. Explain clearly the ideas in the theories of the origin of the solar system.
3. Distinguish between rotation and revolution.
4. What are shooting stars?
5. Would it be dangerous for the earth to collide with a comet?
6. Name the constellations of the ecliptic.
7. Why is Venus difficult to study?
8. What do we know about Jupiter?
9. How was Neptune discovered?
10. What is a meteorite?
11. What is the "evening star"?
12. Venus is seen often as a crescent. Explain.
13. List the planets in order of their distance from the earth.
14. Is Jupiter ever a crescent shape? Explain.

Visual Aid

"The Solar Family," University of Chicago Film

Topics for Discussion

Meteorites	The Kaaba at Mecca	Halley's Comet
Nebular Hypothesis	The Fission Theory of Ross Gunn	Mars

Experiments

1. Make a distance chart of the planets.
2. Draw the planet faces.
3. Use the Nautical Almanac to find the time of planet appearance for each month of the year.
4. Draw a horoscope for the day that you study this chapter. (For this purpose, use the Nautical Almanac or any almanac found at your bookstore.)

5. THE EARTH AS A PLANET

Many an aeon moulded earth before her highest, man, was born,
Many an aeon too may pass when earth is manless and forlorn.
—ALFRED TENNYSON

Naturally, the most important planet to us is the earth. Our planet, because of its rotation, is an oblate spheroid and not a sphere. The earth has a diameter of about 8,000 miles (7,927 miles at the equator), and weighs about six sextillion tons. It has an atmosphere containing, among the other gases, oxygen, water vapor, and carbon dioxide, three substances which are essential to life. (See Chapter 11.) Because of the inclination of the axis of rotation to the plane of the orbit, people on the earth experience a change of seasons. The earth rotates on an axis once in 24 hours, and revolves about the sun at a speed of about 1,000 miles per minute, making the complete circuit in 365¼ days, or a year. It travels in an elliptical path. In this path the earth is *closest* to the sun in *January* (perihelion), and *farthest* away in *July* (aphelion). The difference is about 3,000,000 miles. The earth has one satellite, the moon.

THE SEASONS

One of the most interesting of the many phenomena that the inhabitants of the temperate and polar zones of the earth experience is the cycle of the seasons. During the year, the sun *apparently* moves north to a position above the Tropic of Cancer, and south to a position above the Tropic of Capricorn. (In January, Chile and Paraguay are having their hottest weather. People there are likely to be at the beaches, and wearing summer clothing. In the same month, the United States is experiencing its coldest weather. Conversely, in July the United States has hot weather, and Chile is in the midst of winter.) As a result, the temperature varies greatly during the period, causing the seasons.

There are three principal causes for the change of seasons. One of these is the variation in the length of day and night during the year. Secondly, less energy is received on each square mile of area in the winter season, owing to the obliquity of the sun's rays. The third very important reason is that, when the sun is low on the horizon, the radiation must pass through a great thickness of atmosphere, and, as a result, much of the

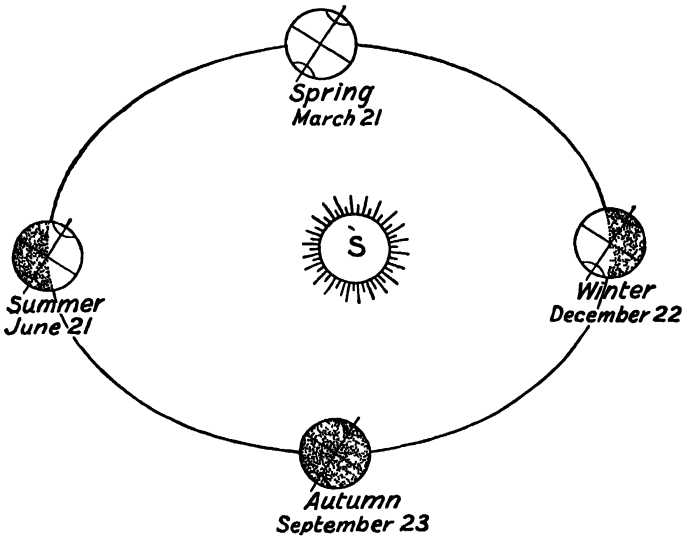


FIG. 46. The positions of the axis of the earth during the solar year. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

total radiant energy is absorbed, only a part reaching the earth to produce heat. Consequently, despite the fact that the earth is *nearer the sun in January than in July*, the northern hemisphere is colder in January, since a change in distance of 3,000,000 miles produces only a 7 per cent change in heat received on the earth.

Consider a square mile of surface at the Tropic of Cancer. On or about June 21, when the sun is shining directly on this region, this area receives a certain amount of solar radiation or *insolation*. On or about December 21, when the sun is shining directly on the Tropic of Capricorn, the rays strike the surface in the region of the Tropic of Cancer obliquely, and each square mile receives less energy.

The earth is rotating on an imaginary axis which is tilted 23½ degrees from the perpendicular to the plane of the orbit (Fig. 46). Its motion resembles that of a spinning top revolving about a point on the floor. On December 22, the north pole is tilted away from the sun, and for several weeks the sun never illuminates this pole. This is the northern winter. In the northern hemisphere during this period, nights are longer than days. In the latter part of December, at Philadelphia, latitude 40 degrees North, the day is about 9 hours long; at Winnipeg, latitude 60 degrees North, the day is 8 hours long. During the 15 hours of night at 40 degrees North Latitude, the loss of heat by radiation out into space is greater than the nine hours' reception of energy. When the earth is at the equinox positions, the sun shines directly on the equator and the days and nights everywhere are of equal length. This usually occurs on March 21, and is

the *Vernal Equinox.* Likewise we have the *Autumnal Equinox* in September.

As spring progresses in the northern hemisphere, the sun rises earlier each morning and sets later each evening until June 21. On June 21, people at 40° North Latitude receive radiant energy during the entire 15 hours that the sun is above the horizon. As a result, the temperature of the northern hemisphere is increasing day by day and the sun shines more nearly overhead. Both of these factors raise the temperature.

In June and July, the north pole is tilted toward the sun and it is illuminated during the entire 24-hour day (Fig. 47). On June 21, Hammerfest in northern Norway has sunshine for the entire 24 hours (Midnight Sun). Even in Denmark, twilight lasts all night during the month of June. Points inside the Arctic Circle would not be able to celebrate with fireworks on July 4th because of the continuous daylight. However, because of the obliquity of the sun's rays, the polar regions never get very warm except for brief periods. On the other hand, during the northern winter the people inside the Arctic Circle do not see the sun for many days.

Although the northern hemisphere receives its greatest amount of heat from the sun on June 21, this date does not usually represent the hottest part of the year. July and August usually have the hottest weather. During the spring, more heat is received than is radiated away and the temperature rises. Some time after June 21, the amount radiated is much less than the amount received, so that we have the warmest weather. After some weeks, the temperature begins to decline. The more dense the atmosphere, the greater the lag of temperature behind the sun's heat. As

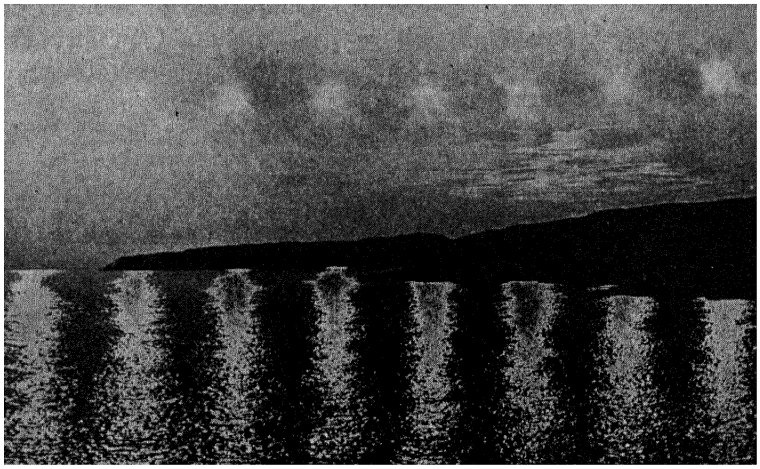


FIG. 47. The Midnight Sun at Etah, Greenland. Photographs taken at 20-minute intervals. (Courtesy, Baker: "Astronomy," New York, D. Van Nostrand Co.)

has been stated (Chapter 3) there is very little lag of temperature on the moon because of the lack of atmosphere there.

Evidence for Rotation

The fact that the earth turns on an axis was suspected by early observers and was predicted by Copernicus, but it was not until 1851 that L. Foucault performed the experiment which definitely proved the fact. He hung a heavy iron ball by a wire 200 feet long and allowed it to swing over a bed of sand. A pin on the bottom of the ball cut a new path each swing, showing that the earth was turning under the pendulum (Fig. 48).

If a pendulum bob at the equator is suspended by a wire and started swinging, there will be no change of path during the day. On the other hand, if the pendulum is swinging over the pole, the path of swing apparently will change. The bob will trace a new path each swing so that in 24 hours the pendulum bob *apparently* will have changed its path by 360 degrees. Actually, the path of swing does not change since the point of support is a special mounting which cannot twist the wire. At New York, 42° North Latitude, the period of rotation is 32 hours. The pendulum is started in a North-South direction, and, being in the northern hemisphere, the plane of the swing seems to rotate in a Northeast-Southwest direction. Evidently the room in which the pendulum is mounted is turning around and the sand bed is rotating under the pendulum. At latitudes

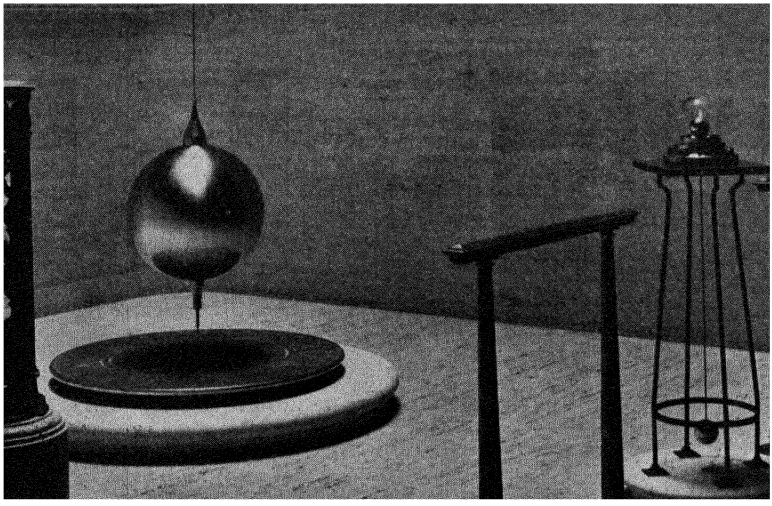


Fig. 48. The Foucault pendulum at the Franklin Institute. The heavy ball is suspended by a wire nearly 100 feet long. At the right is shown a small model of the instrument. (Photo Gladys Müller.)

between the equator and the pole, the path change depends upon the latitude. The motion has been observed at many points on the earth's surface. We have here a direct visible proof of the rotation of the earth on its axis.

Earth Structure

For purposes of study, scientists divide the earth into spheres (Fig. 49). The inner sphere is called the *centrosphere*. Surrounding this is the surface rock layer 40 to 60 miles thick which is called the lithosphere. Upon this lies the water layer, the *hydrosphere*, and the air layer, the *atmosphere*. We shall discuss only the centrosphere in this chapter, reserving treatment of the others for subsequent chapters.

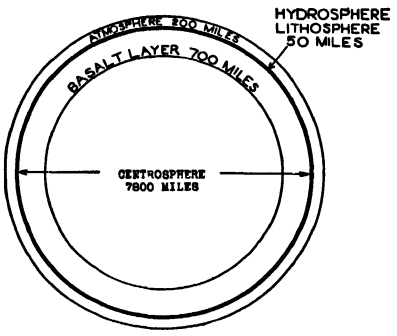


Fig. 49. The spheres of the earth.

Centrosphere. A study of the interior of the earth is of necessity based upon indirect information. The theory of Laplace predicated that the center of the earth was a liquid on which floated the solid crust like ice on a lake. Several facts seem to disprove this theory. If a hardboiled egg is caused to spin it will rotate freely, but a fresh egg refuses to spin. The explanation is that the spinning of the soft egg is stopped by the friction of the liquid inside the shell. In the same way a liquid center in the earth would have caused the earth to stop rotating long ago. Moreover, the crust would not float on top of the liquid since solid rock is denser than molten rock. On the other hand, some studies of earthquake propagation through the center indicate that there is a spherical core about 4000 miles in diameter which is in a plastic state. Perhaps the core resembles a dense liquid under great pressure. (Other studies indicate that the core is solid.) Above this lies a layer about 2,000 miles thick. This layer is covered by the basalt layer. Over all lies the lithosphere. (Perhaps the center of the earth is a core of iron. In Greenland we find great blocks of iron which may have come up in ancient lava.)

There is general agreement that the center of the earth is very hot. In some gold mines which are over a mile deep, special cooling systems must be provided to keep the temperature low enough for the workmen. Hot springs, geysers, and volcanoes all indicate a high temperature deep in the earth.

THE VOLCANO

There is no more awe-inspiring spectacle on the earth's surface than a volcanic eruption. Recently, due to the motion pictures, the airplane, and

the radio, many persons have had the opportunity of having a ringside seat at the 1928 eruption of Krakatoa in the Malay Archipelago, and the outbreak of the new volcano, Paricutín, in Mexico.

Those who have visited the western part of the United States have been thrilled by the sight of the cones of Mt. Rainier in Washington, and of Mt. Shasta and Mt. Lassen in California. Many of us have been charmed by the beauty of Crater Lake (Fig. 50) in Oregon, which lies in the abyss once occupied by the cone of an ancient volcano called Mt. Mazama by the geologists.

Many persons have had the good fortune to visit Hawaii, where Mauna Loa and Kilauea (Kilawaya) still pour out lava and gases.

In the southwestern part of the United States, the traveler finds evidence of extensive volcanic activity in fairly recent geologic time.

A volcano gives us information as to the structure of the basalt layer. From the volcano there issues molten rock called lava, as well as steam, dust, and various gases. The lava is usually composed of feldspars, quartz, mica, and hornblende (see Chapter 9). The explosions are due to the steam and other gases which are dissolved in the lava. The only reason that some volcanoes are mountains is that they have built up the peaks by repeatedly pouring out molten rock which, in time, forms the cone and later the mountain. Cotopaxi in Equador is 19,000 feet high. The new volcano in Mexico began to form a cone in 1943.

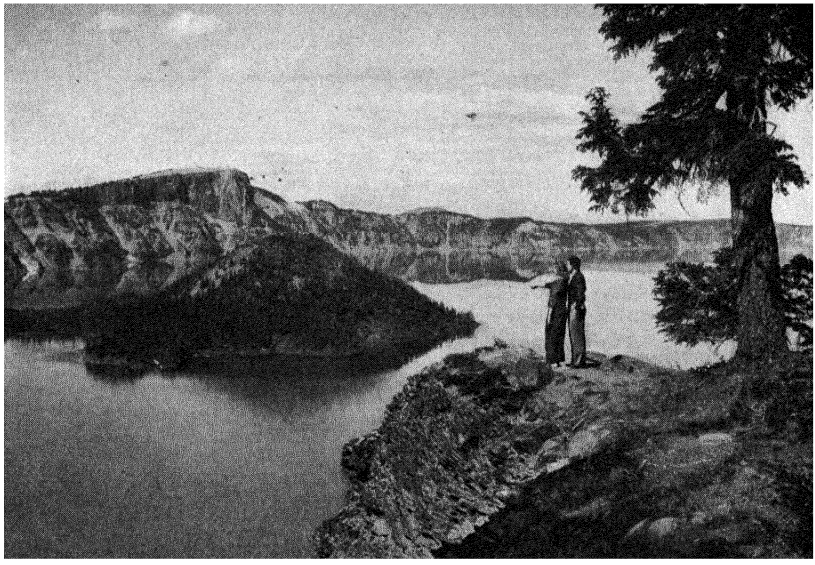


FIG. 50. Crater Lake. This deep lake rests in the crater of an ancient volcano. The cone in the center is called Wizard Island. (Courtesy, Oregon State Highway Commission.)

A volcano is a channel which opens up a connection between the basalt layer and the surface of the ground. Possibly the cause of the eruption is that the molten rock, which is under tremendous pressure, reaches the surface through faults or channels formed by warping or carthquake faulting. The rock is heated above the melting point (temperatures of about 2000° F. have been recorded in volcanic lavas) but normally is kept solid by the great pressures. When the pressure is released, the rock melts. The violent eruption of a volcano may be compared to the boiling of a pot of mush. As the mush thickens, the steam will form large bubbles, and, if it is not stirred, the mixture will overflow. In like manner, the dissolved gases in the molten rock cause the outrush of lava.

There are, in general, two types of volcanoes. There is a type, of which Vesuvius in Italy (Fig. 51) and Pelée in Martinique are examples, which pours out the materials explosively, sometimes burying and asphyxiating the entire surrounding territory. The eruption of Mt. Pelée in 1902 killed 30,000 people by poisonous gases. Another type, like Mauna Loa in Hawaii, pours out lava in a quiet river-like stream, erupting about once every four years. Dr. Jaggers has maintained a Volcano Observatory

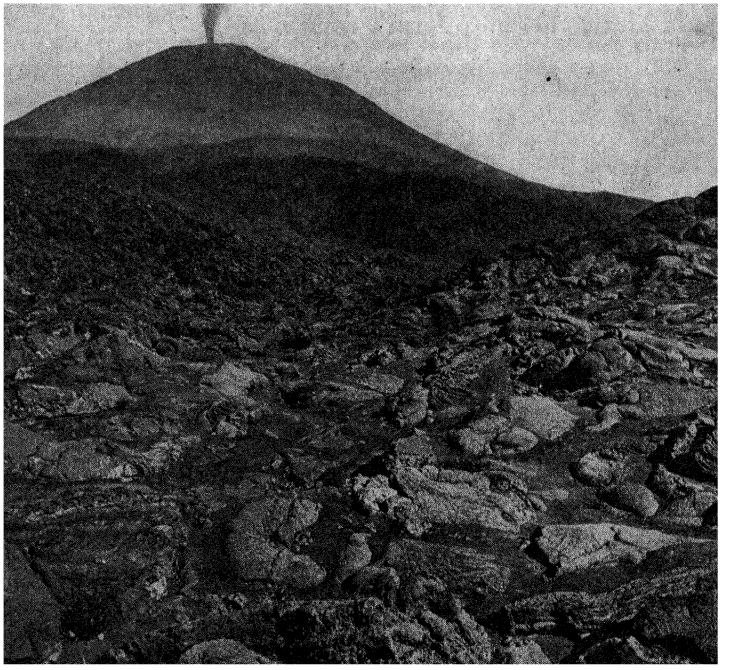


FIG. 51. Vesuvius under ordinary conditions. (From Tarr and Von Engeln: "New Physical Geography." By permission of The Macmillan Company, publishers.)

in the crater of Kilauea in Hawaii for some years. As a result of his observations, often made at the risk of his life, scientists have now a fairly accurate picture of the operation of volcanoes. The word *extinct* is often applied to volcanoes. This is misleading because volcanoes often remain dormant for hundreds of years, then suddenly break forth. Mt. Somma was dormant for 500 years before it erupted in A.D. 79, burying Pompeii to a depth of 30 feet. There have been about 30 volcanoes active since 1920. Java alone has many active ones.

EARTHQUAKES

The best method of investigating the centrosphere is that of earthquake study. An earthquake is the sudden shifting of the earth's crust. Down deep in the lithosphere there occurs a twist, a fold, or a break in the rock. Rocks are elastic, but, if the stress becomes too great, the rock layer may split apart and slip, causing a fault. An earthquake comes as a sudden shock accompanied by waves passing over the ground. The average earthquake is of short duration, lasting only a few seconds. For each earthquake there are three quivers. The first wave called a P (primary) wave or "push" is a longitudinal, or compressional one, traveling at a speed of about 8 miles per second. This wave passes through the centrosphere of the earth. It is followed some seconds later by an S (transverse) or "shake" wave which likewise passes through the centrosphere. There is also a slower L (surface) wave which travels in the surface rock (lithosphere). It is this wave that causes most of the damage to buildings.

Earthquakes occur frequently in the lithosphere and no part of the earth's surface is immune. However, they occur more frequently in regions where the continental shelf is very steep, and also in the region of active volcanoes. The regions along the Pacific Coast, including Japan and California, seem to be danger points. An earthquake in Japan in 1923 killed nearly half a million people. Experience has shown that flimsy buildings on soft rock are dangerous. Modern concrete and steel structures erected on bed rock seem to survive the effects of earthquakes best. Earthquakes beneath the ocean cause great waves which are very destructive. A rather destructive earthquake occured in Seattle, Washington, in 1949.

Science has devised an interesting instrument for the study of earthquakes. It is called a *seismograph*. The earlier types of this apparatus consisted of a heavy pendulum hung over a blackened surface. Fig. 52 is a schematic diagram illustrating the operation of this type of instrument. The base of the instrument is mounted on bed rock. The essential parts are a rotating cylinder and a heavy pendulum bob carrying a pointer. When the bed rock shakes, the base and the cylinder are jarred and moved before the pendulum can get into motion. As long as no shock affects the instrument, the pointer traces a straight line on the cylinder. If earthquake

shocks occur, a sudden oscillation causes the pointer to make a mark at right angles to the straight line, the length of this mark indicating the severity of the shock. Due to the three quivers just mentioned, there are three types of oscillation of the pointer. The primary and secondary waves produce short vibrations, while the surface wave causes the indicator to execute a long vibration. The direction of motion of the P and S waves give us the information concerning the various shells of the earth's core.

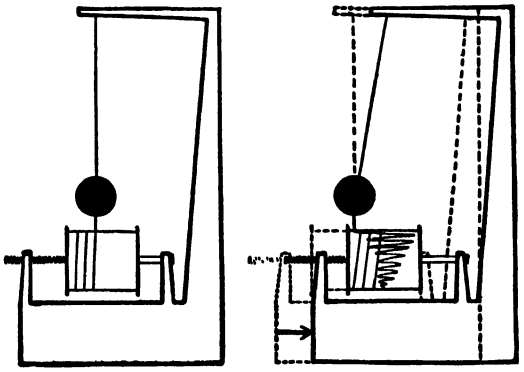


FIG. 52. The pendulum seismograph. (Courtesy, Professor Lynch, Fordham University.)

The vibrations of an actual earthquake which occurred in Turkey in 1939 are illustrated by the traces of Fig. 53. This set of waves was recorded by the Harvard University seismograph. It will be noticed that the trace really consists of three parts, one for each type of wave. Apparently the earth is as rigid as steel to sudden shocks and rather plastic to slow movements.

The newest type of seismograph consists of a horseshoe magnet with movable pole pieces. As the pole pieces vibrate, they change their positions relative to the magnet and a current of electricity is induced in the wire coils wound on the magnet arms.

AGE OF THE EARTH

Most scientists believe that the earth grew by absorbing other meteoric material. As the size increased, it was compressed and thus became hot. Radioactive material added to the heat. As conditions became suitable, gases began to accumulate from the rocks and, as a final stage, water vapor was formed.

Many estimates have been made of the age of the earth. At best these are inaccurate, but a brief description of some of the evidence will be of interest.

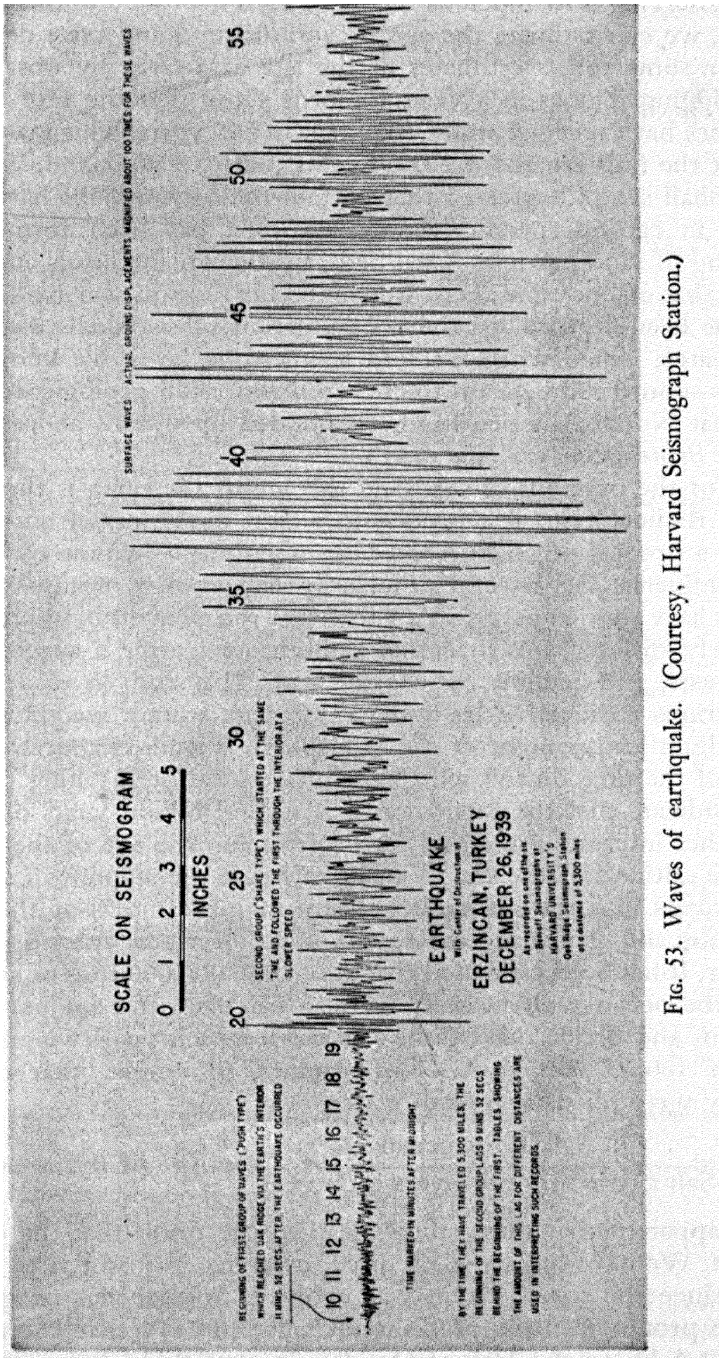


FIG. 53. Waves of earthquake. (Courtesy, Harvard Seismograph Station.)

By observing how much of the material is deposited in the oceans year by year, we can estimate the age of various mud and marl deposits. We can form some rough estimates of the age of a river by observing how much digging it does in a year. Records show that the Horseshoe Falls of Niagara have receded about 1000 feet in 265 years. This makes it probable that the falls are about 20,000 years old.

We shall see (Chapter 7) that certain rock formations have been developed in certain specific ways. Sandstone has been formed by the cementing of sand particles. Coal beds, by their plant fossils and imprints, indicate that at one time there was luxuriant flora in marshy land. Limestone has been formed by the accumulation of sea shells and skeletons under water; hence when we find a limestone layer we know that the land was submerged beneath the ocean. From such geologic evidence we know that North America has been flooded by oceans at least 15 times since the Proterozoic era (see p. 91).

One of the methods of studying the age of the earth is that of *radioactivity*. Radioactivity is a process in which the atoms of an element go through a process of change and become atoms of a new element. Man cannot influence this natural process by any known means. Only a few elements have this property. We know that the element uranium (Chapter 27) slowly disintegrates, becomes radium, and, after a space of several billion years, will become radioactive lead. This study is made easier because various radioactive leads have different atomic weights. The uranium-radium-lead content of the lithosphere is studied and an estimate is formed of the time during which the process has been taking place. Such studies indicate that the earth's crust is several billion years old.

Another interesting method for determining the age of the earth is to study the saltiness of the sea. We can calculate the amount of salt carried by the rivers into the sea each year by taking samples of the water of great rivers and estimating the total volume of water entering the ocean each year. It has been estimated that about 160,000,000 tons of salt are carried to the ocean each year. If we also calculate the amount of salt in the oceans and divide this by the salt carried each year, we arrive at the figure of 100,000,000 years. This assumes, of course, that the oceans originally were filled with fresh water.

$$\frac{\text{Salt in the ocean}}{\text{Salt carried by the rivers each year}} = \text{Age of the ocean}$$

It is apparent that these studies lead to the result that the earth is of great age. We have of course no direct evidence as to the time which has elapsed since the solar system was evolved. Science has progressed far since the pronouncement of Bishop Ussher in 1654 that "creation took place at 9 A.M. on the 26th of October in 4004 B.C."

References

Allen: "This Earth of Ours," Milwaukee, Bruce Publishing Co.
Byerly: "Seismology," New York, Prentice-Hall Inc.
Croneis and Krumbein: "Down to Earth," Chicago, University of Chicago Press.
Heck: "Earthquakes," Princeton, Princeton University Press.
Leet: "Causes of Catastrophe," New York, Whittlesey House.
Lynch: *Scientific American*, December, 1938.
Murray: "The Ocean," New York, Henry Holt and Co.
Pirrson and Schuchert: "Textbook of Geology," New York, John Wiley and Sons.
Reeds: "The Earth," New York, The University Society.
Russell: "The Solar System and Its Origin," New York, The Macmillan Co.
Swann: "The Architecture of the Universe," New York, The Macmillan Co.

Questions and Problems

1. Give evidence that the earth is rotating on an axis.
2. What is the evidence that the center of the earth is hot?
3. What is the character of the centrosphere?
4. What evidence does an earthquake give as to the character of the centrosphere?
5. What do we learn from volcanoes?
6. Explain why our hottest weather occurs in July rather than June?
7. What is the cause of the Midnight Sun?
8. Give three causes of the changes of seasons.
9. Is it correct to say that "the northern hemisphere has winter because it is farther from the sun"?
10. How can we determine the age of the earth?
11. If the earth's axis were perpendicular to the plane of the orbit, what would be the type of seasons?
12. What is meant by the term "perihelion distance"?
13. How can we prove that the earth is round?

Topics for Discussion

Volcanic Eruptions	Geysers	Mt. Everest
Earthquakes	Age of the Earth	Crater Lake
The Foucault Pendulum	The Midnight Sun	Seismographs

Visual Aid

"The Earth in Motion," University of Chicago Film

Experiments

1. Make a field trip to a mine, quarry, or road or railroad cut. Examine the various layers of rock.
2. Locate volcanoes on a world map. Connect them with a line. You will find that most volcanoes lie along one of three lines.
3. Make a drawing showing changes of seasons.
4. Try to spin a fresh egg. Why is it difficult? Cook it and try again.
5. Make a report on some limestone cave in the vicinity.
6. If the building has a stable foundation, hang up a heavy bob as a Foucault pendulum and observe the apparent shift of the plane of rotation. In the temperate zone, it will change about 10 degrees per hour.

6. THE EARTH A CLOCK

Time and the hour runs through the roughest day.
—SHAKESPEARE

For ages man has attempted to use the heavenly bodies to record the time of certain events, such as wars, religious festivals, and great calamities. The two objects which first suggested themselves as timekeepers were the sun and the moon. Most ancient peoples and the savage tribes have used the interval between two full moons as a measure of time. It is interesting that the word *month* comes from the word *moon.*

The Mohammedans use the lunar year consisting of 12 months, some having 30 days and some 29 days. The sacred month of Ramadan is the ninth month of the year. Each month begins with the rising of the new crescent moon. Because the moon makes a revolution about the earth in about 29 days, there is not an exact number of full moons in a year of 365 days. There are 12 full moons and about 15 days. As a consequence the month of Ramadan may occur at any season of the year. This is very unsatisfactory.

The ancient Chinese had a calendar consisting of 12 months to which they added one month in every 30. Their new year began with the first full moon after the sun entered the constellation Aquarius.

It will be of interest to describe the Chinese calendar in some detail since it illustrates clearly the difficulties of lunar calendars. Because of the fact that the solar year of 365 days determined the seasons, while the lunar year was only 354 days, it was necessary to insert seven months in every 19 years to regulate the seasons. The rule for intercalations was as follows: the vernal equinox must fall within the second month. If the seasons occur so that the second month contains no equinox, the third month becomes the second month. The summer solstice must fall in the fifth month, the autumnal equinox in the eighth month, and the winter solstice within the eleventh month. Modern China now uses the Gregorian calendar.

SIDEREAL TIME

The earth rotates on its axis in exactly 24 hours *sidereal* time (star time). If Vega in the constellation Lyra is on the observer's meridian (a line passing through the zenith from the north pole to the south pole) at 18 hours sidereal time, the star will be again on the meridian exactly 24 hours later. This is the time that is preferred by the astronomer. (Zero

sidereal time at a place is when the vernal equinox is on the meridian of the place. Sidereal time is measured from zero to 24 hours.)

Because of the fact that the earth is continually moving around the sun, completing the circuit in a year of about 365¼ days, the sun, each noon, seems to be about one degree farther east among the stars than it was the day before. The various positions of the sun among the stars are called the *Zodiacal* positions (see p. 49). On June 21, the sun is said to be passing through the constellation Cancer, and on December 22 it is said to be in the region of Capricornus. (It is interesting to note that the present positions are really Gemini and Sagittarius because of a shift in the earth's axis during the 3,000 years which have passed since the Zodiac constellations were first allocated.) In Fig. 54, if the month is June, the sun seems to be in the direct of Gemini. As the earth moves about the sun, the sun seems to move among the stars.This motion of the earth has the result of causing the stars apparently to cross the meridian about 4 min-

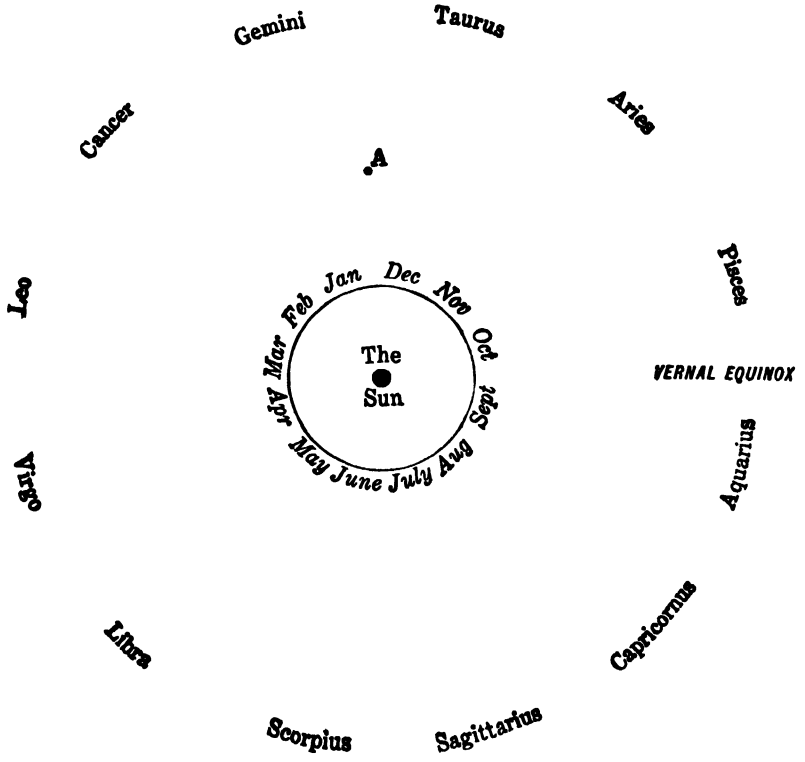


FIG. 54. A drawing illustrating the sun's apparent motion among the stars. For example, if the earth is in the position marked June, the sun seems to be in the direction of star A. (Courtesy, Duncan: "Astronomy," New York, Harper and Bros. Used by permission.)

utes earlier each day than on the preceding day, if we reckon by sun (solar) time. Thus the sidereal day is 23 hours, 56 minutes, and 4.09 seconds of mean solar time. If we reckon time by the sun, the stars rise about two hours earlier each month. Since we regulate our mode of living by the sun, sidereal time would be inconvenient since sidereal noon would occur at all times of the day and night.

The apparent motion of the sun among the stars can be demonstrated by the use of a planetarium and an electric light. The electric light will represent a fixed star when placed some distance from the planetarium. Allow the earth to revolve about the sun and it can be seen that the star seems to rise earlier each evening because of the motion of the earth about the sun.

Mean Solar Time

Were the apparent eastward motion of the sun uniform, each solar day would be longer than the sidereal day by the same number of minutes. Noon, true solar time, is that time when the sun is on the observer's meridian. P.M., or post meridian, represents time since the meridian crossing. However, the motion of the sun is not uniform. In February, it is 14½ minutes slow and in November it is 16½ minutes fast, so that the days vary slightly in length. The earth travels in an elliptical path, traveling more rapidly in winter than in summer.

The motions of the earth and the other planets follow the laws of Johannas Kepler. Kepler (1571–1630) was a German astronomer. As a result of his correspondence with Galileo, he became convinced that certain fixed laws governed the motions of the celestial bodies. He tried many theories concerning the motions, among them being the old concept of "Music of the Spheres." This fanciful theory assumed that the planets sang as they moved. After many years of work on the problem, he finally arrived at the correct result. His findings are incorporated in three laws named after him.

The laws are as follows:

1. Each planet moves in an ellipse which has the sun at one of the foci.
2. A line joining the center of each planet to the center of the sun passes over equal areas in equal intervals of time. The result of this law is that the planet moves most rapidly when it is nearest the sun.
3. The cubes of the mean distances of any two planets from the sun are to each other as the squares of their periodic times of revolution about the sun.

Fig. 55 illustrates the first and second laws. The sun is at one of the foci of the elliptical path in which the planet moves. Also area ABS at perihelion equals area CDS at aphelion. The third law can be tested from data in the planet table of Chapter 4, using Mars and the earth.

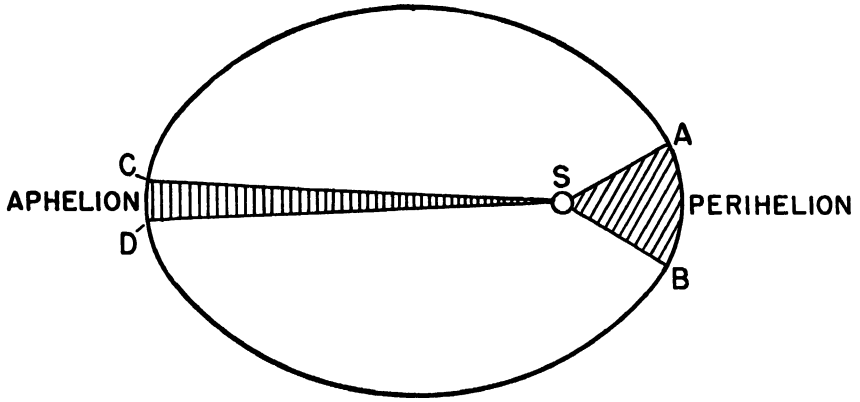


FIG. 55. Kepler's Law of Areas. The planet covers the distance CD at aphelion in the same time that it covers the distance AB at perihelion. The areas ABS and CDS are equal. (The eccentricity of the orbit is not drawn to the correct scale.)

$$\frac{(93 \times 10^6)^3}{(141 \times 10^6)^3} = \frac{(365)^2}{(687)^2}$$

The second law indicates that the planet at perihelion travels faster in its path than when it is at aphelion. It is evident that the distance traveled on December days is greater than the distance traveled on June days. It requires 186 days for the earth to travel from vernal equinox to autumnal equinox (March 21 to September 22) and only 179 days to return. Since the earth is nearer the sun in the northern winter, it is attracted by a greater force and thus moves more rapidly. Because of this lack of uniformity of motion we use as our timekeeper not the real sun but an imaginary sun which does move with uniform speed through the heavens, traveling the same distance each day. This sun gives us *mean solar time*. A second is 1/86,400 of a mean solar day.

If each community operated by its mean solar time, time would vary from place to place, and only those places having the same longitude would have the same time. To remedy this, standard time was adopted by the railroads in 1884, so that time would change only at intervals or belts of distance. As can be seen from the map (Fig. 57), these belts are irregular and their positions are located to suit business conditions. The Interstate Commerce Commission of the United States has the authority to change the time belt for any section of the country. North America has five belts: Atlantic, Eastern, Central, Mountain, and Pacific (Fig. 56). All communities in a zone observe the same time.

In order to suit business conditions, the mean solar day begins and ends at midnight. This is called the *civil day*.

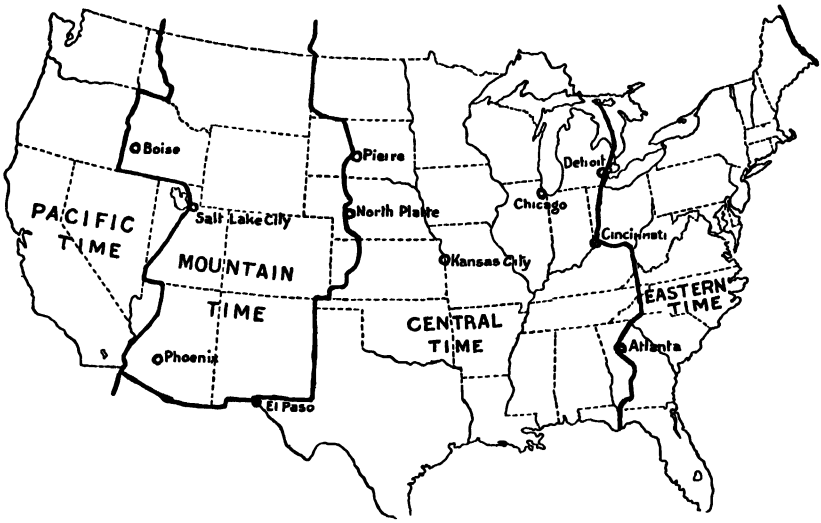


FIG. 56. Time belts in the United States. (Map, courtesy, Stephen Elinsky.)

LONGITUDE

The meridians of longitude are imaginary great circles that are drawn around the earth from pole to pole. Because of the fact that the mean sun apparently passes around the earth once in 24 hours, we divide the 360 degrees of longitude into 24 zones of 15 degrees each, one for each hour of the day. Thus the sun is said to pass over 15 degrees of longitude each hour. By international agreement, the meridian of longitude passing through Greenwich is numbered zero and the degrees are numbered westward toward the United States and eastward toward Asia. For example, the longitude of New York is about 74 degrees West, which means that there is a time difference of 5 hours between London and New York. When it is 12 noon in New York, it is 5 P.M. in London. Most evening radio listeners are familiar with the sound of "Big Ben" striking midnight in London. In 1886, Japan made its time that of the meridian 135 degrees East, 9 hours FAST from London.

LATITUDE

In order to locate positions on the earth, we need the coördinates of longitude and latitude. The zero reference line for latitude is the equator, a great circle drawn around the earth equidistant from the north and south poles. Parallel circles are drawn on the earth from the equator to the poles, giving us north and south latitude. The poles are 90 degrees latitude. *Latitude is defined as the angular distance north and south from the equator measured on the meridian of longitude.* Since latitude is measured from the equator to the pole, it is possible to determine one's lati-

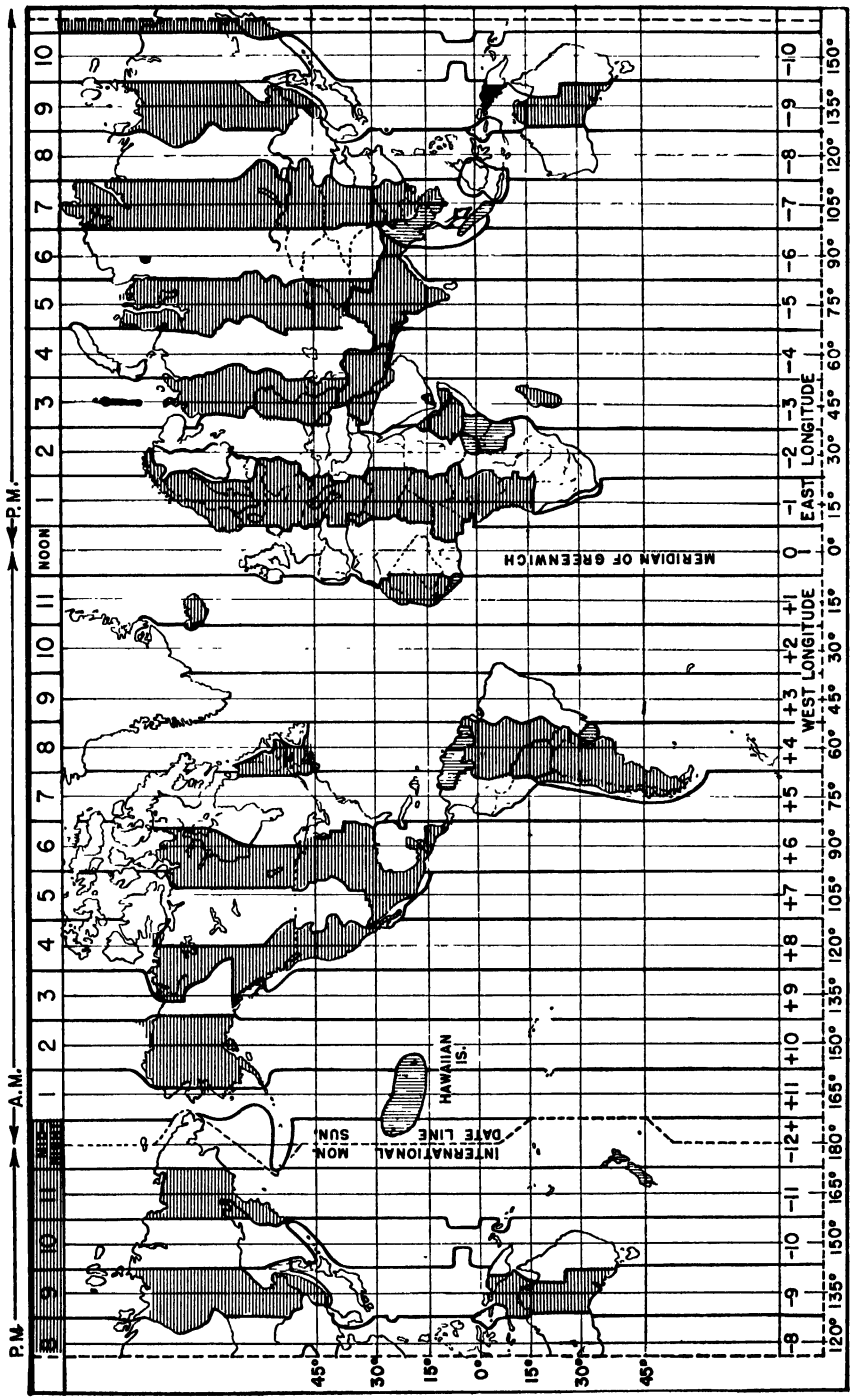


FIG. 57. Map of the world, showing time zones and date line.

tude by observing the elevation of the pole star (Polaris) above the horizon. (It is not easy to determine one's longitude.)

The rule follows: the latitude of the place is the altitude of Polaris. At 90° North Latitude, Polaris has an altitude of 90 degrees. At the equator, Polaris is on the horizon with altitude zero.

In speaking of celestial bodies, we make the celestial equator the reference circle and use the term *declination* (see p. 28) instead of latitude. The declination of a star is the arc of an hour circle included between the star and the celestial equator. The declination of the sun is its angular distance north and south of the celestial equator. On or about December 22 the sun's declination is 23½° South. On June 21 the declination is 23½° North. When the sun crosses the equator at the vernal equinox, spring begins.

The Date Line

The two types of longitude meet at 180 degrees, which is called the International Date Line. The reason for this name will be made clear by examples. If one should make a world tour traveling westward from Philadelphia, he would need to set his watch back one hour for each of the time belts. The consequence would be a whole day lost on his return. On the other hand, if he traveled eastward, the watch would need to be set ahead one hour for each zone. Another example may be of interest. Let us imagine an aviator leaving London at noon on July 1, traveling around the world westward at 40° North Latitude at a speed of 750 miles per hour. At this speed, the sun would always be overhead, and upon return to London no night would have been experienced, hence no new day. The inhabitants of London would have had night and thus a new day, July 2. The aviator would be one day behind London.

In order to obviate these difficulties, the 180-degree line was chosen as the meridian where the day begins. This means that New Year's Day is first observed on the westward (toward Asia) side of the line. Some interesting results of ocean travel at the line arise from the change of day. If a passenger traveling toward Japan from the United States arrives at the line at 8 A.M. December 25, he will have no Christmas dinner, since the day becomes December 26. On the other hand, if a passenger traveling from Japan to San Francisco arrives at the line at 8 P.M. December 25, he will have another Christmas Day. Since the time difference between Japan and New York is 14 hours, 7 A.M. Saturday in Japan is 5 P.M. Friday in New York. We often read on Monday items from Japan dated Tuesday.

Edgar Allen Poe used the International Date Line as the theme of his short story "Three Sundays in a Week."

The Calendar

From earliest times, man has used some sort of calendar. As early as 4000 B.C., the Babylonians divided the year into 12 months of 30 days each and divided the week into seven days. Somewhat later, Egypt constructed a year of 12 months of 30 days each and added 5 holidays. This method was adopted by Greece and Rome, but, when Julius Caesar came into power in 45 B.C., the calendar was in hopeless confusion. In order to rectify the error, the astronomer Sosigenes of that time made the year 365 days and added a leap year every four years. Also the months of July and August were added. January was named for the god Janus, February was named for a festival, March for Mars, April for Venus, and May and June for lesser gods. We note that September, our ninth month, means seventh. This is the result of the old Roman calendar, which began in March.

However, the Julian year is too long by 11 minutes, since the solar year is exactly 365 days, 5 hours, 48 minutes, and 46 seconds. This produces an error of about one day for each century, causing the seasons to come earlier. In 1582, Pope Gregory and his councilors dropped 10 days from the calendar, making October 5 become October 15, and a change was made to correct the error for the future. The Gregorian Calendar has the same year and leap years as the Julian Calendar except that the century years, 1700, 1800, and 1900, were not leap years. Century years must be divisible by 400. Because of religious difficulties, the Greek and Protestant sects did not immediately recognize the change. However, in 1752, 11 days were dropped in England and America, and January instead of March became the first month. We celebrate February 22, 1732 as the birthday of George Washington, but he was born on February 11 by the Julian calendar. The Greek church adopted a new calendar in 1923 which differs slightly from the Gregorian.

There are other calendars, the Jewish dating from the "creation of the world" in 3761 B.C., and the Mohammedan dating from the Hegira in A.D. 622. The days of the week are named for Saxon gods, the number 7 being a holy number in ancient religions.

Sunday–Sun	Monday–Moon	Tuesday–Tiw
Wednesday–Woden	Thursday–Thor	Friday–Freya
	Saturday–Saturn	

One of the great difficulties confronting archeologic research is the confusion in numbering the years. Ancient peoples named the year after a certain reign or event. Several hundred years ago it was decided to begin an era with the birth of Christ.

Calendar Reform. One of the most serious drawbacks to the present calendar is the fact that the days of the week fall on various days of the

month. It would be desirable if Sunday always fell on the 1st, 8th, 15th, and 22nd of each month. Moses Cotsworth has proposed a 13-month calendar which would make this possible. Each month would have 28 days with one day called New Year's Day belonging to no month. Another suggested calendar is the World Calendar, in which the year is divided into quarters.

The Clock

Although the earth's rotation gives us the 24-hour day, to divide this interval we must use other devices. One of the oldest types is the sundial, invented by the Egyptians. The obelisk was a form of sundial. Unfortunately, the sundial is of limited use because sunshine is intermittent. The hourglass was another type of hour divider.

Galileo noticed when watching a swinging chandelier in the cathedral at Pisa that it retraced its path in exactly equal intervals. It is said that he used his pulse as a time clock. By a series of observations he established the laws of the pendulum. A pendulum kept at a constant length and having a constant force of gravity acting upon it will always execute a swing in the same interval. In order to keep the pendulum at a constant length, methods must be used to keep the temperature from affecting it.

Since most materials increase in length as the temperature is increased, various devices are used to counteract this effect. One type uses two metals which have unequal expansions. The two expansions neutralize each other. A simple pendulum about one meter long beats seconds in New York. The time of the swing of a pendulum equals:

$$3.1416\sqrt{\frac{\text{length in centimeters}}{\text{acceleration of gravity in cm/sec}^{-2}}}$$

After the invention of the escapement by Christian Huygens in 1656, the pendulum became a means of keeping accurate time. In the hands of the astronomer, the pendulum clock is a very accurate instrument. Astronomical clocks are wound every minute and the clock is kept in a constant-temperature room. The balance wheel of a watch is also a timekeeper. The newest type of clock, the electric one, depends upon the fact that electric current which flows in the wires of the house is alternating, or reversing its direction many times a second (see p. 379). The clock contains a tiny synchronous motor which keeps in step with alternations. If the number of alternations (frequency) is carefully controlled at the power house, the electric clock is an accurate timepiece.

References

Duncan: "Astronomy," New York, Harper and Brothers.
Foley: "College Physics," Philadelphia, The Blakiston Company.

Philips: "The Calendar," New York, The Macmillan Co.
Way: "Time and its Reckoning," New York, Chemical Publishing Co.
Circular Number 399 of the Bureau of Standards.

Questions and Problems

1. Why do we use mean solar instead of real sun time?
2. If it is 4 A.M. Tuesday in Japan, what is the time in New York? Answer: 2 P.M. Monday.
3. If it is 1 A.M. Monday in London, what is the time in New York? Answer: 8 P.M. Sunday.
4. Four P.M. Thursday in Hawaii is what time in Chicago?
5. Explain the reason for the change of the calendar in the sixteenth century.
6. If a star rises tonight at 9 P.M. mean solar time, at what time will it rise 20 days hence? Answer: 7:40 P.M.
7. Where does the day begin?
8. Is there a place of zero latitude and zero longitude?
9. Why is the International Date Line necessary?
10. The time is 8 P.M. Friday at 120° West Longitude. What is the time at 120° East Longitude? Answer: 12 Noon Saturday.

Topics for Discussion

Calendars — Sun Dials — The Pendulum
The Feast of Ramadan — The Chinese Calendar

Experiments

1. Make a time belt map of the United States.
2. Set up a simple pendulum by fastening a ball to a string. Make the length 60 cm. and record the time of 100 swings. Change the length to 120 cm. and again record the time of 100 swings. What effect does the change of length have on the time of swing? Adjust the length until the pendulum ticks seconds. Measure the length.
3. Use a bottle with a small opening and make an hourglass.
4. Set up a sundial by using a sheet of metal on which you have engraved the hours of the day. Decide which direction the pointer must be set to record the hours correctly. Look up the method in an encyclopedia.

7. THE EARTH'S CHANGING CRUST

There rolls the deep where grew the tree.
O earth, what changes thou hast seen!
There, where the long street roars, hath been
The stillness of the central sea.

—ALFRED TENNYSON

As we look about us at the hills, rivers, and mountains, we think of them as everlasting and stable. But when we look at tiny streams carrying sediment to the rivers, at winds blowing dust over the land, at debris falling from cliffs after every heavy rainfall, we must realize that the lithosphere of the earth is undergoing constant change. The very region in which we live has undergone great changes in the millions of years that have elapsed since the earth was formed. It is probable that many changes will take place in future eras. Perhaps the locality will be submerged beneath ocean waters; a volcano may cover the region with lava; a sheet of ice may cover the area; a mountain may be thrust up, changing pleasant plains to steep rocky cliffs. Even today we know that many diastrophic[1] changes are taking place; the British Isles are slowly being submerged; the west coast of Greenland is sinking; the northern shore of Lake Superior is rising and tilting the lake over into Wisconsin and Michigan. The entire crust of the earth seems to be shrunken and folded like the skin of a withered orange.

Because of these diastrophic changes which are constantly taking place in the earth's crust, the scientist is able to secure information about prehistoric conditions. From the studies of rock formations and fossils, a table of geologic time has been constructed (Table 4). Just as the archeologist is able to trace the history of civilization by digging down into buried cities such as those of the Sumerians, where he finds a series of cities built one over the other, so the geologist finds successive layers of rock built up in such a manner that he can draw conclusions as to the method of formation and the length of time during which the layers were formed.

If we look closely at the walls of a railroad cut, we note that many of the rocks are arranged in nearly parallel layers. Perhaps we find a limestone bed, then a sandstone layer, then another limestone layer, and per-

[1] Diastrophism is the term used to describe the movements of the lithosphere. The causes of such movements are shrinking, displacements, and folding.

Table 4

TABLE OF GEOLOGIC AGES (DURATION OF TIME EXPRESSED IN MILLIONS OF YEARS)

Eras	*Periods*	*Chief Events*	*Predominant Life*
Cenozoic 60	Pleistocene Miocene Oligocene Eocene	Glaciation over large areas. Soft coal, salt, gypsum. Extensive volcanism. Rocky Mts. formed. Many lava flows in west. Grand Canyon formed.	First true man, e.g. Heidelberg man. Mammals such as mastodon. Modern birds and plants. Primitive forms of mammals. Primates.
Mesozoic 100	Cretaceous Jurassic Triassic	Sandstone, clay, coal. Sierra Nevada Mts. Sandstone, coal, salt, quartz, petrified forests, volcanism. Sea invasions.	Placental animals and flowering plants. Great reptiles and reptile-like birds. Marsupials, dinosaurs, crocodiles. Modern insects.
Paleozoic 300	Permian Pennsylvanian Devonian Silurian Ordovician Cambrian	Appalachian Mountains. Coalbeds, limestone. Penna. oilsands, shale, sandstone. Aridity, rock building. Taconic Mountains. Limestone, shale. Sea invasions in North America.	Land vertebrates, strange reptiles, mollusks. First reptiles and insects. Ferns. First forests, first amphibians, corals. Coal producing plants. Lung fishes, air-breathing animals. First fishes. Trilobites and brachiopods. Fossils.
Proterozoic 500	Upper Pre-Cambrian	Glaciation Volcanism. Erosion, diastrophism.	Few fossils. Algae present. Single celled plants and animals. Cephalopods.
Archeozoic 500	Laurentian Keewatin Grenville	Igneous rocks. Sedimentary. Oldest limestone, marble, slate, schist. Volcanism, iron, gold. Mountain building.	No fossils. Perhaps bacteria. Presence of iron and limestone give indirect evidence of some life forms.
Azoic		Development of solid earth ball.	No life.

haps a bed of shale. Moreover, as we examine these layers, frequently we find evidence that the upper layers have been laid over layers of older rocks which previously have been eroded. Such an *unconformity* (Fig. 58) means that in past ages the older rocks have been elevated above the water, have suffered erosion, and have been submerged again as the earth's crust



FIG. 58. An unconformity. (Courtesy, U.S. Geological Survey.)

has wrinkled. Subsequently, the eroded layers were covered by the strata of a later age. In many cases, some of the layers have been tilted from their horizontal positions by diastrophic forces. Very often we find layers which, originally horizontal, have been bent into a series of folds (Fig. 59). The crests of these folds are called *anticlines* and the troughs are called *synclines*. Such folded rocks make coal mining rather hazardous since the mine roof may be weak.

The Grand Canyon of the Colorado River gives the scientist an excellent view of unconformities. The dividing line between strata of different ages is easily seen. Some of the lower strata were horizontal when first deposited. Later, these beds were tilted, as can be seen in Fig. 60. The reason that the upper layers are still horizontal is that they were not formed until after the tilting of the lower layers had occurred.

If the forces exerted in the process of bending the layer have been excessive, the rock may be broken or faulted somewhat as a stick may fracture if bent too far. Faultings may be accompanied by earthquakes which cause great destruction of property and much loss of life.

The types of layers which we find give us information concerning the condition of the earth when the rock was formed. A limestone bed generally indicates that the locality was submerged below the surface of quiet water. A sandstone layer or a shale bed indicates that moving water deposited sediment over the area. Successive rock layers tell us that there were depressions and upheavals of the crust over long periods of time.

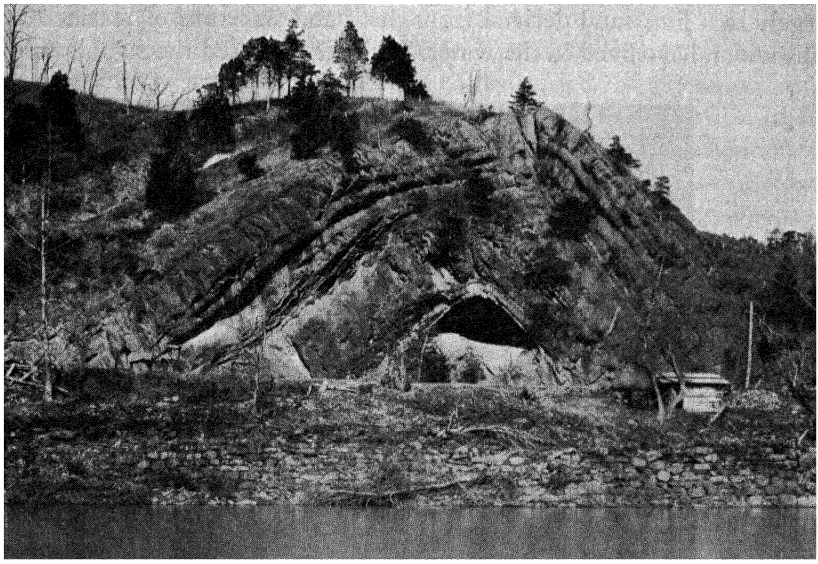


FIG. 59. An anticline. (Courtesy, U.S. Geological Survey.)

Moreover, such layers tell us that a hydrosphere and an atmosphere were present millions of years ago.

The deepest rock layers may be igneous or metamorphic, upon which are laid sedimentary beds. In addition, many of the sedimentary beds contain immense numbers of fossils, the remains of animals and plants.

FOSSILS

As a rule, when animals die their bodies soon completely disintegrate or are devoured by scavenger animals. Fortunately for our study of the earth's history, some skeletons have escaped destruction and have been preserved for millions of years.

Perhaps the most interesting method of natural preservation is that typified by asphalt pits and peat beds. At Rancho La Brea, in Southern California (Fig. 61) there exists an asphalt pit which has acted as a trap for prehistoric animals. Apparently the animals were trapped as they wandered to the pit in pursuit of other animals and birds which were already caught in the viscous mass. The antiseptic properties of the asphalt prevented the decay of the skeletons. Many specimens of fauna of the Pleistocene geologic period have been found buried in this pit.

We also find the debris of many marine animals on the floor of the

ocean. In fact, we know that our limestone and chalk deposits are due largely to a lime mud derived from shells and skeletons of marine organisms which have lived in the water. Such animals used the soluble calcium



FIG. 60. A tilted bed. (Courtesy, U.S. Geological Survey.)

salts in the ocean to form calcite in their shells. At death these shells collected as a lime mud which hardened to limestone. If the limestone



FIG. 61. Rancho la Brea, near Los Angeles, California. (Mural by Charles R. Knight. Courtesy, American Museum of Natural History, New York.)

layer became covered with layers of sand and clay, we find strata of sedimentary rocks frequently containing fossils.

In a few cases, completely preserved prehistoric animals have been found frozen in ice beds. During one of the periods of glaciation a number of Arctic mammals of types now extinct were trapped in ice. In 1900, a great hairy mammoth was discovered in Siberia in an excellent state of preservation. The flesh was still edible and the dogs enjoyed a feast on the oldest known cold storage meat. Some of the ivory of commerce has come from the tusks of these extinct elephants which were buried thousands of years ago.

Amber, the resin of prehistoric pine trees, trapped insects in its sticky mass. As the resin hardened, these insects were perfectly preserved. Another example is that of dinosaur footprints which are found in hardened shale in Connecticut. These stone footprints are for sale commercially.

In many cases, fossils are found in various states of petrification (stone replicas). In this very interesting process the forms of the original structures were preserved by minerals which were dissolved in the water which covered the buried material.

During the Triassic period many pine trees in the region of the state of Arizona fell into sand beds and were covered by volcanic ash. Present in the ground was water charged with silica. By some mysterious process the wood cells were replaced by silicon dioxide. Some of the silicious minerals found are quartz, chalcedony, jasper, onyx, and agate. These minerals are often of gem quality. Some of the stone trees are over 100 feet long and have diameters of 10 feet (Figs. 62–63).

The age of rocks can be dated by the fossils found in them. In any series of layers of sedimentary rocks, the low stratum is the oldest. The



FIG. 62. A tree in the petrified forest of Arizona. (Courtesy, Atcheson, Topeka and Santa Fe Railway.)

great gash in stratified rock called the Grand Canyon of the Colorado River has exposed successive layers (Fig. 64). The lower layers contain fossils which are not present in the upper layers. From the mass of such information the scientist constructs the periods of the earth's history. Occasionally volcanic ash covers the remains of life, as was the case of Pompeii after the volcanic eruption in A.D. 79. Many persons were buried in the ash. During recent excavations much information was gained concerning the dress and habits of life in the ancient Roman city.

The Chart of Geologic Time

The geologic chart (Table 4) is divided into eras and periods covering millions of years. Despite the fact that the actual length of time intervals is subject to much uncertainty, the table presents an interesting record of geologic changes. A study of the table shows that an interval of about one billion years has been named the *Azoic era.* Concerning this interval there is much uncertainty. Some scientists believe that during this time the earth was cooling from a hot globe to its present condition, and that during this era the oceans and atmosphere were forming. This theory is based on the Nebular Hypothesis of Laplace (Chapter 4). Other scientists believe that, during this interval of time, the earth was growing by gathering to itself meteoric material, and that the atmosphere increased as the earth grew larger. This is the Planetesimal Theory (Chapter 4). In the Azoic era we have no certain evidences of actual life, but we have reason to believe that organic colloids (see p. 259) were present. Rocks of the era are sometimes called the fundamental gneisses.

Following this era comes the Archeozoic (primordial life) interval. It is evident from studies of rock layers that this era was a time of extensive rock formation and mountain building. There was much volcanic activity and great quantities of lava poured over portions of the earth.



Fig. 63. Sections of petrified trees showing surface textures. (Courtesy, U.S. National Park Service.)

Most of the rocks are of the igneous type, but some are quartzites, marbles, schists, and other metamorphic rocks. These indicate that some sedimentary rocks were formed during this era.

The Archeozoic era was succeeded by the Proterozoic (primitive life) interval. Here we find great quantities of sedimentary rocks as well as metamorphic rocks. The rocks of this era show unconformity with the rocks of the Archeozoic era. The metamorphic rocks indicate much diastrophism of the earth's crust, including mountain building. Also we find that the rocks of the Proterozoic era contain extensive deposits of gold, silver, nickel, and copper. The erosion of the rocks of the Archeozoic era produced the great iron ore deposits of this era.

In marked contrast to the lack of exact knowledge of earth evolution in the Archeozoic and Proterozoic eras, often called the Pre-Cambrian interval, we find that the 300,000,000 years of the Paleozoic (ancient life) era produced an abundance of fossil-bearing rock formations, principally shales and limestones. By studies of these rocks, we are able to secure much information about the climatic conditions which existed. We believe that ancient plants and animals must have been exposed to tempera-

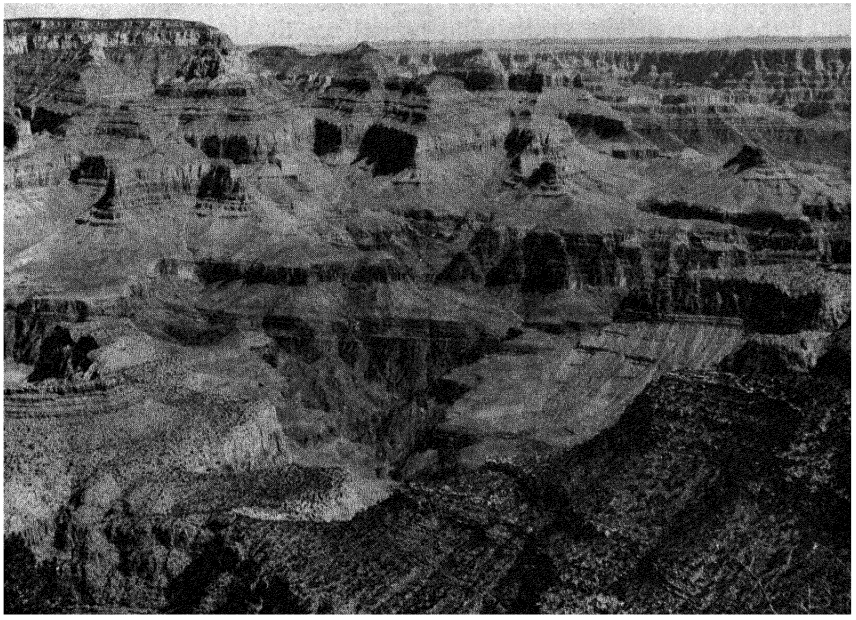


FIG. 64. Grand Canyon. View from Grandview Point, showing four geological eras, the Archeozoic, Proterozoic, Paleozoic and Mesozoic. (Courtesy, U.S. National Park Service.)

ture conditions about as we know them today. This leads to the belief that the earth as a whole has experienced about the same climatic conditions for at least a billion years, although many localities may have had climates different from those of today. During the Cambrian period of this era, seas began to move over the land, carrying certain animals called trilobites (animals somewhat akin to the king crab) and brachiopods (a type of shellfish). Although there are no trilobites or brachiopods today, we find great numbers of these fossils in the Cambrian rocks. There is evidence that much of the present land area of the United States was submerged beneath the surface of marine water during this interval. In fact, it appears that, at times, the Atlantic and Pacific Oceans met in Central United States, and the Arctic waters met those of the Gulf of Mexico. At the close of the Cambrian period the waters receded. In the Ordovician period the sea again encroached upon the land. The evidence for this is that most of the sedimentary rocks in both the Grand Canyon and the eastern mountain ranges are of marine origin. Apparently the water was shallow like that on the present-day continental shelves along the coast. In this period new types of animals such as clams and snails came upon the scene, leaving great limestone deposits. Such limestone is quarried in New England, Pennsylvania, and the Central States. The Ordovician rocks are the source of much marble and slate.

At the close of the Ordovician period we find the land elevated in North America. However, in the subsequent Silurian period, the land was depressed again. A great inland sea spread over the central states. In this period we find much coral. Probably the climate was semitropical—much

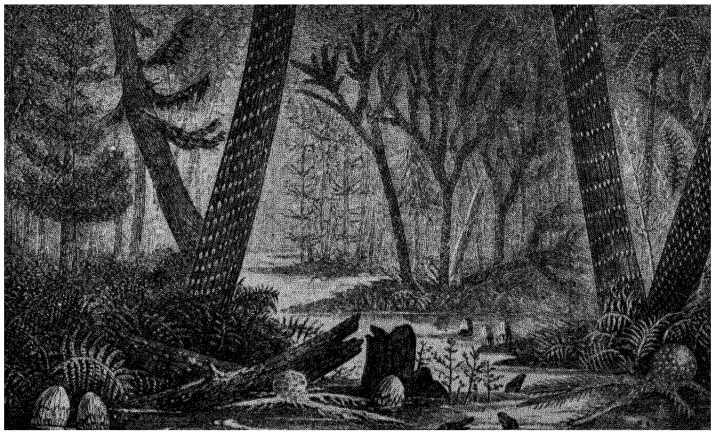


FIG. 65. An artist's drawing of a coal forest. Such scenes were probably common in the coal-forming periods. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

like the coral regions in the Pacific Ocean at the present time. There is evidence that the Great Plains States were once heavily forested.

During the latter part of the Silurian period, the land was rising, and, as the water evaporated, great beds of gypsum and salt were deposited. We find such beds in central New York, northern Ohio, and southern Michigan. Later in the Paleozoic era came the Devonian period, during which much shale, sandstone, and limestone were deposited. Some of these sand deposits in Eastern United States are oil-bearing and are the source of Pennsylvania "crudes."

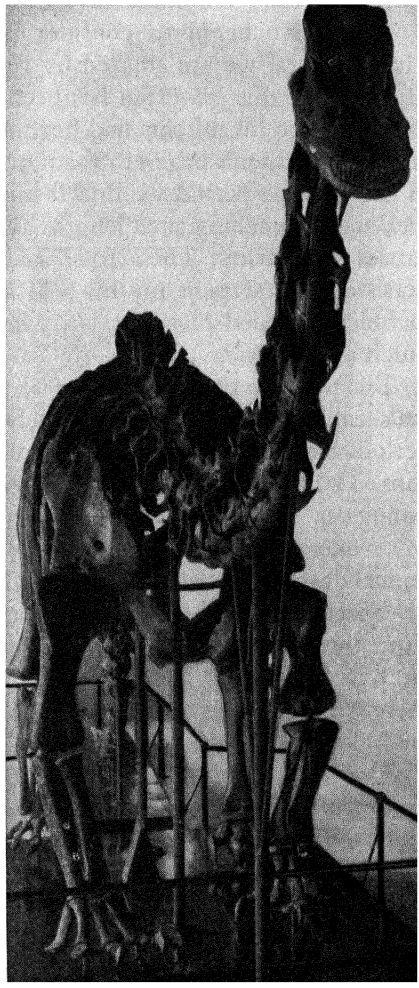


FIG. 66. Diplodocus. (Courtesy, Carnegie Museum, Pittsburgh.)

In the Mississippian and Pennsylvanian periods, the great coal measures of Eastern United States and Central Europe were formed. At this time the climate was warm and moist, and the coal beds were swamps. The eastern part of the United States probably sank and rose many times during the millions of years of the Pennsylvanian period and great forests grew and decayed, the bacterial decomposition leaving the great beds of coal. Each layer of coal tells of a forest and the sediment above the coal contains twigs, leaves, cones, seeds, and even entire trees, making it fairly easy for us to identify the type of plants that formed coal. As these club mosses and tree ferns fell in swamp land, the water prevented complete oxidation of the cellulose, and the carbon in the plant tissue became separated as coal, in layers sometimes over 100 feet in thickness. The semitropical climate necessary for coal formation must have been widespread at various times. It is startling to find coal in such extreme latitudes as Spitsbergen and the Antarctic Continent (Fig. 65).

In a few areas such as those of northeastern Pennsylvania, the coal was subjected to great pressure and was changed to anthracite. Some of the rocks of the Pennsylvanian period have furnished much excellent petroleum and much of the better limestone used as building material. The more important limestone caverns are of this period.

When we begin to consider the changes taking place during the Mesozoic era, we are amazed by the tremendous development of animal life. In fact, this era often has been called the "Age of Reptiles." Up to this time, the inhabitants had been animals with no backbone, but in this era the vertebrates began to roam over the earth. In the sedimentary rocks of the Triassic period we find fossils of those curious sea creatures called *plesiosaurs,* reaching such lengths as 40 feet with features resembling both turtles and snakes. These fossil remains are probably the source of the persistent sea serpent myths. Still more strange were the flying reptiles technically called *pterodactyls,* which apparently had wingspreads of as much as 30 feet.

But perhaps the strangest of all reptilian forms were the swamp animals called dinosaurs, which reached their greatest size in the Jurassic period. Some of these animals were flesh eating and some were herbivorous. They seem to have lived during most of the Mesozoic era. Every youngster is familiar with the names brontosaurus and diplodocus (Fig. 66). For years people have looked with awe at the specimen of the diplodocus which is to be found in the Carnegie Museum.

Toward the end of the Mesozoic era there was much volcanic activity along the Atlantic Coast of the United States. The Palisades of the Hudson are hills formed by lava flow. Along the west coast of the United States there was much activity of the earth's crust resulting in most of the mountains along the Pacific Ocean.

One of the most mysterious of environmental changes is the disappearance of these tremendous reptilian beasts. Only a few types remain, such as the alligators, crocodiles, turtles, and iguanas. Perhaps climatic changes were responsible. The reptiles were displaced ultimately by the more modern mammals.

As we enter the Cenozoic (recent life) era, we find that most of the world had begun to have the familiar features that we know today. During the earlier eras the earth had gone through great upheavals, but during the Cenozoic interval we find that most of North America was in much the same condition as at present. However, salt beds and petroleum deposits, as well as glaciated areas, give evidences of some changes in the earth's structure and climate. During this era we find fossils of many mammals resembling those of the present day. Many of the oil deposits of the Gulf Coast are found in rocks of the Cenozoic era.

Finally, in the Pleistocene period, less than one million years ago, man

appeared on the scene. Fossils of early man are very rare and not until burial became a practice were many relics of early man preserved. The species of modern man may be said to begin with Cro-Magnon man, whose skeletons are found in caves in France.

References

Allen: "This Earth of Ours," Milwaukee, Bruce Publishing Co.
Branson and Tarr: "Introduction to Geology," New York, The McGraw-Hill Book Co.
Croneis and Krumbein: "Down to Earth," Chicago, University of Chicago Press.
Hobbs: "Earth Features and Their Meaning," New York, The Macmillan Co.
Hotchkiss: "The Story of a Million Years," Baltimore, Williams and Wilkins Co.
Reeds: "The Earth," New York, The University Society.
Snider: "Earth History," New York, D. Appleton-Century Co.

Questions and Problems

1. What is meant by a geologic age?
2. What is a geologic era?
3. What is diastrophism?
4. What does an unconformity teach us?
5. Describe the characteristics of each era.
6. What is a dinosaur?
7. What is a pterodactyl?
8. For what is the Pleistocene period noteworthy?
9. Distinguish between syncline and anticline.
10. What are the sources of limestone?
11. What is petrified wood?

Topics for Discussion

The Reptiles of the Mesozoic Era
Amber
Rancho La Brea
Océans in Continental North America

Experiments

1. The biology department can furnish several types of fossils for study.
2. A trip to a natural history museum will be of great value for this chapter.

8. THE HYDROSPHERE

Where the streame runneth smoothest, the water is deepest.
—LYLY

The origin of water on the earth is associated with the origin of the solar system. Many scientists believe that the elementary gases, hydrogen and oxygen, combined to form steam at the high temperature of the earth when it was in the astral condition.

Perhaps, as the earth cooled, the water vapor finally condensed to form water which filled the depressions in the earth's crust, thus forming oceans. As we have stated (see p. 72) the calculation of the amount of salt in the sea leads to the result that at least 100 million years have elapsed since the first water was condensed to form the oceans.

The Oceans

Most of the earth's surface is covered by great bodies of water called oceans. The average depth of the oceans is about two and one-half miles. There are, however, great extremes of depth, one of the deeps being Blake deep (28,000 feet) in the Atlantic, and Swire deep (35,000 feet) near Japan. Inasmuch as one of the highest mountains (Mt. Everest) is only about 29,000 feet, one can say that the deeps are greater than the heights. If all the mountains and hills were worn away, water would cover the entire earth.

A study of the depth of the oceans has been carried on for many years. By use of the depth-sounding apparatus (Fig. 67), such studies have been carried forward with great rapidity. By means of the equipment, a high-frequency wave is sent down from the vessel and the time is noted for the wave to return after being reflected from the ocean bottom. Oscillators and microphones are used in the production and detection of the sounds. Great areas of the ocean floor have been mapped by this means.

Ocean Drifts. Some of the interesting features of the oceans are the drifts or masses of water which flow in the ocean somewhat like rivers (Fig. 68). One such drift is the rather large circular movement of water in the Atlantic Ocean in the region of the equator. The water, being heated over the equatorial region, expands and flows along the surface of the ocean. The Trade Winds in turn blow the water westward. Because of these two forces, the drift flows toward Brazil, where it divides,

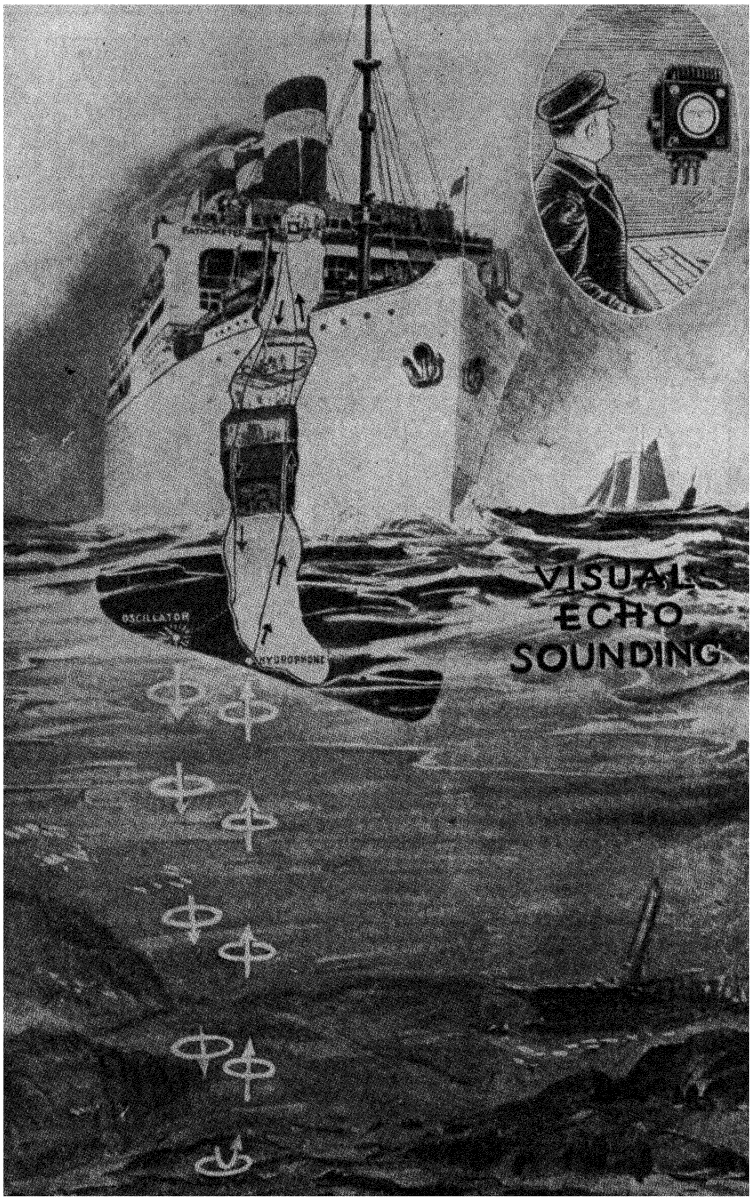


FIG. 67. Visual echo sounding. Black arrows indicate electrical impulses. White rings and white arrows indicate sound waves. (Courtesy, Canadian National Railways Magazine.)

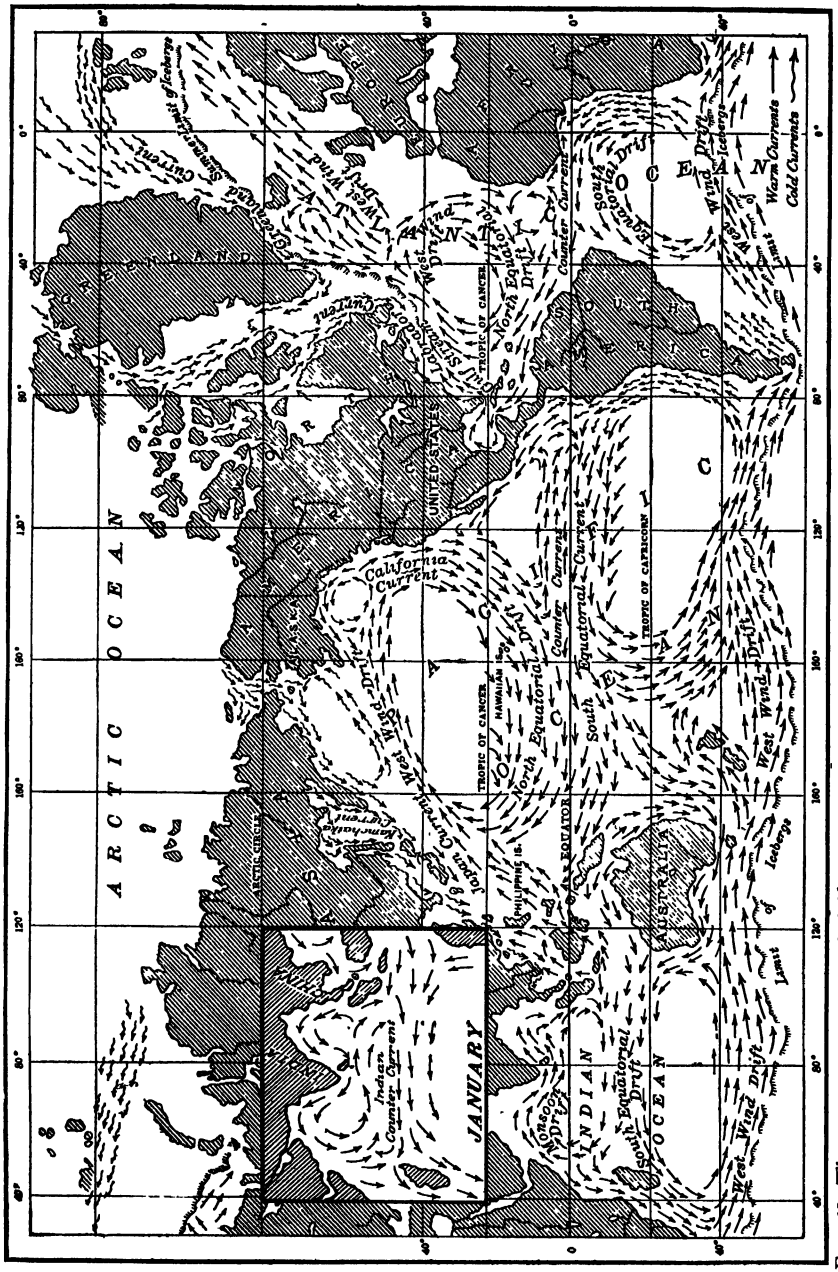


FIG. 68. The ocean currents and drifts. (From Tarr and Von Engeln: "New Physical Geography." By permission of The Macmillan Company, publishers.)

some flowing north and some south. A portion of the North Drift is warmed further in the Gulf of Mexico and passes up the Atlantic coast as the rapidly moving Gulf Stream. Upon reaching the belt of the *prevailing westerlies*, the Gulf Stream is deflected eastward, part flowing past the British Isles and the remainder flowing past Spain as the Canaries Current. The maximum speed of the current in the vicinity of Florida is about four miles per hour. This North Atlantic Current is very important. It provides a mild climate for the British Isles, France, and Spain. It is of interest that land lying near the Canaries Current may have a climate which varies as little as 15 degrees throughout the year. A further study of the map reveals that there are regions where the water has little motion. One such region is the Sargasso Sea in the North Atlantic.

Many superstitions were prevalent concerning this area. Sailing ships were supposed to be trapped there due to the lack of wind and the abundance of seaweed. No such area of seaweed actually exists.

Another famous current is the Japan Current in the North Pacific, which flows across the ocean from the Philippine Islands. This current moderates the climate along the west coast of North America.

COLD DRIFTS. There are also movements of cold water which complete the cycle of ocean currents. The dense water of the Arctic Drift flows around Greenland, past Labrador, and drops to the ocean floor as it moves under the Gulf Stream. This cold water flowing past Labrador makes that land very inhospitable, although its latitude is that of the British Isles. Newfoundland and Quebec have a cold climate despite the fact that the latitude is that of France. The frequent fogs off the coast of Newfoundland are caused by the Arctic Drift meeting the Gulf Stream. The mingling of these currents causes a condensation of the water vapor in the chilled atmosphere.

EROSION

Ever since the atmosphere and the oceans have existed on the earth, the lithosphere has been subjected to processes by which the rock material has been worn away and disintegrated. All of these processes constitute *erosion*. A large part of erosive action is termed weathering, a term including those changes which cause rocks to break up, forming mantle rock and soil. There are three agents of weathering: physical, chemical, and biologic.

Examples of physical weathering are the expansion and contraction of rock due to temperature changes and the breakup of rock due to the action of ice in crevices. Water seeps into spaces between rock layers and, as it freezes, the rock is split up.

Closely associated with the processes of physical weathering is the action of chemical agents. Chemical disintegration of rocks depends on

the fact that carbon dioxide, water, and oxygen combine with the minerals such as iron, feldspar and calcite in rocks. As a result, the rocks break down, forming clay, iron oxide, and soluble salts. Water charged with carbon dioxide is able to change insoluble calcium carbonate into a soluble form, thus hastening rock decay.

Last but not least, there are biologic agents which contribute to erosion. Some plants, such as lichens, cling to rock and etch it out by secreted acids. We often find that trees growing on a hillside have their roots embedded in rock crevices. As the roots enlarge, the rock is broken apart. Earthworms feed on soil, changing its character. Small rodents burrow in the rocks.

GROUND WATER AS AN EROSIVE AGENT. Water is evaporated from oceans; water vapor is blown over land and is precipitated as rain or snow. About one-third of this runs off and returns to the oceans by rivers. Another third evaporates into the atmosphere. The balance seeps into the ground and is called *ground water*. Such water may exist in porous rocks at depths of several miles. Even igneous rocks are somewhat porous and take up ground water.

The upper limit of saturation, known as the *water table*, may be at the surface, as in marshes, or 200 ft. or more beneath the surface, as in deserts. In dry seasons the water table falls and in wet seasons it rises nearer the surface.

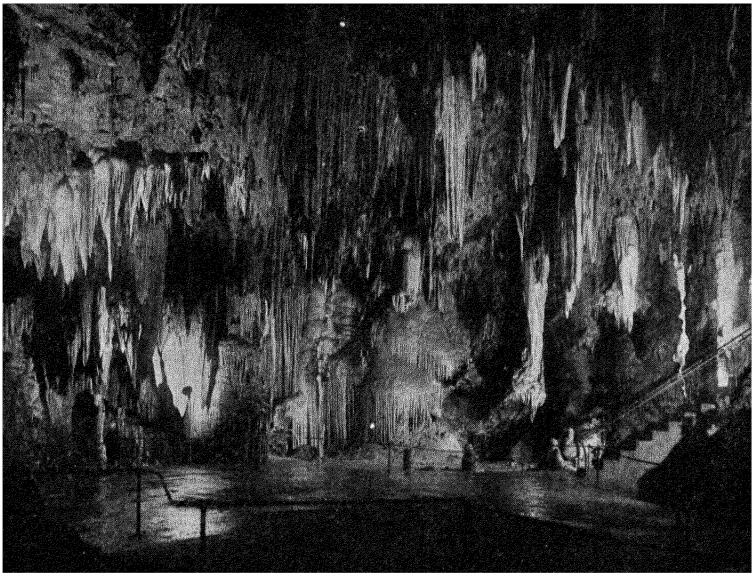


FIG. 69. A limestone cave, showing stalactites and stalagmites. (Courtesy, Luray Caverns Corp.)

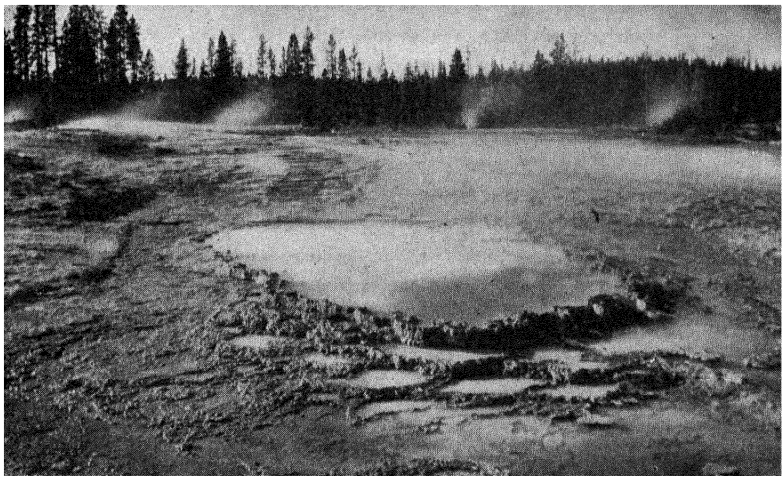


FIG. 70. White Velvet Spring, Yellowstone National Park. (Courtesy, U.S. Geological Survey and W. H. Jackson.)

One important feature of ground water is its solvent action and deposition. Because of the great pressures far beneath the surface of the earth, water dissolves minerals which are insoluble under ordinary conditions. Limestone and silicates will not appreciably dissolve in pure water, but will go into solution very slowly if the water contains other compounds. Limestone caves are formed by the action on limestone of water carrying carbon dioxide in solution. The limestone, water, and carbon dioxide form calcium bicarbonate according to the chemical reaction,

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2.$$

This mineral is much more soluble in water than is limestone. If this mineral-laden water flows into cracks or rock strata where there is a smaller amount of carbon dioxide, the mineral may revert to limestone again and be deposited in the form of stalactites (icicle-like forms hanging from the roofs of caves) and stalagmites (pinnacles built up from the floor) (Fig. 69). Many of the beautiful deposits in Yellowstone Park are formed of travertine precipitated from water issuing from hot springs and geysers (Fig. 70).

Sometimes the ground water fills a layer of porous rock which is between two layers of nonporous rock (Fig. 71). If these layers are tilted, a well drilled through at the bottom of the layer will permit the water, which is under hydrostatic pressure, to rise to the surface forming an artesian well, named from Artois, France, where such a well was discovered. Chicago, Illinois, has many artesian wells, due to tilted sandstone beds.

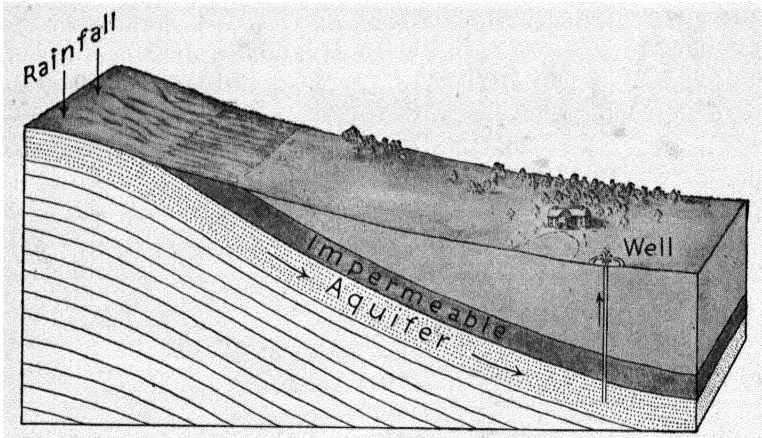


FIG. 71. A simple artesian system. A permeable sandstone layer (an aquifer) crops out in the hill to the left and absorbs rainfall which descends along the sandstone, sealed in beneath a capping layer of impermeable rock. A hole bored down into the aquifer, farther down its slope, becomes an artesian well. In the vicinity of the well, the water table may lie in any position above the aquifer. (Reproduced by permission from "Outlines of Physical Geology," 2d ed., by Longwell, Knopf, and Flint, published by John Wiley and Sons, Inc., 1941.)

A rather unusual manifestation of ground water action is the geyser, of which many examples are found in Yellowstone Park, New Zealand, and Iceland. It appears that geysers are formed in fissures extending down to hot rock some distance below the surface. These fissures are narrow and have constrictions along the wall. Ground water runs down the channel to the hot rock. The water at the bottom is heated, and, since the steam cannot escape rapidly, the temperature rises somewhat above the normal boiling point. When the pressure has increased to a certain point, the water and steam are forced out with explosive violence. An interval of time then elapses until the water can flow in and repeat the process. Everyone is familiar with the story of "Old Faithful" in Yellowstone Park. This geyser pours out great quantities of water at regular intervals (Fig. 72). In fact, the time of each eruption is posted on a bulletin board in the inn nearby.

EROSION BY RUNNING WATER. Probably the most important factor in the changes of the earth's crust is running water. We are all familiar with the roadside gullies that form during a heavy rain. Many a farmer finds that his hillside soil is being swept away by torrents of rain. Heavy rainfall in the arid regions of western United States forms great washes. All rivers are constantly carrying fine rock fragments to the sea. The Mississippi and its tributaries, the Missouri ("Big Muddy") and the Arkansas, carry 400,000,000 tons of clay and sand to the Gulf of Mexico each year. Because the river is moving slowly at the mouth, the load of sediment

is dropped in a fan-shaped area called a *delta*. The delta formed by this deposition grows very rapidly and is a constant problem in navigation. The lower Amazon always has a yellow color due to the immense amount of materials which it sweeps along. At Macao in China, it is necessary to dredge the channel of the Pearl River every few months so that steamers can pass. This constant transportation of soil material has denuded many areas, such as those of northern China. Other regions acquire great fertility by this circulation of water.

Not only does running water carry away an immense amount of the weathered mantle rock and soil, but it abrades the solid rock, due to the load of sand and gravel which it transports. In this way much rock is broken off and carried out to the stream mouth. The effect of running water is to carve out gashes in the lithosphere and to wear down hills.

As an example of the erosive action of running water, one may mention the Grand Canyon of the Colorado River and the gorge of the Yellowstone. In these regions the rivers have cut out great valleys deep in the sedimentary rocks. The rock terraces that one sees are manifestly due to the fact that some rock layers are harder and more resistant to water erosion than others. The hard layers have steep slopes while the softer ones are indicated by the gentle character of the terrain.

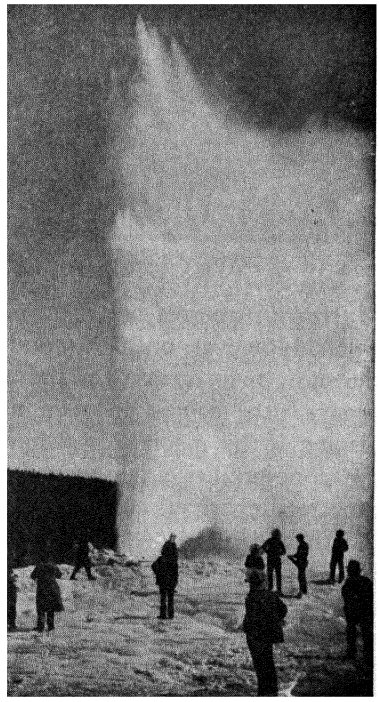


FIG. 72. Old Faithful Geyser. (Courtesy, U.S. Geological Survey and W. H. Jackson.)

The tops of the mesas which are formed in the southwestern part of the United States are layers of rock which have resisted water erosion while the lower layers were cut away. The undermined cliff finally collapsed, leaving plateaus with sides having steep slopes (Fig. 73).

The Falls of Niagara are changing due to the erosive action of running water. The top layer is hard limestone. The rocks underneath are shale and sandstone. These softer rocks wear away, leaving a scarp which finally breaks, cutting back the Falls several feet each year. The Cave of the Winds lies under the falls.

EROSION BY SNOW AND ICE. Most of the snowfall in the central part

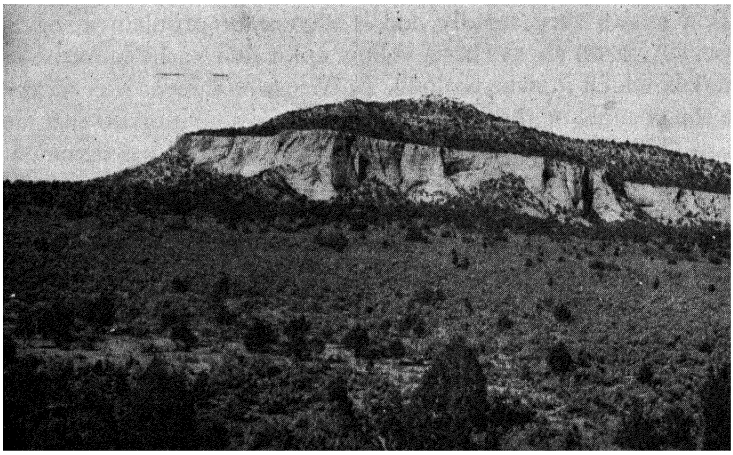


FIG. 73. A mesa. (Courtesy, U.S. Geological Survey.)

of North America and Europe melts in the spring and runs away as water. However, on high mountains and inside the Arctic Circle some of the snow may remain for the entire summer. The snowfall of each successive year causes an accumulation of ice until the mass becomes a glacier. If this glacier ice accumulates in mountain valleys, it flows down the slope until it either reaches the sea, forming icebergs, or melts away, thus feeding rivers and lakes. Many of the high mountains of western North and South America contain valley glaciers. Mt. Evans in Colorado, Mt. Shasta in California, and Mt. Rainier in the state of Washington are typical examples. Glacier Park contains many glaciers. The Alps are famous for valley glaciers (Fig. 74).

Most of the continents of Greenland and Antarctica are covered by enormous ice sheets. These continental sheets are held back by a wall of mountains. The sheets extend out over the sea and break off, forming immense icebergs which drift into warmer water, imperiling ocean travel in the sea lanes.

The causes of glacial motion are rather complex. We know that glaciers near the melting point move faster than cold glaciers. The glacier does not slide as a unit. An average motion of a glacier is a few inches a day in the warm season. It is possible that the ice at the bottom melts under the great pressure of the upper layers. Perhaps the ice acts as a plastic mass, since it tends to follow irregularities in the valleys down the side of the mountain.

At any rate, a combination of such effects makes the motion of the great body of ice possible. Because the glacier does not move uniformly, great stresses which make the surface very irregular are developed.

Usually the surface is crisscrossed by great cracks called crevasses. These become covered with ice and snow, making travel across the glacier very dangerous. Admiral Byrd and his party had many narrow escapes when they crossed these hidden crevasses in the great ice sheet in Antarctica.

Anyone who observes a glacier will notice a mass of small rocks on the surface and imbedded in the ice. This material has been acquired by the ice in various ways so that the glacier is a mixture of ice, pebbles, sand, clay, and boulders, all moving at a slow rate over the bed rock. The effect on the floor of the glacier is like that of a great sandpapering machine grinding over the rock. Moreover, the glacier tends to widen the valley, changing a V-shaped valley to a U-shaped one. Characteristic scratches will be found on the bed rock, giving a clue as to the direction in which the glacier moves over the region.

It was early noticed that much of the land areas in the northern part of the United States and Europe are covered by a heterogeneous mass of boulders, rocks, and soil which are unlike the rock strata of the region. For example, pieces of red granite of the St. Lawrence valley have been found as boulders in southern New York State. Moreover, there are peculiar rounded hills called drumlins, rolling plains called moraines, and small lakes scattered over the region. The scientist Louis Agassiz concluded that these features were the result of widely extended glaciation. He believed that in the Pleistocene geologic period several great ice sheets moved out of Canada and spread southward over the northern

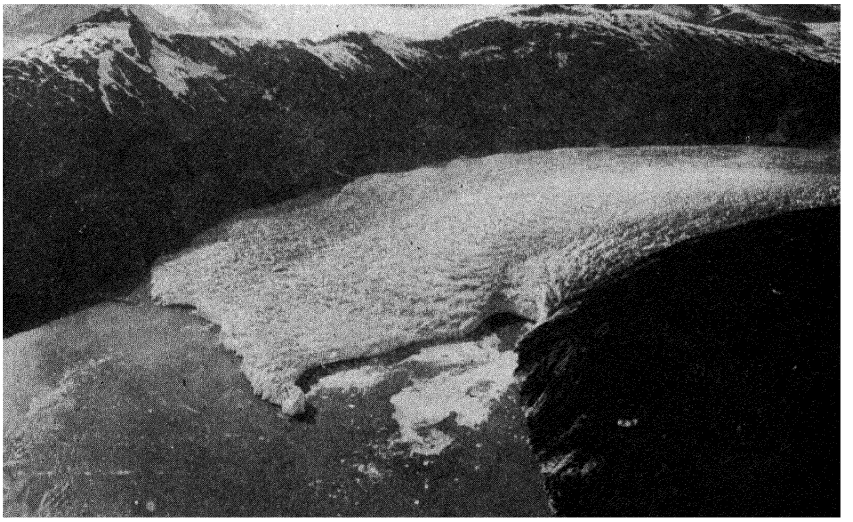


FIG. 74. A valley glacier. (Courtesy, U.S. Geological Survey.)

part of the United States. At the same time, ice sheets covered northern Europe.

By a study of the rocks, we feel certain that at least in four separate periods, glaciers have covered part of North America. During the latest of these ice ages, it appears that the glaciers developed and disappeared at least five times. This means that between the periods of cool climate there were intervals of subtropic temperatures. The southern hemisphere has had at least one glacial period.

It appears that the continental glaciers in North America had their origins in at least two great ice sheets in Canada. One, the Keewatin, had its center near Hudson Bay, and the other centered in what is now the Province of Labrador. These sheets spread southward, enveloping most of Canada and extending as far south as the Missouri and the Ohio Rivers. In the east they extended to central New Jersey and across central Pennsylvania. They covered New England and New York.

The casual observer can discover many evidences of glaciation. One famous example is a boulder in Bronx Park, New York City, which rests on a striated base of a different type of rock. Many rocks contain parallel striations on the surface. The glaciers gathered great quantities of rocks from one region and scattered them over another part as the ice melted.

The last of these glaciers in the United States is believed to have receded about 50,000 years ago. The Great Lakes and many modern rivers were formed at the time of the last glacial recession. The great number of lakes in Minnesota and Wisconsin are of glacial origin. It is possible to trace the shore lines of older lakes which disappeared during glacial epochs and were superseded by other lakes of later epochs.

There is no satisfactory explanation for the advance and recession of these ice sheets. All our evidence indicates that climatic conditions in various parts of the world varied at different periods of the geologic eras. Some authorities believe that the amount of carbon dioxide in the atmosphere may have changed in some way. This might influence the climate.

It is possible that the sun is a long period variable star (see p. 33) so that during the periods of glaciation there was a decrease in the amount of solar energy. There may have been a change in the shape of the earth's orbit. The inclination of the axis of the earth may have changed, causing a cooler climate. There is no certain evidence for any of these theories.

WIND EROSION. The transportation of rock particles by the wind is a far more important method of erosion than most of us realize. In a region having a soil composed of sand and clay particles, a wind can pick up and carry away the clay as a dust. This dust may be deposited far from the source. In ancient times, such dust was deposited in several regions of western and central United States as a *loess*. Such soil is very

fertile but is subject to frequent erosion by both wind and water. Much of this loess in semi-arid localities was originally covered with a thin sod which acted as a blanket to prevent excessive erosion. Such areas were excellent grazing land.

During the First World War the demand for farm produce became so great that much of this sod was plowed up and the soil planted to corn and cotton. This procedure was followed by a succession of years of scanty rainfall. In 1935 the process culminated in a calamity in which thousands of farms in the Great Plains States were denuded of fertile top soil by great dust storms. As a consequence many families were forced to leave the Dust Bowl, as it was called, and migrate westward and northward (Fig. 75). Other sections of the world suffer periodically from the effects of wind erosion. Conservation methods are being used to combat such destruction.

The dunes of Indiana are examples of the effect of the wind on sandy areas. The "Bad Lands" of the Dakotas derive their peculiar form from the erosive action of the wind and water. Travelers in the Rocky Mountains of Colorado are familiar with the beautiful "Garden of the Gods" whose red sandstone formations have been carved into curious shapes by the erosive action of wind and water (Fig. 76).

SOIL

A crystal of sand could tell us an interesting story as we play on the beach at the seashore. Hundreds of millions of years ago it was possibly on

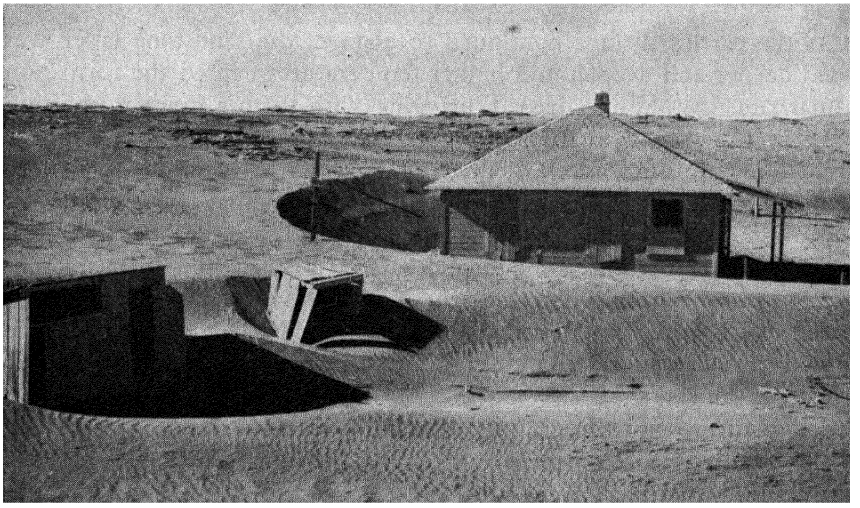


FIG. 75. Photograph of an abandoned farm in Oregon, showing the effects of wind-blown sand. (Courtesy, U.S. Soil Conservation Service.)

the shore of another ocean. As time rolled on, the small crystal became covered with other sands blown or washed over it from nearby hills. Gradually it became cemented to other sand grains, forming a soft sandstone. Perhaps the shore became submerged beneath the ocean. A layer of mud which was deposited over it changed to shale, which, in turn, was covered by a layer of sea shells, the process occupying millions of years.

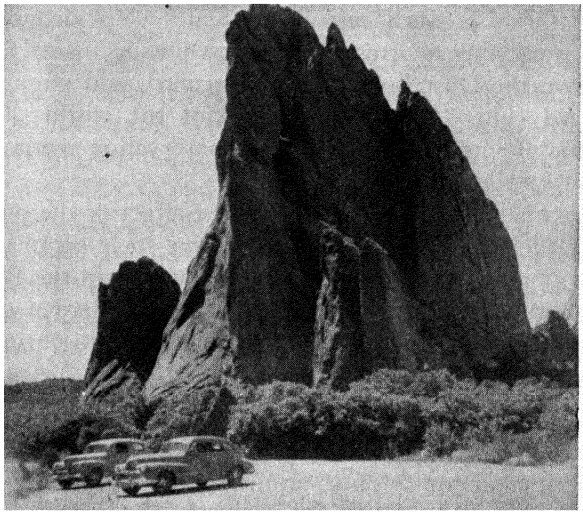


FIG. 76. Garden of the Gods.

As the earth's surface continued to change, the sandstone layer was folded deeper and deeper, and higher temperatures caused the formation of quartzite. Untold ages passed, bringing with them a gradual uplifting of the highly heated quartzite. As the rock rose, it cooled, still under tremendous pressure, until finally this quartzite became part of the igneous rock, granite. Perhaps this granite formed a great mountain range. Later, the conditions of temperature and pressure became such that the granite became metamorphosed into gneiss. Still other millions of years passed during which time the mountain was attacked by various weathering agents. The rock crumbled and hidden rock layers became exposed and disintegrated into sand. Rains and streams gradually returned the sand to the sea.

Soil is formed by the disintegration and decomposition of rock, and by the accumulation of plant and animal remains. As we have seen, weathering agents change rock to soil.

Soils also contain certain plant and animal materials. These include

decaying plants and animals as well as the materials discarded by them in the living condition. Phosphorus, sulfur, and nitrogen compounds are principally of organic origin. "Limestone soils" usually are more fertile than soils derived from sandstone and shale. Feldspars contribute sodium, potassium, calcium, and magnesium to the soil. A good soil may contain a mixture of sand, clay, humus, lime, and soluble mineral nutrients of value for plant growth. Such a soil may have the fine texture characterized by the term *loam*. If the clay of the soil is excessive, the soil becomes compact and remains wet, so that it is difficult to drain. On the other hand, a sandy soil permits the water to drain away rapidly, so that in periods of dry weather the crops wither from lack of moisture. Plants derive nearly all of their mineral salts from the soil. They secure oxygen and carbon dioxide from the atmosphere. Green plants manufacture foods, pigments, and woody fibers from such materials as carbon, calcium, hydrogen, iron, magnesium, nitrogen, oxygen, phosphorus, and sulfur.

In addition to these materials, there are millions of bacteria in the soil. These organisms vary from season to season, their number being greatly influenced by temperature and moisture in the soil. Bacteria of decay and nitrifying bacteria are responsible for the chemical changes which break down manure, leaves, and bonemeal to materials which plants can utilize. The chemical changes taking place produce carbon dioxide and ammonia. The ammonia then undergoes further chemical changes by which it is converted into nitric acid and finally into nitrates. The process of changing organic matter into nitrates is called *nitrification*. Likewise, there are formed phosphates, sulfates, and carbonates, all valuable soil materials.

For a long time farmers have known that certain crops such as wheat and oats exhaust the soil, while other plants known as legumes seem to act as fertilizers. These plants include beans, clover, alfalfa, and peas. It may be of interest to repeat the statement of a Roman writer of the first century. "Some of the plants manure the soil and make it fertile. Lupines, peas, and vetches seem to enrich the land."

We now know that the roots of plants known as legumes act as host to a parasitic type of bacteria called nitrogen-fixing bacteria. These bacteria live in nodules on the roots of the plants, taking food materials from the plant. They have the unusual property of absorbing free nitrogen from the atmosphere and causing it to combine with carbon, hydrogen, oxygen, and other elements to produce complex nitrogen compounds such as plant proteins. When the legumes die and decay, the root nodules disintegrate. The proteins are rapidly broken down by bacteria in the soil and are converted to ammonia and nitrates which can be readily absorbed by the next crop.

References

Coleman: "Ice Ages Recent and Ancient," New York, The Macmillan Co.
Daly: "Architecture of the Earth," New York, D. Appleton-Century Co.
Hobbs: "Earth Features and Their Meaning," New York, The Macmillan Co.
Loomis: "Physiography of the United States," New York, Doubleday, Doran and Co.
Lyon and Buckman: "Nature and Properties of Soils," New York, The Macmillan Co.
Mills: "Romance of Geology," Boston, Houghton Mifflin Co.
Ries: "Economic Geology," New York, John Wiley and Sons.
Wright: "The Ice Age in North America," New York, D. Appleton and Co.

Questions and Problems

1. What is an ocean drift?
2. What is the cause of the Gulf Stream?
3. Explain the formation of a geyser.
4. What evidence is there for ice ages in North America?
5. What are causes of soil formation?
6. What is a fertile soil?
7. What is the most desirable soil and why?
8. Why are there frequent fogs off the coast of Newfoundland?
9. What causes an artesian well?
10. Name three ocean drifts.
11. What causes wind erosion?

Visual Aids

"Soil Formation," Eastman Classroom Film
"The Mining and Production of Coal," Anthracite Industries, Inc.

Topics for Discussion

Soil Formation	Glaciers	Nitrifying Bacteria
The Bad Lands	Byrd in the Antarctic	The Dust Bowl

Experiments

1. Make a tube of loam, one of clay soil, and one of sandy soil. Study the rise of water in the various tubes. Decide which is the best type to preserve the water level in the field.
2. If possible, study the rock formation in a limestone cave.
3. The biology department can furnish root nodules on which are nitrifying bacteria. Examine the nodules closely.
4. The biology department or geology department have specimens of stalactites. Examine them.

9. ROCKS AND MINERALS

To the solid ground of Nature trusts the Mind that builds for aye.
—William Wordsworth

The rock sphere of the earth is termed the lithosphere. This layer, about 50 miles thick, contains the rocks, minerals, and gems which we shall study in the present chapter.

Minerals

Minerals are substances with a chemical composition which can be expressed by a chemical formula. They include the substances quartz, the feldspars, the micas, hornblende, calcite, and many others. When grains of these minerals are cemented together, they constitute the materials which we call rocks. Some of the minerals—for example, graphite, quartz, diamond, and calcite—are also rocks. In order to study minerals, the scientist has devised a series of tests by which various compounds can be identified. Some of these tests include hardness, malleability, cleavage, color, streak, fluorescence, as well as chemical tests.

Hardness. A scale of hardness is used by the scientist. Ten representative minerals are arranged in their order of ability to scratch other minerals.

10. Diamond (hardest)
9. Corundum (scratches topaz)
8. Topaz (scratches quartz)
7. Quartz (scratches glass and steel)
6. Orthoclase feldspar (scratches window glass, not scratched by knife)
5. Apatite (scratched by steel)
4. Fluorite (easily scratched by steel. Does not scratch glass.)
3. Calcite (scratched by a new copper cent)
2. Selenite or gypsum (scratched by thumbnail)
1. Talc (soft, feels greasy)

Any mineral in the table will scratch any of those below it in the table. Minerals harder than quartz are not common.

(It is important to emphasize that hardness is not the same as brittleness.)

Cleavage. If one breaks a specimen of rock salt (halite) by striking it a sharp blow with a knife, the mineral will cleave or slice into rectangular segments or small cubes. Rock salt, in common with many other min-

erals, is classed as a cubic crystal form (Fig. 77). Some minerals, such as calcite, split into rhombs (Fig. 78). Still others, for example, mica, cleave into thin sheets. *Crystals* are solid bodies having smooth faces which meet in definite angles. The shape of the crystals seems to be determined by the molecular structure.

All crystals can be included under six types: cubic, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic. By a study of the angles between cleavage surfaces, the mineralogist can identify many of the common minerals. The study of the crystal form of substances constitutes the subject of *crystallography*.

COLOR. Many minerals have a definite color, copper sulfate being blue; malachite, green; cinnabar, a reddish brown; magnetite, black; pure calcite, white or colorless; iron sulfide, yellow. Quartz has a number of characteristic colors depending upon the impurity in the mineral. However, because of these impurities, the beginner must use the color test with caution.

STREAK. Many minerals leave a streak when rubbed on a white tile plate, such as a floor tile. It is curious that the streak color may bear little resemblance to the surface color of the material. Many of the ores—minerals from which the metals are obtained—have characteristic streaks. Noteworthy among these are the lead, zinc, and iron ores.

FLUORESCENCE. This is a phenomenon which has some importance in

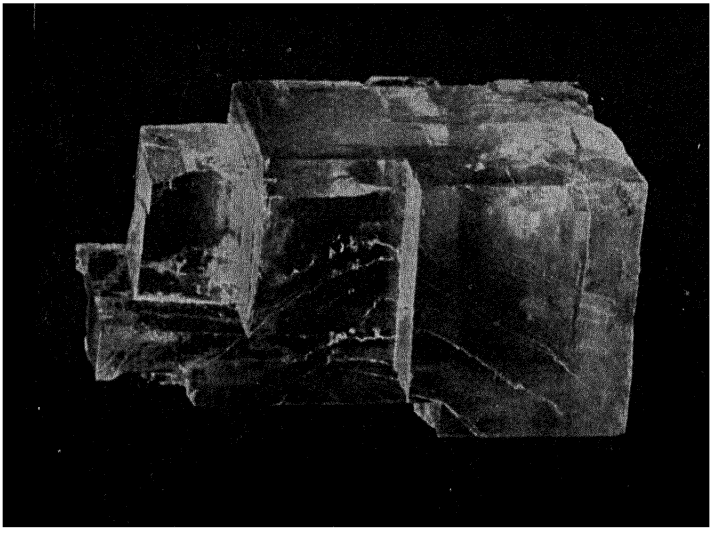


FIG. 77. Rock salt, cubic crystals. (Courtesy, English: "Getting Acquainted with Minerals," New York, McGraw-Hill Book Co., Inc.)

mineral tests. Many rocks and minerals when illuminated by ultraviolet rays emit beautiful colors which in some cases absolutely identify the stone. Some of the most interesting are willemite, which fluoresces green; some of the calcites, which give red; and some fluorites, which shine with a blue-violet color when illuminated. The uranium ores often fluoresce, and this method has been used in prospecting for that valuable material. Lamps are on the market which give ultraviolet for a study of fluorescence. By using such a lamp, one can produce remarkable fluorescent effects. Every student of minerals should study some of these colors if for no other reason than the pure beauty of the display.

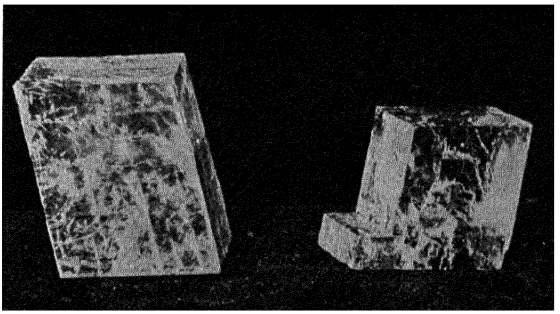


FIG. 78. Rhombic crystals. (Courtesy, English: "Getting Acquainted with Minerals," New York, McGraw-Hill Book Co., Inc.)

CHEMICAL TESTS FOR MINERALS. While such tests are reliable, they are rather complicated in most instances. An exception is the acid test for limestone and dolomite, which will be described at a later point in the chapter.

GEMS

Minerals which possess the characteristics of beauty, durability, rarity, and portability are classed as *gems*. The most famous type of gem is the *diamond*. This gem has been known from the earliest times. Diamonds are found in volcanic pipes mixed in a peridotite rock, and are pure carbon crystals. Most of them are transparent, a few being blue and some black (Fig. 79).

Diamonds have been found in India, South Africa, Brazil, and in some parts of the United States, notably Arkansas. The production and sale of diamonds are rigidly controlled by the syndicates which operate the diamond fields. As has been noted, the diamond is the hardest mineral known. Besides being used as a gem, it finds much use in rock drilling, as a die for drawing tungsten lamp filaments, and in grinding operations.

For many years scientists have attempted to produce diamonds in the laboratory without success.

The history of some of the great diamonds is very interesting. We shall describe only a few of the most interesting gems and refer the reader to the references on p. 123 for a fuller description. The largest diamond ever found was the Cullinan diamond which weighed more than a pound (3025 carats) in the rough condition. Since a diamond has little beauty in the natural state, the Cullinan was cut into a large number of smaller stones which are a part of the crown jewels of Great Britain. One piece is the Jonker, having a weight of 725 carats. Many diamonds have adorned idols whence they were stolen and passed from hand to hand, often accompanied by murder and violence. Some famous gems are the Kohinoor (Mountain of Light) of England, the Orloff of Russia, and the Tiffany of the United States. The beauty of a cut diamond is due partly to the fact that the mineral has the highest index of refraction of all optical media (see p. 344). Because of this fact, the light is reflected internally from facet to facet inside the gem, giving the appearance of a glow of light inside the jewel. (See *Frontispiece.*) Yellow diamonds are most common, while blue-white are most rare. In cleaving a diamond the grain must be found. This may require months. A small notch is made and a sharp tap on a blunt edged tool splits the gem.

Another famous and valuable gem is the emerald, a mineral composed

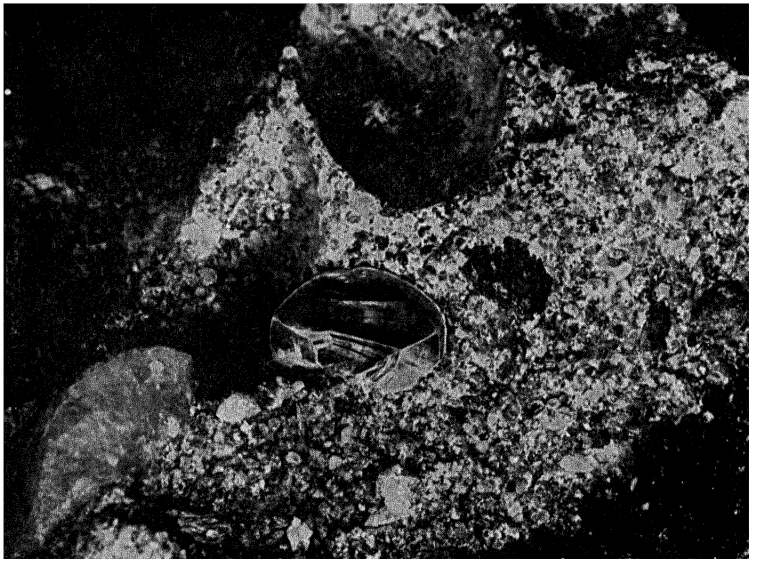


FIG. 79. A diamond in its matrix. (Courtesy, English: "Getting Acquainted with Minerals," New York, McGraw-Hill Book Co., Inc.)

of aluminum, beryllium, silicon, and oxygen—a beryllium-aluminum-silicate. Its color is a deep green and a perfect emerald is more valuable than a diamond of equal weight.

The ruby is much prized as a gem, both it and the sapphire being corundum, an oxide of aluminum (Al_2O_3). It is now possible to produce rubies and sapphires in the laboratory, but, because of the difficulty of manufacture, the cost is still high.

Quartz is an important gem-forming mineral. Although quartz (silicon dioxide, SiO_2) is a very common rock—pebbles being quartz—good gems are rather rare. Quartz crystallizes in the pyramidal form (Fig. 80). The transparent form is called rock crystal. Among the quartz gems are amethyst, chalcedony, carnelian, agate, sardonyx, jasper, and opal. Opal deserves special consideration. The opal of gem quality has a marvelous mixture of colors. Perhaps the most valuable opals of the present time are the so-called "black" opals of Australia. Unfortunately, opals are rather fragile, which makes them unfit for hard usage.

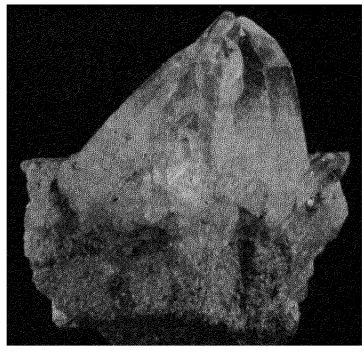


FIG. 80. A quartz crystal.

Pearls, too, are gems of great value. This mineral is a hydrated calcium carbonate found in the shells of a certain mussel or pearl oyster. The method of formation appears to be as follows: A small grain of sand or other impurity gets into the shell. The mussel covers the irritating substance with successive layers of calcium carbonate, a pearl thus being produced over a period of several years. In recent years men have found it possible the place seeds in the shells of certain mollusks and to control the growth. Pearls are rather fragile, being attacked by acids. The luster of perfect pearls is unequaled by that of any other gem. Unfortunately, pearls deteriorate if left in safe-deposit boxes and are harmed when worn on a dry skin.

ROCK CONSTITUENTS

It is impossible in a text of this character to describe many of the minerals which exist in nature. Those to be described are types which can be found in most localities so that they are familiar to the average person. Fortunately, most of the common rocks are composed of only a few minerals, and these will be described in detail. There are several excellent handbooks which can be used in field study.

CARBONATES. Among the carbonates which are well known are *calcium*

carbonate (limestone, chalk, and calcite crystals) and *calcium magnesium carbonate* (dolomite). Although these minerals exist in a great variety of colors, it is a simple task to identify them by the acid test. Cold hydrochloric and other acids placed on calcium carbonate generate carbon dioxide, while hot hydrochloric acid attacks dolomite. Dolomite is harder than calcite.

Another test for calcite in crystal form is the rhombic cleavage which occurs when it is broken into parts. *Calcite* (Iceland spar) is frequently a transparent crystal which resembles quartz upon casual inspection (see Fig. 78). It has, however, an entirely different crystal form. It is the cementing material for many sedimentary rocks such as sandstone.

Limestone is the common form of calcite. It is widespread, consisting of the skeletons of marine animals and plants (Fig. 81). These shells accumulate in layers at the bottom of the ocean water and over a long period of years become rock. Due to impurities, limestones are found in many colors, including gray, white, and blue. Because of the method of its formation, limestone is classed as a sedimentary rock. When limestones undergo great heat and pressure they metamorphose (change) into marble. Marble is classed as a metamorphic rock. Other interesting limestone formations are the stalactites and stalagmites found in many caves.

SILICA AND THE SILICATES. Silica is usually called quartz (silicon dioxide). Quartz is a very common mineral existing in a great variety of shapes. There are transparent crystals which have a characteristic pyramidal shape, and there are great masses of milky quartz. Some common varieties are rose quartz, smoky quartz, agate, amethyst, and milky quartz. Some other varieties have already been mentioned in the discussion of

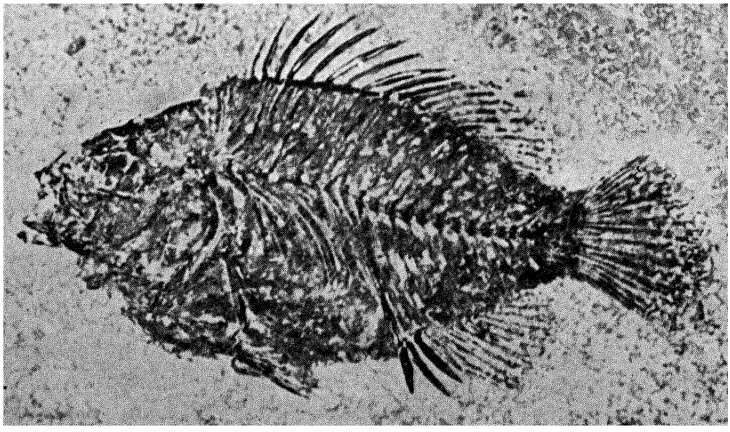


FIG. 81. A fossil fish embedded in limestone

gems. Quartz is a constituent of all granites and of many other igneous rocks. It can usually be recognized by its glassy appearance, although milky quartz is also a common ingredient of rock.

When silica is combined with other minerals, we have the great class of silicates. The silicates which we shall have occasion to indentify are the feldspars, the micas, hornblendes, and serpentine. Serpentine, a rather common mineral in eastern United States and in Europe, is a magnesium silicate. Most varieties are green or yellow and they are prized as building stone. It is found in Quebec, Arizona, Pennsylvania, and Georgia. Much of the "green marble" seen in soda fountains is serpentine quarried in Georgia.

Feldspars are a group of minerals which are light colored with right-angle cleavage. Some varieties are colored by impurities. They resemble both quartz and calcite. Fortunately, simple tests distinguish these minerals. Quartz is harder than the feldspars and will scratch them. Feldspars are not so glassy as quartz and calcite. Most acids do not attack the feldspars. These minerals are potassium-aluminum-silicates and sodium-calcium-aluminum-silicates. In the field it is usually possible to identify the family by scratching with a knife. This distinguishes them from quartz. Feldspars are the most abundant of all minerals, making up over half the rocks of the lithosphere. Some of the common varieties are orthoclase, plagioclase, microcline, albite, and labradorite.

The micas are an interesting type of silicate. These complex silicates, often called "isinglass," are best known in two forms: muscovite, which is either transparent or has a light color, and biotite, which is colored black or brown. The micas occur in six-sided crystals which cleave into sheets of almost microscopic thinness. Since they are well known, they can be readily identified by the shining flakes in many types of rocks. Sheets of mica are used as insulators in electric apparatus such as flatirons and toasters.

Hornblende, a variety of amphibole, is a dark green, brown, or black silicate having a variable chemical composition. Its hardness is about 5 and it is a constituent of many igneous and metamorphic rocks such as granite and gneiss.

When some silicates break down, the calcium oxide combines with carbon dioxide to form calcite. The disintegration of the feldspars results in the material called clay—a hydrated silicate. Silicon dioxide has a tendency to combine with metallic oxides to form silicates.

OTHER MINERALS. Gypsum is calcium sulfate. It is used in the preparation of blackboard chalk and plaster of Paris. Pyrite is iron sulfide. It has a brassy yellow color and is often mistaken for gold—hence the name, "fool's gold." It is found in all types of rocks, especially in sedimentary and metamorphic ones.

The pyroxene minerals are silicates of magnesium and calcium. One type, augite, is found in basalt.

Talc is often called soapstone. It is used as talcum powder.

Sedimentary Rocks

Sedimentary rocks are those which have been formed by the deposition of sediment either in water or on land. Rock fragments, clay, and other minerals are piled up and pressed into layers, forming rocks varying from shale which crumbles in the fingers to the hardest of breccias. Such rocks are divided according to their principal constituents.

Calcareous Rocks. Examples of this type are limestone, chalk, and travertine. They consist principally of calcium or magnesium carbonate. Limestone is a valuable building rock and also is crushed for use in road building, for the manufacture of Portland cement, in metallurgy, and in rock-wool insulation. Chalk (not to be confused with gypsum) is a soft limestone which is used in cement manufacture and as a remedy for acid soils. Travertine is used in interior stone work. Dolomite is a harder limestone containing much magnesium carbonate.

Silicious Rocks. The outstanding example of this class is sandstone. This rock consists of small grains of sand cemented together by silica, lime, or iron oxide, and colored with the oxides of iron or other metals. Some varieties of sandstone are very hard and much used as building stone. Other varieties can be broken with the fingers.

If the quartz fragments in silicious rocks are large and rounded, the rock is called *conglomerate*. If the particles are sharp and angular, we call the material *breccia*. If the rock is composed of large boulders, it is coarse conglomerate. Sandstones are classified as calcareous, ferruginous, silicious, or shaly, the names referring to the cementing material. Silicious sandstones are the most durable. Flint and jasper are of this type.

Argillaceous Rocks. The most important members of this group are the shales and clays. As the igneous rocks weather, the quartz grains become sand and the feldspar and mica become clay and then shale. Although shales are usually soft, some varieties can be used as building stones. Blue shale is used in some of the buildings of Princeton University.

Carbonaceous Rocks. Most people do not class petroleum and coal as rocks. Both, however, are composed of carbon minerals. Sedimentary coal exists in such forms as peat, lignite, and bituminous coal. Peat resembles plant fibers and is found in ground where plants fell in water and did not decay. Good peat is brown in color and burns fairly well. It is abundant in Ireland and Minnesota.

As the peat bogs are subjected to great pressure and heat, a variety of coal called *lignite* is produced. It is a better fuel than peat and is found in various parts of the world.

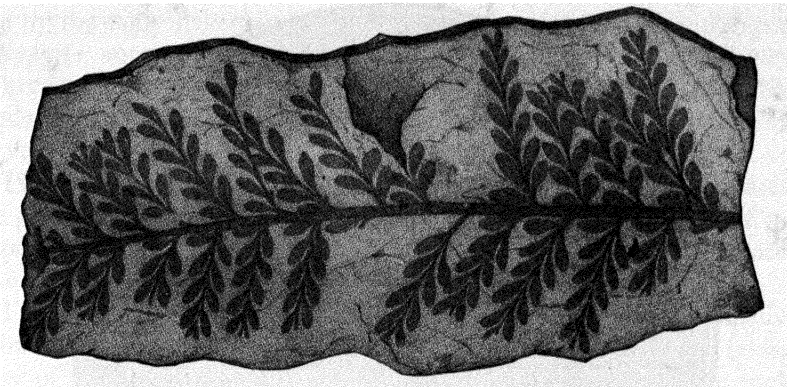


FIG. 82. A fossil leaf found in coal. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

The most abundant form of coal is bituminous, a black, rather dirty fuel which burns with considerable smoke. It has a high fuel value (see p. 311) and is a standard coal in most parts of the world. England, Russia, and the United States produce the greatest part of this fuel rock. Many tree fossils are found in coal beds, proving that coal is a result of tree decay (Fig. 82).

PETROLEUM. Petroleum is a liquid rock composed chiefly of paraffin and other hydrocarbons. Sometimes, as in California petroleum, asphaltum is a constituent. Most persons are familiar with the crude petroleum, a sticky liquid from which we derive such materials as kerosene, gasoline, petrolatum, tar, and many other compounds (see p. 129). Crude oils of Oklahoma and the Gulf Coast have a high content of light oils such as gasoline. Pennsylvania oils have good lubricating properties. California oils contain much asphalt.

Mineralogists are not in agreement as to the origin of petroleum. Did petroleum result from chemical energy in the earth or was it produced by the action of heat on the remains of animals and fish? It is known that heat can cause iron carbide to combine with water to form iron oxide and the hydrocarbons like petroleum. Since the core of the earth may be composed principally of iron, such an explanation is possible. On the other hand, petroleum may have been formed during the decay of organic matter, both plants and animals, in somewhat the same manner that coal was formed. Some support for this latter theory is given by the fact that many oil deposits occur in salt domes which were formed under water in prehistoric ages.

IGNEOUS ROCKS

Igneous rocks were formed by the action of heat. Molten rock from the lower part of the lithosphere was pushed upward and cooled. If the



FIG. 83. Photomicrograph of granite. Note crystals of quartz, feldspar, hornblende, and mica. (Courtesy, Ward's Natural Science Establishment, Inc.)

material cooled slowly far underground, large crystals were formed; if it cooled rapidly, the rock became glassy in texture. It is evident that such rocks will contain no fossils. There will be no evidence of banding or stratification. An igneous rock has the same appearance from all faces.

One group of igneous rocks will receive only passing mention—the volcanic type consisting of obsidian and pumice. Such materials constitute volcanic glass and volcanic ash.

The other great group is called *plutonic*. These rocks were formed below the surface of the earth in the presence of great heat, were slowly cooled under tremendous pressure, and are found in the crystalline state. *Granite*, the best example of this group, is a coarse- to fine-grained rock that makes a hard, durable building stone (Fig. 83). It is possible to recognize the principal constituents—orthoclase feldspar, quartz, and other minerals, such as the micas—by the shape of the grains. In color, granite varies from light to dark-gray and red, the color being determined by the feldspar content. It is capable of being polished and one may find many beautiful specimens in museums. Most granites contain quartz, mica, feldspar, and hornblende. Because of the high percentage of quartz in the rock, it is termed an *acidic rock*. The feldspar content can be identified by the smooth faces of the grains, the quartz by the irregular glassy grains, the

mica by the shiny flakes, and the hornblende by the dark irregular grains.

Syenite, another igneous rock, resembles granite. It differs, however, in that it does not contain quartz. It contains orthoclase feldspar, hornblende, pyroxene, and mica. It is even more durable than granite, but is not very common in North America.

The *basic* type of rock, *diabase*, makes excellent monument material. The grains in this rock are microscopic in size, being composed of magnetite, augite, and feldspar. The Palisades on the Hudson are composed of diabase. The rock resembles basalt and often grades into basalt.

The *peridotites* are a group of igneous rocks consisting principally of pyroxene, olivine, and hornblende. They contain little or no feldspar. Many of the ores and gems are found in peridotite rock. It is the rock in which diamonds of South Africa are found.

Basalt is a rather familiar rock, dark, fine-grained, and dense. It contains feldspar, augite, and olivine. It composes most of the lava flows of Western United States and is used as road material. Basalt is often mistaken for diabase, because of its texture and color.

Metamorphic Rocks

As the name indicates, these rocks have been subjected to heat, pressure, and perhaps other action, in such a way that they have been changed in structure or composition. Because of the peculiar conditions that have

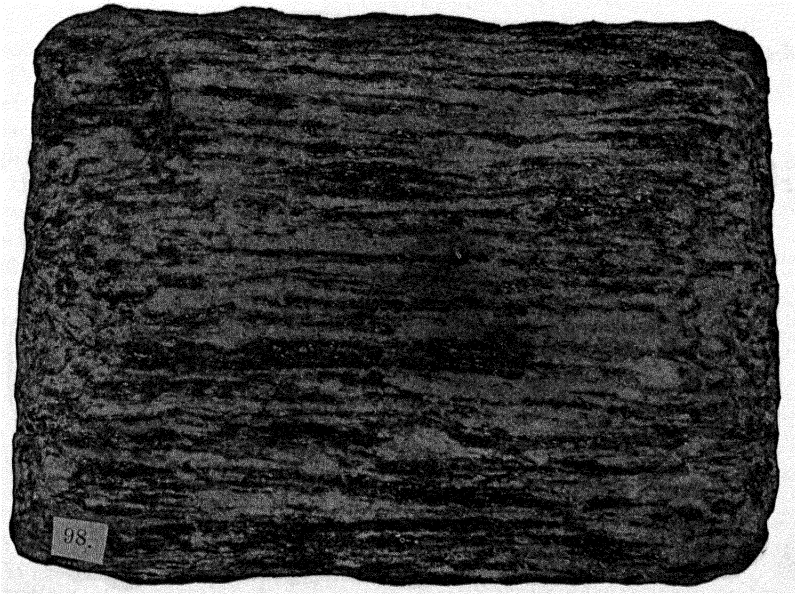


Fig. 84. Photomicrograph of gneiss. (Courtesy, Ward's Natural Science Establishment, Inc.)

produced metamorphic rocks, it is not suprising that they show banding and twisting. Both the igneous and the sedimentary rocks have been changed in this way.

Syenite and granite, as well as conglomerate, change to gneiss or schist.

Diabase and basalt change to schist.

Limestone crystallizes into marble.

Sandstone becomes quartzite or quartz schist.

Shale hardens into slate and mica schist.

Bituminous coal changes to anthracite coal or to graphite.

Gneiss (pronounced *nice*) (Fig. 84), metamorphic granite, is a very common rock. It is hard and shows distinct banding. It resembles granite, containing quartz, feldspar, and mica. Sometimes hornblende is a constituent and occasionally garnets are present.

If mica is present in large amounts in the gneiss-like rock, it is called mica schist (Fig. 85), composed principally of quartz and mica. The schists are used as building stone. They do not weather readily, hence are very durable despite the softness. Mica schist is a rock every observer should know. In most cases the mica is so prominent and the banding so definite that identification is easy. Schists are named for the most prominent mineral; thus we have hornblende schist, talc schist, and chlorite schist. The schists often contain garnets.

The metamorphic rock, *quartzite*, resembles sandstone although it

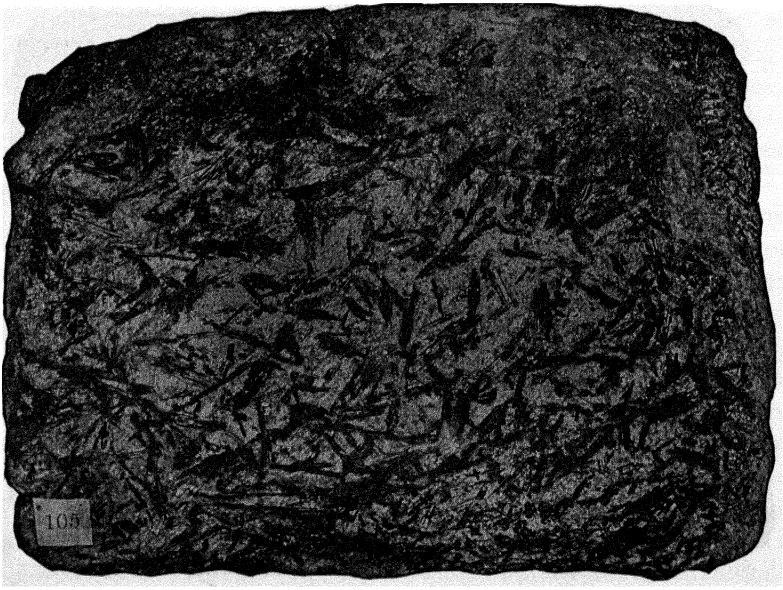


FIG. 85. Tourmaline mica schist. (Courtesy, Ward's Natural Science Establishment, Inc.)

may be so compact that the individual crystals are difficult to distinguish. The rock is often colored by feldspar and iron ore. It is very hard and durable, but, owing to the fact that it splinters, it is difficult to shape into blocks for building stone. It is used in road building. The acid test distinguishes it from limestone. "Stone Age" man used much quartzite as well as flint and basalt in his stone implements and weapons.

Marble comes from limestone and dolomite, as we have already emphasized. The best of the marbles are very fine-grained. Because of the grain structure and on account of the beautiful white color, the marbles of Italy are unsurpassed in the world. Vermont and Georgia also produce much marble. Because of the fact that marble is subject to chemical weathering, it has gone out of fashion as the stone used in monuments which are exposed to the weather. It is difficult to distinguish marble from crystallized limestone. Both show the calcite grains. Many marbles are spotted due to the impurities in the stone.

Slate is a well-known metamorphic rock which splits into layers. No mineral grains can be seen. The principal minerals are quartz and mica. Poor slate is difficult to distinguish from the sedimentary rock, shale.

It is believed that when bituminous coal was subjected to heat and pressure, the rock changed to *anthracite*. Anthracite coal is valuable because it burns slowly with intense heat and emits little smoke. It is probable that graphite and diamond are also metamorphic rocks.

References

Branson and Tarr. "Introduction to Geology," New York, The McGraw-Hill Book Co.
Cole: "Rocks and Their Origin," New York, The Macmillan Co.
Dana: "Minerals and How to Study Them," New York, John Wiley and Sons.
English: "Getting Acquainted with Minerals," New York, The McGraw-Hill Book Co.
Fenton: "The Rock Book," New York, Doubleday, Doran and Co.
Hawkins: "The Book of Minerals," New York, John Wiley and Sons.
Kraus: "Mineralogy," New York, The McGraw-Hill Book Co.
Kunz: "The Curious Lore of Precious Stones," Philadelphia, J. B. Lippincott Co.
Loomis: "Mineralogy," New York, G. P. Putman's Sons.
Pirsson: "Rocks and Rock Minerals," New York, John Wiley and Sons.
Winchell: "Mineralogy," New York, Prentice-Hall, Inc.

Questions and Problems

1. Explain why a metamorphic rock may at one time have been a sedimentary rock.
2. What is a gem?
3. What is: an ore? a mineral? a rock?
4. Distinguish between sedimentary, metamorphic, and igneous rocks.
5. What is the origin of: a pearl? a diamond? an emerald?
6. What is a trap rock?
7. What is fluorescence?

8. Distinguish between calcareous and argillaceous rocks.
9. What is: petroleum? coal?
10. Make a list of the most important rocks used in industry.
11. What is basalt?
12. What is an acidic type rock?
13. What is meant by a hard rock?
14. How can you test for dolomite rock?

Topics for Discussion

The History of Famous Diamonds
Coal Mining
Manufactured Gems
A Study of Gems
The Source of Crude Petroleum

Experiments

1. Identify rocks in the laboratory.
2. Collect and identify 10 rocks and minerals, labeling each.

IDENTIFICATION OF ROCKS

When identifying rocks, we make use of the properties of minerals described in the chapter. Many rocks weather extensively; hence it is necessary to study a freshly fractured surface whenever possible. This gives a clue to cleavage, fracture, and crystalline structure.

Try to determine from the general appearance whether a rock is of sedimentary, metamorphic, or igneous origin. Dip a glass rod into hydrochloric acid and place the drop on the rock. Effervescence of carbon dioxide indicates limestone or marble. If dolomite is suspected, heat the acid slightly. Hard, dense, and heavy rocks are usually either ores or igneous rocks. Most rocks are either coarse- or fine-grained, which gives a clue to their identity. The next operation is to determine the exact mineral composition if possible. One must remember that rocks merge into one another, so that a specimen may have the characteristics of two types.

Coarse-grained rocks may be sandstone, quartzite, granite, syenite, or diorite.

Fine-grained rocks may be shale, slate, gneiss, schist, pumice, or basalt.

Before beginning a study of rocks it is necessary to learn the characteristics of the minerals hornblende, quartz, feldspar, mica, and calcite.

A. Hornblende
   1. Hardness same as glass.
   2. Black or nearly so.
   3. Cleavage.
   4. Does not effervesce with acid.

B. Quartz
   1. Scratches glass easily.
   2. Any color from colorless to black.
   3. Pyramidal crystals in some cases.

4. Breaks like glass.
5. No effervescence with acids.

C. FELDSPAR
1. Scratches glass, but is scratched by quartz and steel.
2. Usually light—white, gray, or pink.
3. Definite cleavage.
4. No effervescence with acids.

D. MICA
1. Easily cut with a knife.
2. Colorless and yellow or brown or black.
3. Luster.
4. Cleaves into thin sheets.

E. CALCITE
1. Very easily scratched by needle or knife.
2. Any color from white to black.
3. Crystal variety has cleavage of rhombic type.
4. Effervescence with acids.

Sedimentary

A. SILICIOUS (sandstone is an example)
1. Stratified; consolidated sand.
2. Fine, rounded, quartz grains or coarse angular particles.
3. Cemented together by *silica* (light colors—white, gray, tan, buff, or yellow); *carbonate* (gray); *iron-oxide* (red or chocolate brown); *clay* (gray).
4. Usually soft and friable.

B. ARGILLACEOUS (shale is an example)
1. Stratified; consolidated clay.
2. Very fine-grained, flattened particles; often small mica flakes.
3. May grade into sandstone or limestone.
4. Black, blue, red, light gray.
5. Splits readily into thin leaves.

C. CALCAREOUS (limestone is an example)
1. Compact. Cannot see stratification in some specimens.
2. Acids cause effervescence of gas.
3. Shell fragments sometimes seen.
4. Soft; scratched by a knife.

D. CARBONACEOUS (bituminous coal is an example)
1. Easily shattered along right angles.
2. Plant imprints sometimes seen.
3. Very soft with exception of jet.
4. Rich in carbon and its compounds.

Igneous (Even texture in all directions)

A. GRANITE
1. Coarse crystalline structure; minerals easily seen.
2. Color light gray, grayish green, red, or pink.
3. Very hard.
4. Contains quartz, orthoclase, hornblende and mica.

B. SYENITE
1. Coarse crystalline structure.
2. Resembles granite except for absence of quartz.
3. Pink, gray, or white.
4. Very hard.
5. Orthoclase, hornblende, augite, mica, but no quartz.

C. DIORITE
1. Medium to coarse glassy grains.
2. Dark gray or green.
3. Long prismatic needles, good cleavage.
4. Plagioclase, hornblende or mica, or both.

D. DIABASE
1. Very fine grains, microscopic in size.
2. Dark color.
3. Augite, no quartz, may also contain pyroxene, hornblende, and mica with magnetite.

E. BASALT
1. Fine-grained; dense and heavy.
2. Dark color, nearly black.
3. Usually augite, olivine, and feldspar.

Metamorphic (Usually banded but not stratified)

A. MARBLE (metamorphic limestone)
1. Crystallized limestone (sugary).
2. Effervesces with acids.
3. White, mottled, or colored.
4. Soft, though harder than limestone.
5. Takes a polish.

B. SLATE (metamorphic shale)
1. Cleavage planes.
2. Splits into sheets.
3. Very fine-grained.

C. ANTHRACITE (metamorphic bituminous coal)
1. Black and shiny.

D. QUARTZITE (metamorphic sandstone)
1. Quartz, with small amounts of impurities.

2. Usually light colored, but may be dark brown.
3. Splintery.

E. GNEISS

1. Crystalline; rather fine minerals. Feldspar, quartz, mica, or hornblende.
2. Banded.
3. Splits in one direction.
4. Hard.

F. SCHIST

1. Crystalline; rather fine-grained.
2. Some mineral usually prominent.

(See text under schist—p. 122.)

10. PRODUCTS OF ROCKS AND MINERALS

It is only by overcoming nature that man can rise.

—SLOSSON

The great industrial development of the United States, Canada, Great Britain, Germany, and France has been due to the extensive development of natural resources which has been made in these parts of the world. By contrast, China, Africa, and to a lesser extent South America, have not utilized the wealth of natural resources available.

The modern way of life uses a myriad number of materials developed from natural sources. Our houses contain asbestos, paint, concrete, brick, steel, glass, linoleum, and alloy cooking utensils, none of which is found in nature. Radios, films, automobiles, shoe soles, clothing—all are manufactured articles.

In this chapter we shall describe some of the products that are produced from rocks and minerals.

PETROLEUM

One of the great industries of the world is the production and refining of petroleum. It is difficult to imagine our world without petroleum products. We use them in automobiles, in airplanes, in ships, in furnaces, in medicines, and as lubricants for machinery.

Petroleum was probably first used as a medicine by the Indians of Western Pennsylvania. Colonel Drake drilled a shallow well near the site of the present Oil City in the year 1860. The principal producers of petroleum are the United States, Arabia, Rumania, Russia, and Persia.

Petroleum consists of hydrocarbons, most of which belong to the methane series. About 30 of the hydrocarbons have been identified with certainty. The crude oil at present is obtained from wells bored into the lithosphere. Some of the wells are over two miles in depth. The various products derived from petroleum (crude oil) are secured by fractional distillation. In this process the crude oil is heated in such a way that the products are collected as gases at different temperatures (Fig. 86). A few of the products of petroleum are listed in Table 5.

Table 5

PETROLEUM PRODUCTS

GASES	Methane	CH_4. Marsh gas. Used as fuel
	Ethane	C_2H_6. A gas
	Propane	C_3H_8. Sold in tanks under the name "Pyrofax"
LIQUIDS	Pentane	Solvent for rubber and varnish
	Benzine	Largely pentanes and hexanes. Used in cleaning
	Gasoline*	A liquid of varying constitution, boiling between 85° and 200° F. The exact composition is not known. Probably hexanes, heptanes, and octanes
	Kerosene	A liquid boiling in the range 200° to 300° F.
	Fuel Oil	The oil remaining after the gasoline and kerosene have been removed. Used in oil burners and in Diesel engines
	Lubricating Oil	High boiling point oils used as lubricants
	Petrolatum	"Nujol" is an example
SOLIDS	Petroleum jelly	One trade name is "Vaseline"
	Wax	Wax candles and "Parowax"
	Tar	Roofing
	Asphalt	Road material

* *Note.* Gasoline is any mixture of hydrocarbons which can be used in internal combustion engines having spark ignition. Ethyl gasoline has had tetra-ethyl-lead added to reduce automobile knocking. The material reduces knocking by retarding explosions in the cylinders.

For many years after the discovery of petroleum, kerosene was the most valuable ingredient. Gasoline was a nuisance. With the coming of the automobile the demand for gasoline became so great that the chemist was compelled to devise new methods to increase the yield. By "cracking"

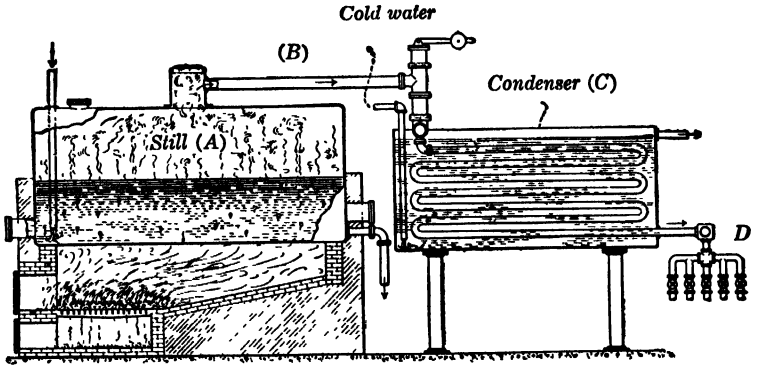


FIG. 86. Petroleum distillation. The crude oil is heated in still (*A*), passes through (*B*), and the vapors are condensed in (*C*). The liquids are drawn off through (*D*). (Courtesy, McPherson and Henderson: "An Elementary Study of Chemistry," Boston, Ginn and Company.)

the molecules of the heavy oils of the kerosene type the compounds can be broken down into lighter molecules for use as gasoline. If the complex molecules are heated to temperatures of about 500° F. they decompose into simpler molecules. It is impossible to write an equation which accurately expresses these reactions. By modern cracking processes, over 70 per cent of the kerosene molecules can be changed into gasoline.

HYDROGENATION

The cracking process involves the process of adding hydrogen to the heavy molecules, since they contain a smaller proportion of the gas than do the simpler molecules. By means of a *catalyst*, hydrogen at high temperatures and pressure is caused to combine with the heavy oils forming the more valuable light oils. The reaction takes place in a large nickel-chromium steel chamber where the hydrogen and petroleum are heated to about 1000° F. at a pressure of 3600 pounds per square inch. This pressure enables the refiners to produce larger yields of gasoline of very uniform characteristics. Much research has been done in this field within the past few years and the process has attained great commercial importance. In addition to gasoline, hydrogenated solvents for the paint, varnish, lacquer, and textile industries are being developed. Gasoline is being manufactured also by the hydrogenation of coal. One ton of coal plus hydrogen can produce as much as five barrels of gasoline. The process was developed by the chemist, Bergius.

Catalysts

A catalyst is anything that aids or retards a chemical reaction without being permanently changed or becoming a part of the final products. It does not change the course of the reaction. A very small amount of catalyst suffices to cause great quantities of material to react rapidly with each other. The hemoglobin in blood is a carrier catalyst. Finely divided nickel, when added to a mixture of hydrocarbons and hydrogen, aids the reaction between them. The nickel is later removed by filtering. Hydrogen combines with hydrocarbons when under very high temperature and pressure, but nickel causes the reaction to take place at a much lower temperature and pressure. Another example of catalytic hydrogenation is the manufacture of such fats as "Crisco," from cottonseed oil (see p. 232). Zinc oxide catalyzes the reaction between hydrogen and carbon monoxide to form methyl alcohol. Platinum is used as a catalyst in the manufacture of sulfuric acid. Copper is used in the formation of certain dyes. These are examples of catalysts which aid a reaction. The antioxidants used in rubber to hinder rotting are examples of retarding catalysts.

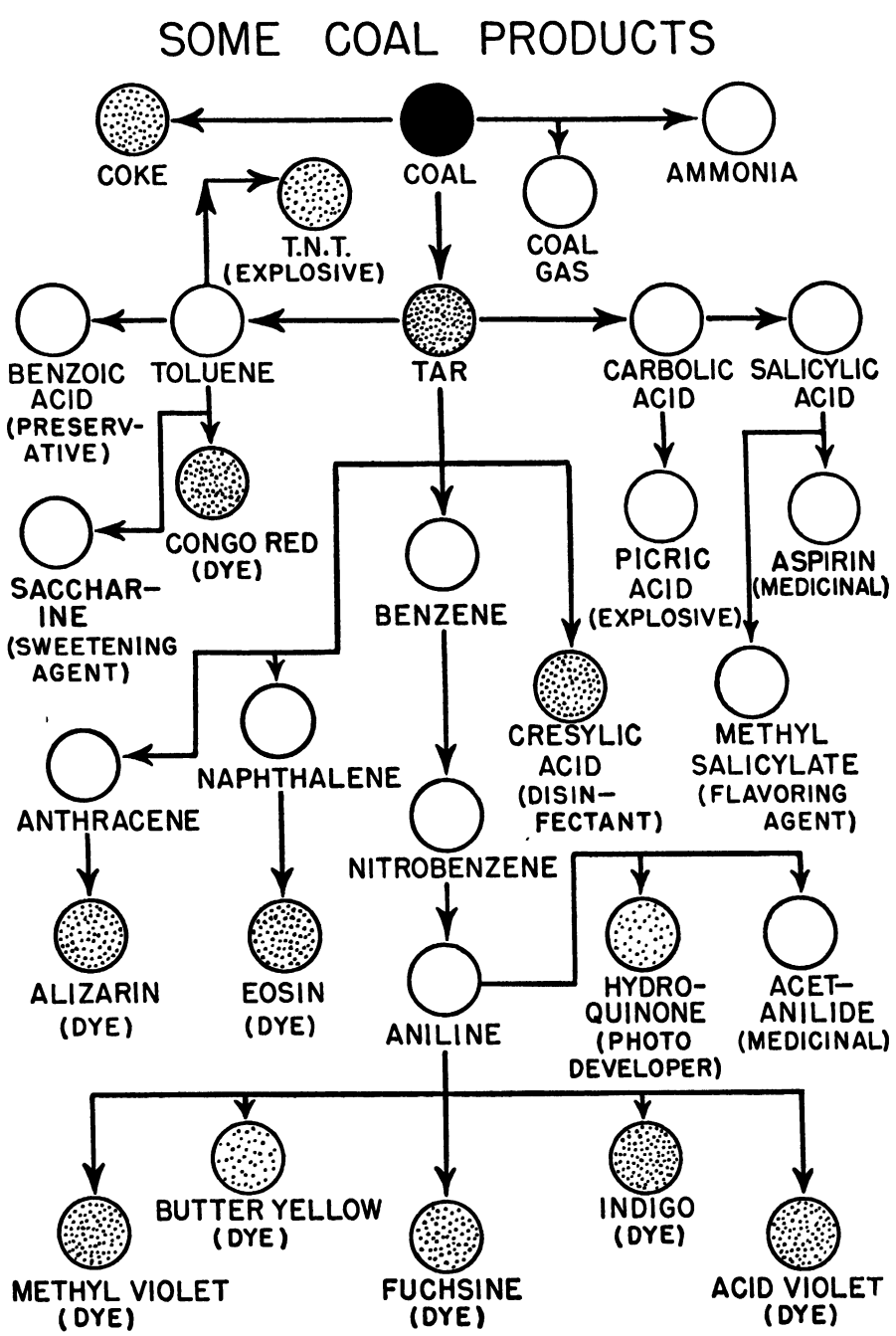


FIG. 87. Some products derived from coal.

Coal Products

Coal is another interesting source from which we derive an astonishing array of products. There are three general groups of coal products: coal gas, coal tar, and coke. These are produced by heating bituminous coal in large retorts without the access of air (destructive distillation). The type of furnace and the character of the product vary since they depend on the purpose of operation. Some companies make fuel gas to supply the heat and light requirements of a community. In this case the equipment and operation are designed to produce a maximum gas yield, coke being but a by-product, and the tar being wasted. Other companies make coke, using the gas to operate the furnaces. One-seventh of all coal mined in the United States is used to supply coke for metallurgical purposes. In many instances the coal tar and ammonia are lost.

Since 1914 there has been such a great demand for coke, ammonia, and coal tar that many by-product ovens have been constructed. Some of the coal gas which is formed in these ovens is used in their operation, but much of it is sold as fuel gas. A ton of soft coal yields about 12,000 cubic feet of gas. The coal tar which is driven from the coal is washed, as much as 25 pounds of ammonium sulfate per ton of coal being reclaimed from the washings. The ammonium sulfate supplies ammonia for explosives, fertilizers, and other nitrogenous compounds. About 125 pounds of coal tar remain, from which are prepared the many substances shown in Fig. 87.

The discovery of William Perkin that "mauve" dye could be made from coal tar opened the door to the development of modern coal-tar products, among which are explosives, antiseptics, dyes, perfumes, aspirin, photographic materials, carbolic acid, and roofing tar. This subject will be discussed more fully in Chapter 15.

A ton of coal also yields about 1200 pounds of coke. Coke is used in a variety of ways. Some is burned as household fuel. Most of it is used for industrial purposes such as the reduction of metals from their ores, the synthesis of methyl alcohol and of acetylene, and the manufacture of carborundum and graphite.

Asbestos

Some forms of this rock closely resemble textile fibers in gross appearance, as can be seen in Fig. 88. It occurs in compact bundles of long, slender, silky, fibrous masses. Chrysolite, tremolite, and actinolite are three minerals whose crystals may form in such a manner as to be termed *asbestos*. Asbestos has many uses due to its flexibility, its fire resistance, and its electric insulating properties. The long fibers are used in the manufacture of asbestos curtains, fire suits, and similar articles. Asbestos is a silicate rock (Chapter 9).

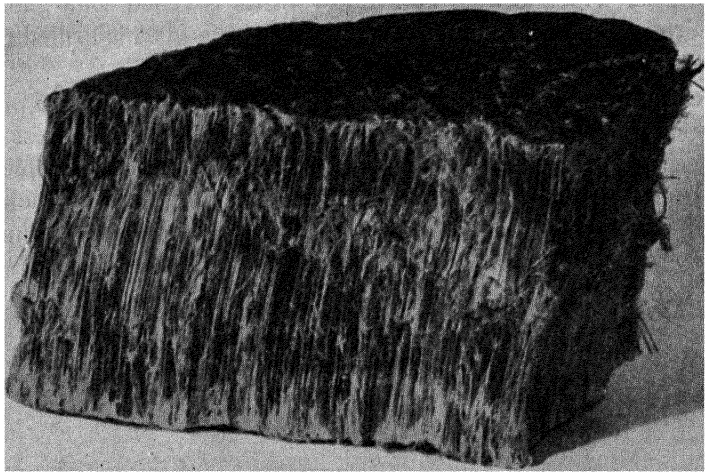


FIG. 88. Asbestos–note fibrous appearance. (Courtesy, Mines Branch, Ottawa, Canada.)

CEMENT

The Romans made cement, but the knowledge apparently died with them, for only since 1900 has cement again become important. It is made by pulverizing and heating a mixture of limestone and clay or shale in rotary kilns. The partly fused clinker mass is again pulverized and sold as cement. It is made into concrete by mixing cement, sand, crushed rock, and water. Concrete is a man-made rock which surpasses natural rock in durability and ease of handling.

GLASS

The art of making glass is old, having been well known in Egypt in 1400 B.C. At present there are many types of glass, such as window glass, bottle glass, cut glass, and pyrex. The general method of manufacture is to heat a mixture of sand (SiO_2), limestone ($CaCO_3$), and sodium carbonate (Na_2CO_3), or sodium sulfate (Na_2SO_4) until they fuse. The molten glass is then blown into molds (Figs. 89–92). Window glass is blown into long cylinders which are cut lengthwise while still hot and allowed to flatten into sheets. Plate glass is rolled into sheets on a hot steel table. Various substances may be added during the fusion process to produce special types of glass. Pyrex contains boron oxide (B_2O_3). This glass is interesting because of its toughness and low coefficient of expansion. In fact, a pyrex dish may be placed over the open flame without any danger. Glass baking dishes are better for baking because they do not reflect the heat as metals do. They also retain the heat better. Pyrex skillets are now available.

Ordinary glass which is used in window panes is called *soda glass*. The glass used for *cut glass* contains lead oxide. Such a glass is brilliant but is not suited for many purposes because of its softness.

The coloring of glass is a very interesting process. In order to produce colored glass various chemicals, principally metals, are added. These metals are mixed in the glass in a colloidal (see p. 259) form. For example, both gold and selenium produce a red glass, but the gold glass is much more attractive. Chromium compounds color glass green, and iron compounds make amber glass. Aluminum and fluorine are used in milk glass.

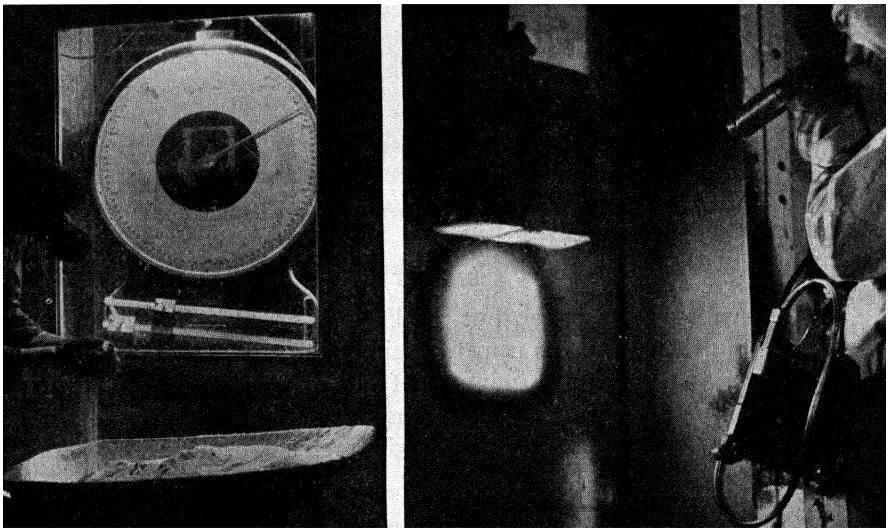


FIG. 89. (*Left*) Weighing the mixture. (Courtesy, Pittsburgh Plate Glass Co.)
FIG. 90. (*Right*) Measuring the furnace temperature with an optical pyrometer. (Courtesy, Pittsburgh Plate Glass Co.)

Most types of glass transmit light but they absorb the ultraviolet. Ultraviolet is useful in the prevention of rickets, hence it is desirable to have a glass which will transmit these rays. Considerable research is being carried on with the aim of providing a cheap "ultraviolet" glass for hospitals, homes, and nurseries. Glass made from fused quartz will do this, but it is too expensive for common use. Examples of ultraviolet glass are "Corex," "Vita Glass," and "Cobalt-Nickel Glass."

Safety glass is made by cementing a sheet of celluloid or other plastic between two sheets of ordinary glass. Bullet-proof glass consists of several layers cemented together. Such glass will crack but will not shatter. A better type of safety glass is still needed—one that is transparent, flexible, and yet rigid enough for ordinary pressures. There is hope that such a

material will be produced from the plastic industry (see p. 279). Some materials now being made, such as lucite, approximate the necessary qualifications (see p. 280).

METALS

A metal is a chemical element or a mixture of elements which, when a solid, is ductile, lustrous, malleable, a conductor of heat and electricity. Metals always have been associated with human progress. In fact, the purification and the utilization of metals such as iron, copper, tin, and the alloy bronze specify certain periods in the development of civilization.

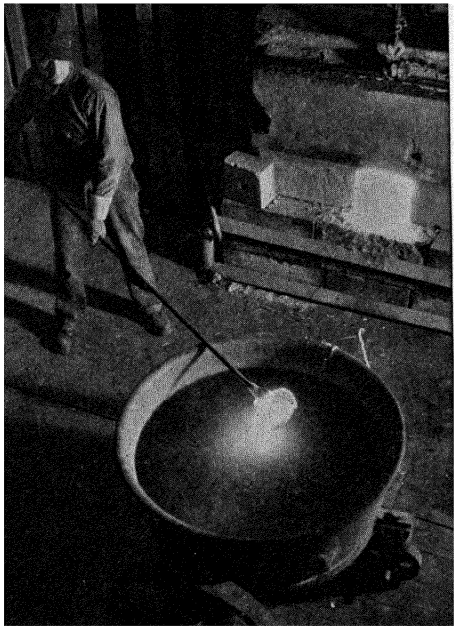


FIG. 91. Taking a sample of the melt.
(Courtesy, Pittsburgh Plate Glass Co.)

No metals are found free in nature except gold, lead, platinum, copper, and silver. For the most part, metals are combined with the other elements, being found as carbonates, sulfides, silicates, and oxides. Such rocks are called *ores*. Iron ore, for example, is a rock which contains large quantities of some compound of iron. Indeed, some ores are nearly pure metallic compounds—for instance, the iron ore, hematite, mined in northern Minnesota. Others contain rather minute quantities of metal, as in 300 tons of the uranium ore *pitchblende* there is only a minute amount of radium!

The manner of securing the metal from the ore depends upon its concentration in the rock, its chemical composition, and its chemical conduct. In general, the ore is crushed and roasted. Coke is added to remove oxygen from the metal and some material is used to purify the crude metal. The molten metal is then drawn off and worked into the desired form. Sometimes electrolysis is used to purify the metal, commercial copper being treated in this manner. The methods of extracting metals from their ores

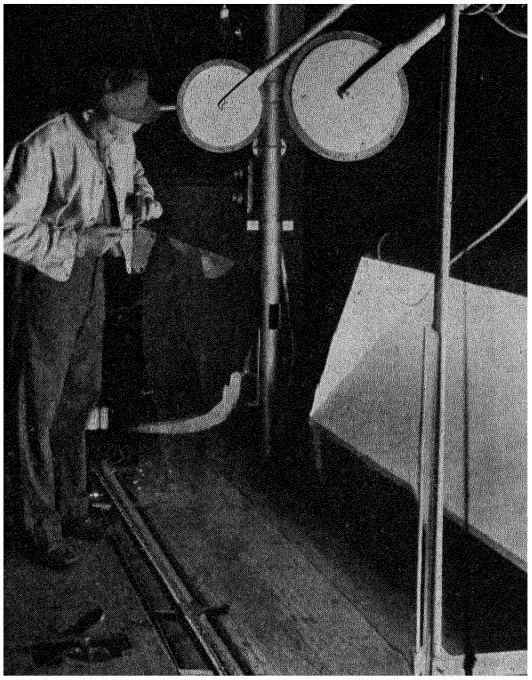


FIG. 92. Testing the glass for uniformity. (Courtesy, Pittsburgh Plate Glass Co.)

constitute the subject of metallurgy. Such processes are treated in the chemistry texts and will not be explained here.

SOME COMMON METALS. The production and use of *copper* dates back to the Egyptians, about 3000 B.C. We know from carvings that much copper was mined and smelted at Mt. Sinai. In smelting the copper ore malachite, charcoal was burned underneath the ore. The burning charcoal reduced the ore to metallic copper.

Copper is one of the most valuable of metals, not only because it is an excellent conductor of electricity, but also because it can be used for water

pipes, wire screens, roofing, and spouting. It is valuable for such purposes because it does not corrode to any extent when exposed to the weather. Its many alloys (among them brass, monel metal, and bronze) are some of our most useful materials.

The metal *iron* seems to date back at least as far as the first settlement of Palestine by the Israelites. In the ninth century B.C. iron was in use in Greece. During early times it was used as money because of its rarity and the difficulty of extracting it from its ores. The great difficulty with the use of iron is that it rusts rapidly when exposed to the air. To prevent the rusting various coatings such as tin and zinc are used. Tin plate and galvanized iron are examples of coated iron materials.

The alloys of iron called *steel* are of tremendous value in industry. Tungsten steel, nickel steel, chromium steel, and vanadium steel are a few of the important alloys.

The metal *tin* is used for organ pipes, as a coating for steel used in tin cans, as an ingredient of solder, in bronze, and in type metal. Most tin comes from the East Indies. It is not a plentiful metal.

Lead is a metal which was known in very early times, perhaps even antedating copper. It is a dense yet soft metal and is quite resistant to chemical action—in fact, this property makes it essential for use in acid-proof tanks and plumbing. It is an ingredient of solder. Lead compounds are used in lead glass for cut-glass articles.

It is of interest to the student of metals that aluminum, one of the most important substances, has been processed only within a few decades. Aluminum is a constituent of clay, but the difficulty of separation made the metal a rarity until recent times. In 1886, a young chemist named Charles Hall solved the problem of separation of the metal by electrolyzing molten cryolite in which aluminum oxide was dissolved. As is the case with many metals, pure aluminum has a limited use due to its low tensile strength. Most aluminum alloys contain a small amount of copper or magnesium. Such alloys are essential materials of industry.

The noble metals—*gold, platinum, silver, iridium,* and *palladium*—have a romantic history. Gold has been known for thousands of years, being found in the pyramids. Much gold was mined in Egypt. Croesus used gold as coins in the year 550 B.C. Pure gold is valuable not only for its beauty but also for its malleability and its resistance to corrosion. Ordinary chemicals do not affect it. Pure gold is as soft as lead, hence it is too soft for most purposes and it must be alloyed with such metals as platinum, silver, or copper.

Platinum is valuable not only for its beauty but also for its hardness and high melting point. It is very resistant to chemical action.

Silver, the least expensive of the noble metals, has well-known uses

in jewelry, in utensils, and in the compounds silver nitrate and silver bromide.

Table 6

PHYSICAL PROPERTIES OF SOME METALS

Metals	*Specific Resistance*	*Tensile Strength*	*Hardness*	*Melting Point (deg. C.)*
Copper	16×10^{-7} ohm	32,500 lb./in.^{2}	3	1,084
Aluminum	29×10^{-7}	12,000	2.5	657
Silver	16×10^{-7}	40,000	3	960
Tungsten	56×10^{-7}	230,000	7	3,370
Iron	97×10^{-7}	41,900	4	1,503
Nickel	123×10^{-7}	50,000	5	1,452

Table 6 indicates that metals vary widely in their ability to conduct electricity. Aluminum, silver, and copper, having a low specific resistance, are classed as good conductors. Iron and tungsten, having a high specific resistance, are used as heating devices. Mercury, being a liquid metal, has many well-known uses in industry.

ALLOYS

An alloy is a mixture of two or more metallic elements (or nonmetals such as carbon, tellurium, and phosphorus) which has a metallic appearance and is either a molecular mixture or a colloidal mixture. Alloys are man-made metals. New alloys are being developed at a rapid rate to meet the ever-increasing needs of mankind. Only a few years ago the breaking of an automobile spring was a common occurrence; today we rarely break a spring, because of the improved alloys that are used. The modern spring does not weaken under the constant vibration which it experiences.

In aviation we need light but strong engine and body metals. No pure metal meets the needs of the airplane. Iron is neither light nor strong enough; aluminum is light but too flexible. By adding some magnesium, copper, or manganese to aluminum, we produce *duralumin* which is ideal for the airplane (Fig. 93). Again there are no metals strong and hard enough to drill and machine certain alloys. Metallurgists are now producing alloys which maintain a sharp edge. Such an alloy is cobalt-tungsten. This material is so hard that it will cut sapphires and will get still harder while it is being used. By its means we can cut glass about as easily as a steel tool cuts brass.

Still another type of alloy is very resistant to corrosion. If chromium, nickel, or copper is added to iron or steel, the stainless steels result. Such

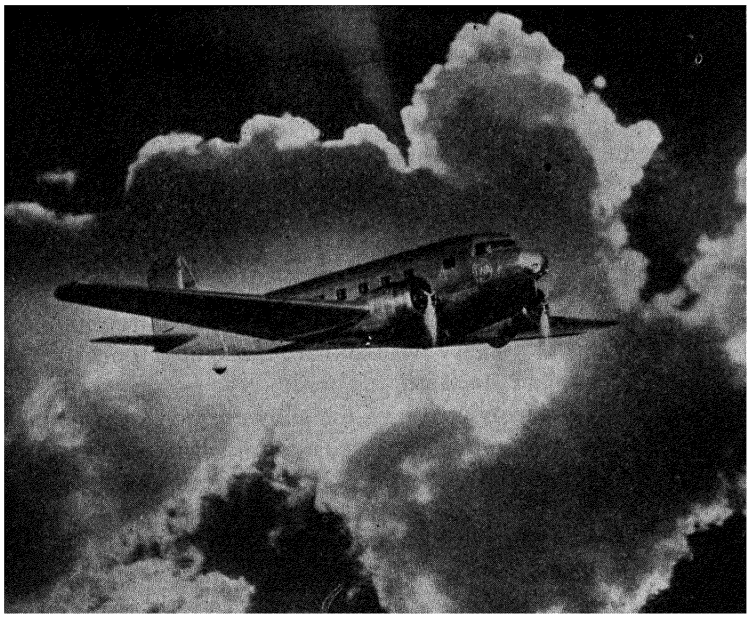


FIG. 93. This modern airliner is made of aluminum alloys.

products can be laid under salt water indefinitely without corrosion. Stainless steels are used for outdoor construction, cutlery, and sheathing. The new lightweight trains built by the Budd Manufacturing Company are constructed of welded stainless steel. The Empire State Building has a stainless steel dome which probably will last as long as the building stands.

In the building of electric lamp filaments the metal tungsten is alloyed with thorium. This makes it possible to draw the metal into very fine wires.

Alloys have been known for centuries, but it is only recently that they have been developed extensively. Copper was probably the first metal which was alloyed. Pliny mentions the substance bronze, which is an alloy of copper and tin. However, the only metals alloyed up to the eighth century were copper, gold, zinc, silver, and mercury. A few examples of early iron remain, one a sword blade from the tomb of Tutankhamen.

Some alloys are chemical compounds, while others are mere mechanical mixtures. Alloys often possess properties strangely different from the parent elements. An outstanding example is Wood's Metal which melts in boiling water, a much lower temperature than the melting points of any of the constituents. Because of its low melting point, this alloy is used

as a plug for fire sprinklers in stores and offices. There are hundreds of alloys, but most of them can be included in a simple classification shown by the following list. *It must be emphasized that the list contains only a few of the many alloys.*

I. IRON. The many alloys of iron are called steel.
   a. Chromium steel.
      1. *Stainless steel* is 18 per cent chromium, 74 per cent iron.
      2. *Armor plate* contains some nickel.
      3. Stellite, a very hard alloy, contains cobalt and tungsten.
      4. Acid-proof pipes, valves, sheathing contain chromium.
   b. Tungsten steels are very hard and are made into tools.
   c. Nickel and cobalt steels are magnetic.
   d. Nitralloy is the name given to the alloy formed by a new process in which the surface of steel is coated with iron nitride by exposing to ammonia fumes at a high temperature. The surface is one of the hardest materials known.

II. COPPER
   a. Brass is made from copper and zinc. One type has 70 per cent copper and 30 per cent zinc.
   b. Bronze is an alloy of copper and tin, composed of 90 per cent copper and 10 per cent tin.
   c. Beryllium and copper are used for fine springs.

III. ALUMINUM. Aluminum alloys are being developed for airplanes, trolley cars, trains, and autos. They are strong and light.
   a. Duralumin contains 95 per cent aluminum, 3.7 per cent copper, and a little magnesium.
   b. Beryllium-aluminum alloys are lighter and stronger than aluminum.
   c. Dowmetal, which is 85 per cent magnesium, is the lightest useful metal known. Being strong, it is used for trucks and stratosphere gondolas. A large covered truck of Dowmetal weighs less than a small open truck of steel.

IV. MERCURY ALLOYS are termed amalgams. They are used in dental fillings.

V. NICKEL ALLOYS are silver colored.
   a. German silver contains nickel, copper, and zinc, but no silver.
   b. Permalloy contains 78 per cent nickel and 21 per cent iron. It has excellent magnetic properties and has made possible high-speed cablegrams and the hand telephone.
   c. Monel metal is about 70 per cent nickel, 28 per cent copper, and 2 per cent iron. It is used for sinks, soda fountains, and in all interior and exterior finishings. It rivals stainless steel in its durability.

d. Nickel coins are a mixture of nickel and copper.
e. The new metal "Alnico" forms such a strong permanent magnet that it is used in the newest radio equipment, making possible a much simpler construction for dynamic speakers.

VI. PURE GOLD is said to be of 24 carat quality. This is too soft for most purposes and it usually is alloyed with either copper or silver.
a. U.S. coins contain 90 per cent gold and 10 per cent copper.
b. British sterling is 91.67 per cent gold and 8.33 per cent copper. (Sterling silver contains 92 per cent silver and 8 per cent copper.)
c. 18-carat gold is 75 per cent gold and 25 per cent copper. It is used in jewelry.

REFERENCES

Collins: "The Metals," New York, D. Appleton-Century Co.
Elberfeld: "Metallurgical Materials and Processes," New York, Prentice-Hall, Inc.
Harrington: "The Modern Metallurgy of Alloys," New York, John Wiley and Sons.
Perry: "The Metallography of Meteoric Iron," Washington, U.S. Government Printing Office.
Slosson: "Creative Chemistry," New York, D. Appleton-Century Co.
Vickers: "Metals and Their Alloys," New York, Henry Carey Baird and Co.

QUESTIONS AND PROBLEMS

1. Explain the terms distillation and fractional distillation.
2. Is there any danger of a shortage of gasoline within the next 50 years or so? Why?
3. Why is an asbestos curtain required in theaters? Discuss the possibilities of a substitute for asbestos.
4. List all the uses of cement which you know.
5. What advantage does pyrex have over other types of glass?
6. Why has it become necessary to develop new alloys?
7. Why are none of the pure metals suitable for: airplane construction? auto frames?
8. Why is steel output a barometer of business conditions?
9. What is Dowmetal?
10. List the alloys that you know.

VISUAL AIDS

Exhibits of alloys, aluminum, copper, ceramics, and coal-tar products are helpful and may be secured from many industrial sources.

Motion pictures: "Bituminous Coal," "Iron to Pig Iron," "Pig Iron to Steel," Eastman Classroom films

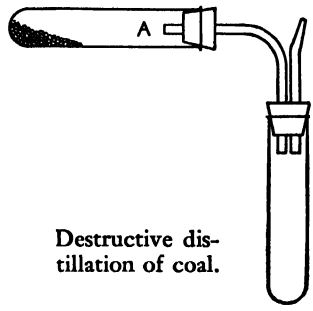
TOPICS FOR DISCUSSION

Ceramic Products	Stainless Steel	"Alnico"
Metallurgy of Various Ores	Permalloy	Refining

Report on any coke plant in your vicinity. Is the tar used or wasted?

Experiments

1. Construct apparatus as shown in the accompanying drawing. Half fill the tube A with crushed bituminous coal. Clamp it in a horizontal position; tap gently to form a pathway for the escape of gas along the top of the coal. Connect the tube to the rest of the apparatus. Heat the coal vigorously. Ignite the fumes escaping from the jet. Continue heating until fumes cease to come from the coal. Examine the coke and tar.



Destructive distillation of coal.

2. Heat a small amount of cinnabar in a pyrex tube. Very cautiously sniff the gas evolved. Describe the residue in the tube. What is it?
3. Mix two parts of sand and one part of cement. Mix in enough water to make a doughy mass. Pour this into a candy box (to make a concrete brick) or cement some stones together. Let it set for 24 hours and examine.
4. Make an alloy such as Wood's metal which has a low melting point.
5. Purchase a horseshoe magnet made of "Alnico" and study its properties.

11. THE ATMOSPHERE

Which is as thin of substance as the air
And more inconstant than the wind.

—SHAKESPEARE

For ages men have known that they lived in an ocean of some mysterious substance. They heard the roaring of the winds and experienced the effects of great storms. In their superstition they attributed these effects to the wrath of angry gods and to the moaning of lost souls. Today, we know that these effects are caused by the atmosphere of gases around the earth which we term the *air*. It is not surprising that ancient peoples did not recognize the existence of the atmosphere. As long as we are at rest in the atmosphere, we are not conscious of it. We only notice it where the pressure on one side of a surface is greater than that on the other side, such as an automobile windshield. The first realization of atmospheric pressure came when Otto von Guericke pumped out the air from a cask with the result that the cask collapsed.

Galileo established that air was a material substance by proving that it had weight. He found that a flask filled with air weighed more than the same flask which had been heated to drive out some of the air.

Table 7

GASES PRESENT IN THE LOWER ATMOSPHERE

Nitrogen	78.03%	Hydrogen	0.01%
Oxygen	20.99%	Argon	0.94%
Carbon dioxide	0.03% (approx.)	Neon	0.0018%
Water vapor	Variable	Helium	0.0005%
Xenon	0.000009%	Krypton	0.0001%

The atmosphere of a heavenly body is the gaseous envelope around it. On Jupiter the atmosphere is composed partially of methane and ammonia. On the earth the atmosphere is principally oxygen and nitrogen. The air is a mixture of various gases. Since these gases are not combined in a chemical way, they do not bear a definite proportion to each other and the constituents can be separated by physical means. Nevertheless, at the surface of the earth the amount of each is rather constant.

Because of the earth's atmosphere we have a comparatively uniform

temperature. The radiation from the sun is intercepted so that the earth becomes neither excessively hot at midday nor too cold at night, as it would be if there were no atmosphere. (As has been mentioned on p. 41, the lack of atmosphere on the moon causes great extremes of temperature there.) At night the air acts as a blanket that retains the heat of the earth. Clouds also blanket the earth, preventing severe extremes of temperature. Few of us realize the extent to which the air protects us. Even in the polar regions the temperature rearly falls below —65° Centigrade. The atmosphere is like a greenhouse in that it permits the energy of light and heat to enter, but prevents the escape of heat energy from near the ground. Much of this protection is due to the water vapor and carbon dioxide. Our atmosphere scatters the sunlight, giving us daylight. It also makes possible the transmission of sound waves.

Oxygen, nitrogen, and carbon dioxide, as well as water vapor, are all essential for life on the earth. It seems that the proportions of these gases have remained about the same for long geologic periods. As has been stated in Chapter 7, it may be that during the coal-forming periods there was an excessive amount of carbon dioxide in the air, and that during the glacial ages there was less than at present; however, we have no direct evidence for this theory. All animals use atmospheric oxygen and eliminate carbon dioxide. All plants which contain chlorophyll absorb carbon dioxide and eliminate oxygen in the daytime. At night the process is reversed. Carbon enters plants by photosynthetic reduction of carbon dioxide. In this way the balance of oxygen and carbon dioxide in the atmosphere remains rather constant.

Oxygen was first made by Joseph Priestley (Fig. 94) in 1774. He heated some mercuric oxide (HgO) and found that the gas given off caused substances to burn vigorously. Even red-hot iron burned in the gas. Antoine Lavoisier (Fig. 95) also studied the new gas, giving it the name oxygen. He also explained the role that the gas plays in combustion.

One of the functions of nitrogen in the air is the dilution of oxygen. Were the air pure oxygen, fires would be uncontrollable and metals would oxidize rapidly. On the other hand, life would still be possible because of the fact that we can breathe pure oxygen. The lungs absorb only the amount needed and reject the balance. (Because of this fact, oxygen is used for persons ill with pneumonia, for mountain climbers, and for aviators.) In the atmosphere, nitrogen is rather inert. When combined with oxygen or hydrogen, however, it forms a great number of important compounds. By causing nitrogen and hydrogen to unite in the presence of a catalyst (see p. 130), ammonia gas is produced. The chemist can use ammonia in the production of nitrates both for fertilizers and for explosives. It is interesting that, although nitrogen is not active in the air, yet in

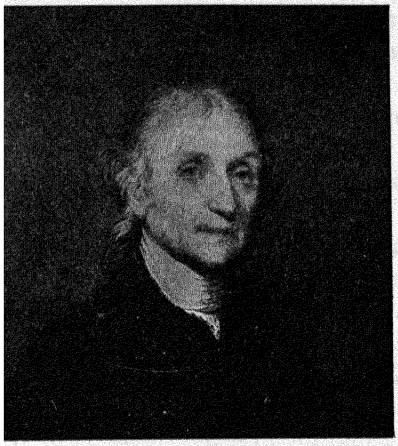


FIG. 94. Joseph Priestley (1733–1804). English clergyman, schoolteacher and scientist; discovered a number of gases, including oxygen, nitrous and nitric oxides, sulfur dioxide, and hydrogen chloride; settled in Northumberland, Pennsylvania in 1794, where there is now a memorial to him. (Courtesy, "Hackh's Chemical Dictionary," Philadelphia, The Blakiston Company.)

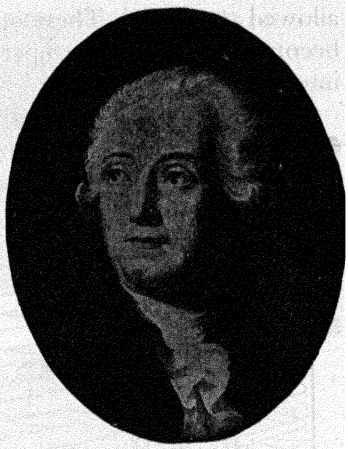


FIG. 95. Antoine Lavoisier (1743–1794). Named oxygen and other chemical substances, introduced quantitative chemistry. Has been called the "Father of Nutrition." (Courtesy, Brownlee, Fuller and Hancock: "Elementary Chemistry," New York, Allyn and Bacon.)

chemical combination with other elements, it is an important constituent of such active substances as explosives and protein foods. Many nitrogen compounds are manufactured from atmospheric nitrogen. A great plant at Muscle Shoals, Alabama, produces nitrogen compounds in this manner.

LIQUID AIR

Although oxygen and nitrogen exist as a mixture, it is difficult to separate them. Perhaps the best method is that of liquefaction and subsequent fractional distillation. Air, when highly compressed and cooled, becomes a liquid. One of the amazing feats of science was the development of a method for the production of liquid air. In order to change a gas to a liquid, it is necessary to subject the gas to a certain critical pressure and to a certain critical temperature. In the process of liquefying air the gas is first brought to a pressure of about 3,000 pounds per square inch (200 atmospheres) by the pump *P* (Fig. 96). Since the operation of compression has heated the gas, it is now cooled by the water in cooler *C*. The gas is now allowed to escape through the valve *V*, the resulting expansion cooling the air further. This chilled air is recompressed, cooled, and again

allowed to expand. These operations are continued until some of the air becomes a liquid at a temperature of about —192° Centigrade, and drops into the flask *F*.

Liquid air has very interesting properties. Since its temperature is extremely low, mercury can be frozen when placed in the liquid. Rubber becomes a brittle solid, so that a frozen rubber ball will break if bounced on the floor. Lead becomes so elastic that a bell of the metal at liquid air temperature has a tone like a bell of silver. Liquid air is used in many commercial operations which involve low temperatures. If the liquid is poured on a cake of ice it will boil like water that is heated on a red-hot stove (Fig. 97).

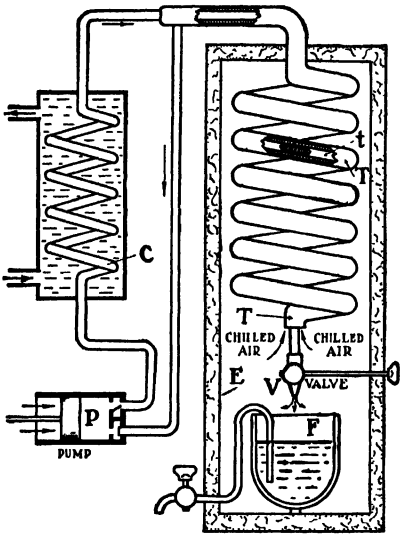


FIG. 96. A simplified diagram of a liquid air machine. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

If liquid air is carefully heated, the gases can be separated. Nitrogen boils off first. The oxygen follows at a temperature of —182.5° C. Each of the inert gases can be isolated by carefully controlling the temperature. By this means all the gases can be produced. It costs but a few cents per cubic foot to produce the rare gas, argon. Even the rarest gas, xenon, can be produced at moderate cost.

For a long time the inert gases had no commercial value. Today, argon is used in the manufacture of electric light bulbs. By filling the bulb with a small amount of argon and nitrogen, the evaporation of the filament is retarded, which lengthens the life of the bulb. Everyone is familiar with the red glowing signs containing the gas neon. By using argon, helium, and mercury vapor in discharge tubes, various colors are produced in advertising signs. Up to the present, krypton and xenon have been laboratory curiosities, but new uses are developing in electronic tubes. Helium is used in balloons, in dirigibles, and in electronic tubes.

The element helium has been isolated and studied only within the past 40 years. The spectrum lines of helium were observed in the spectrum of the sun by the astronomer Janssen in 1868.

Up until 1903, helium was a laboratory curiosity. In that year, helium was discovered in gas wells in Texas and Kansas. One of the wells in New Mexico contains nearly 8 per cent of the gas. In commercial production the natural gas is liquefied. The helium gas, having the lowest boiling point, leaves the liquid during the fractional distillation.

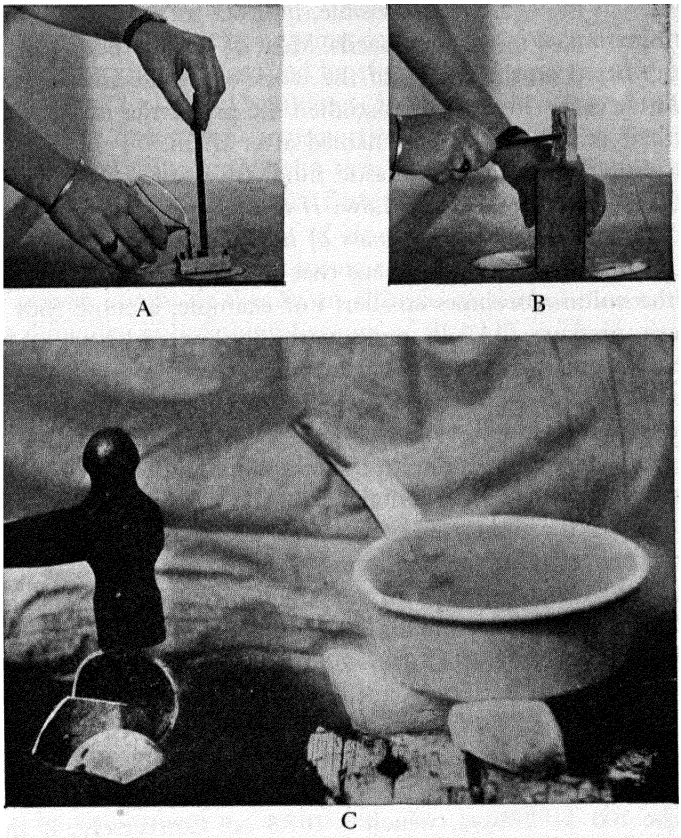


FIG. 97. Experiments with liquid air. (A) Pouring mercury into a paper mold to be frozen. (B) A hammer made of mercury being used to drive a nail. (C) A rubber ball frozen in liquid air breaks under the blow of a hammer. The pan of liquid air is boiling on a cake of ice. (Courtesy, Air Reduction Sales Company.)

NATURE OF THE GASES

We recognize at least three states of matter: gas, liquid, and solid. For example, the forms of water are ice, liquid water, and the gas called water vapor. A gas is composed of atoms or molecules which are quite distant from each other. These particles are in rapid motion, traveling at speeds of the order of 2,000 feet per second. They are believed to be constantly colliding and flying apart, moving in various directions. We can easily test this theory by opening a bottle of ammonia in the room. Within a few seconds the odor of ammonia can be detected in all parts of the room because of the rapid diffusion of the gas. The higher the temperature, the greater the speed.

Inasmuch as molecules are invisible, indirect methods must be used in the determination of molecular speeds. Most of our methods for the study of gases are based on the results of the work of Boyle, Charles, and Gay-Lussac. These early investigators studied the properties of gases and summarized their results in the laws named after them.

Boyle thought of air as an elastic fluid. By a series of interesting experiments he established Boyle's Law: *If the temperature of a gas remains constant, the volume of a given mass of it varies inversely as the pressure to which it is subjected.* This means that as the pressure on the gas is increased, the volume becomes smaller. For example, a cubic foot of air at atmospheric pressure (14.7 lb. per square inch) would have a volume of only ½ cubic foot if the pressure were made twice as great (29.4 lb. per square inch). If the pressure were made four times as great, the volume would be only one-fourth as great. The reason for this effect is that the pressure exerted by a gas is due to the combined impacts of the molecules as they strike the walls of the container. As the volume is halved, the number of molecules remaining the same, there will be twice as many impacts per second, hence twice the pressure.

The Law of Charles deals with the effect of temperature on a gas. The law states that all of the common gases undergo a change in volume of $\frac{1}{273}$ of their volume at 0° Centigrade when the temperature of the gas is raised one degree Centigrade, the pressure remaining the same. If one cubic centimeter (1 cc.) of air at 0° C. is heated to 1° C. without changing the pressure, the new volume will be $\frac{274}{273}$ cc. If 100 cc. of air changes from 0° C. to 20° C., the pressure being constant, the new volume will be $100 + \frac{2000}{273}$, which is 107.3 cc. Conversely, if the gas is cooled from 0° C. to −100° C., the new volume will be $100 - \frac{10,000}{273}$, or 63.4 cc.

If we were able to lower the temperature to −273° C., it would appear that there would be no volume. Actually all gases including helium become liquids before this temperature is reached. The temperature of −273° C. is called the *absolute zero* (see p. 301).

By studying the changes of volume with pressure and temperature, we arrive at the conclusion that a space such as the room is filled with molecular bullets moving at speeds of perhaps 2,000 feet per second, colliding with each other and rebounding from the walls. The lightest gases —for example, hydrogen—seem to have the highest speeds at any given temperature. Because of the gravitational attraction of the earth, the slow-moving molecules are held close to the surface, while the lighter gases can escape. It is believed that all of the gases on the moon have escaped during past ages because of the small force of gravity on the moon.

Because we are unable to see air, we fail to realize that it is made up of

any material substance. However, when a strong wind is blowing and we are obliged to push ourselves against it, we realize that even though we cannot see it we are being pushed by the force of air pressure. A wind of tornado velocity can wreck buildings. If we could insert a little window in the side of a tire which is supporting a heavy weight, we would be unable to see anything inside the tire. But if we puncture the tire we hear the escaping gas and the tire flattens. Thus we realize that the air is supporting weight. The millions of air particles are constantly bombarding the inside of the tire, thus causing the pressure.

As a person climbs or flies to an altitude of several thousand feet, he notices a difficulty in breathing because of the thin air. It is necessary for him to breathe in more of the air to secure sufficient oxygen. At very high altitudes, tanks of oxygen must be carried. It is estimated that the air extends to a height of about 300 miles. One-half of the air by weight lies below the three-mile level.

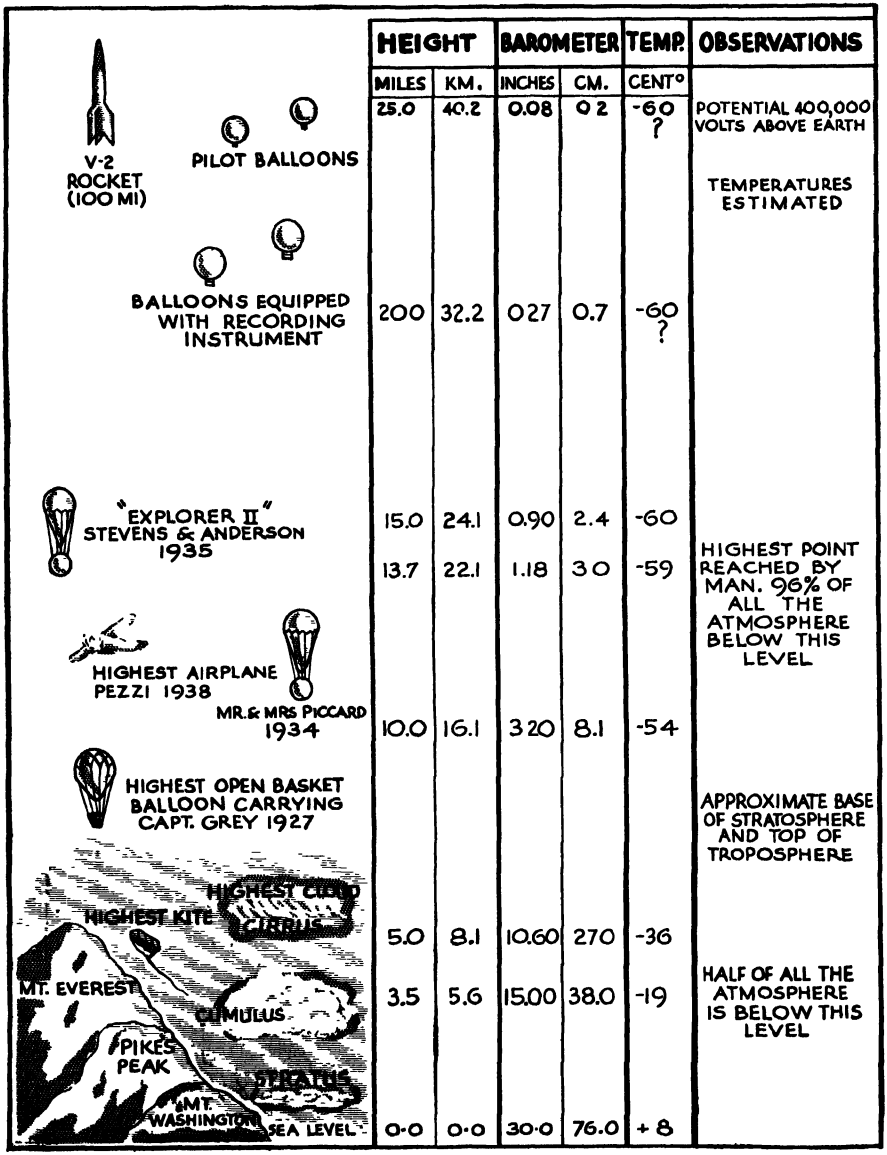
In 1935, Albert Stevens and Orvil Anderson using a stratosphere balloon, The Explorer II, reached a height of 13.7 miles (72,395 feet). At this height the air pressure was 0.6 lb. per sq. inch, or 4 per cent of the pressure at sea level. The aviators were sealed in a spherical ball of Dowmetal and breathed oxygen from liquid air. They found that at this elevation the stars were shining in the daytime because there was little atmosphere to scatter the light. The sky was black. At present, rockets are being sent up to heights of more than 100 miles in order to study the upper atmosphere.

Some of the interesting facts about the atmosphere are shown in Fig. 98. The atmosphere is divided into two layers, the troposphere and the stratosphere. In the troposphere the air is always in motion and water vapor is found in the layer. In the stratosphere there are no convection currents and the temperature is rather constant, about —60° C. Above 70 or 80 miles the atmosphere probably consists mainly of hydrogen and

Table 8

Altitude (ft.)	*Barometric Height (in.)*	*Pressure (millibars)*
0	29 92	1,013
2,000	27 80	945
4,000. .	25 80	875
10,000.	20.60	700

helium. In the flight of Stevens and Anderson it was found that an ozone layer exists at a height of about 10 miles. Since ozone absorbs ultraviolet



HEIGHT		BAROMETER		TEMP.	OBSERVATIONS
MILES	KM.	INCHES	CM.	CENT°	
25.0	40.2	0.08	0 2	-60 ?	POTENTIAL 400,000 VOLTS ABOVE EARTH
					TEMPERATURES ESTIMATED
200	32.2	027	0.7	-60 ?	
15.0	24.1	0.90	2.4	-60	
13.7	22.1	1.18	3 0	-59	HIGHEST POINT REACHED BY MAN. 96% OF ALL THE ATMOSPHERE BELOW THIS LEVEL
10.0	16.1	3 20	8.1	-54	
					APPROXIMATE BASE OF STRATOSPHERE AND TOP OF TROPOSPHERE
5.0	8.1	10.60	270	-36	
3.5	5.6	15.00	38.0	-19	HALF OF ALL THE ATMOSPHERE IS BELOW THIS LEVEL
0-0	0-0	30-0	76.0	+ 8	

FIG. 98. Some facts about our atmosphere. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

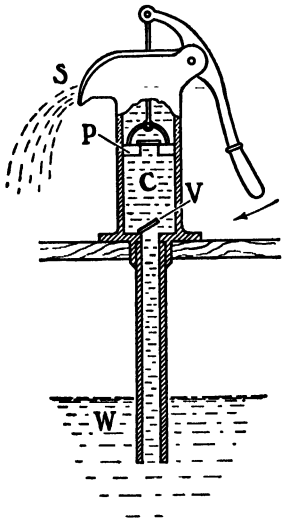
rays strongly, this layer may be responsible for the absence of short ultraviolet radiations in the sun's rays striking the earth. It was also noted that the intensity of cosmic rays (see p. 417) was greatly increased at the height of 13 miles. Due to the uniform atmospheric conditions, airplanes often travel in the lower stratosphere. However, because of the rarefied atmosphere, the passenger compartments are sealed and oxygen is supplied to both persons and engines.

Weight and Pressure of Air

Air is a substance which occupies space and has a definite weight. One liter (about one quart) of clean dry air weighs 1.293 grams at 0° C. (32° F.) and 760 millimeters pressure. This is equivalent to about one ounce per cubic foot. The air in an average room weighs more than 100 pounds. Because the air has weight, the blanket of air which covers the surface of the earth exerts an enormous force upon the surface.

A new fluffy pillow is light in weight. When 100 such pillows are piled on top of each other, the total weight will be considerable. The feathers in the top pillow will not be pressed together while those in the bottom pillow will be very compact. In the same way the molecules of gas making up the air are widely scattered at high altitudes but the lower molecules are highly compressed. The air exerts an average pressure of 14.7 pounds per square inch at sea level, and 12.1 pounds per square inch at an altitude of one mile. A man of ordinary size has a force on his body of about 14 tons, but, because of the air in his body cells, he is not aware of this great force unless he ascends rapidly. Airplane travelers are advised to swallow while the plane is rising. This equalizes the pressure in the middle ear.

We utilize the pressure of the atmosphere in many common operations of daily life. We "suck" liquids through a straw by creating a vacuum in the tube. The atmosphere then forces the liquid up into the tube. (In ancient times the explanation was, "Nature abhors a vacuum.") In the ordinary lift pump (Fig. 99), the upward motion of the piston creates a vacuum in the pipe, and the water is forced up to a height of about 33 feet by atmospheric pressure. It is evident that the piston must be within 33 feet of the water surface in the well if the pump is to operate. In the operation of the pump, the valve *V* opens as the piston rises. Water flows into the pump chamber *C* due to the atmospheric pressure. As the piston descends, the valve *V* closes and the valve *P* opens, permitting the water to flow into the upper part of the pump cylinder. The siphon (Fig. 100) is another interesting application of the pressure of



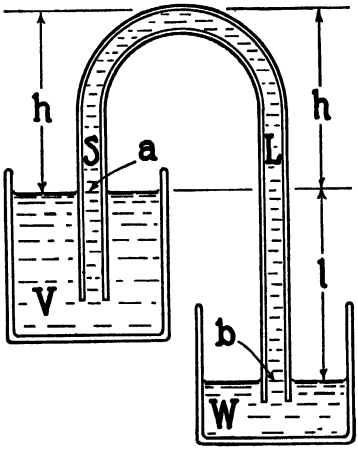


FIG. 99. (*Left*) The lift pump. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

FIG. 100. (*Right*) The siphon. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

the atmosphere. The device is used to transfer a liquid from one container to another at a lower level. A siphon cannot be used to drain liquid from a lower to a higher level. Since a siphon operates by atmospheric pressure, the height h cannot be greater than 33 feet. The level of the liquid in the vessel W must be lower than the level in the vessel V. Many a householder has tried in vain to drain the cellar by placing one end of the hose on the lawn and the other at a lower level in the cellar. An interesting experiment for illustrating the great force of the atmosphere can be performed in the following way: Some water is placed in an empty can having a small opening which can be closed by a cork. The water is boiled with the can open so that the steam will force the air from the can. After the water has boiled vigorously for about one minute, the can is removed from the flame and closed with a cork. As the water vapor condenses, a partial vacuum is created in the can and the force on the outside crushes

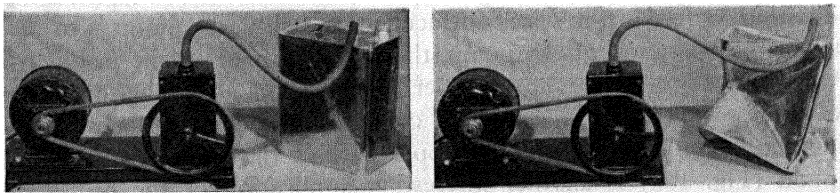


FIG. 101. Illustrating the effect of atmospheric pressure. The can on the left is at atmospheric pressure. Some air has been exhausted from the can on the right.

the can (Fig. 101). A variation of the experiment is to exhaust the air with a vacuum pump.

MEASUREMENT OF AIR PRESSURE

The barometer is the instrument used to measure air pressure. It can be made by filling with mercury a stout glass tube about 33 inches long sealed at one end. A finger is placed over the open end (Fig. 102) and the tube is inverted in a dish of mercury. A column of mercury (h) approximately 30 inches high will remain in the tube, being supported by the air pressure on the mercury in the dish. As the air pressure varies, the height of the column changes. Fig. 103 illustrates a commercial mercurial barometer.

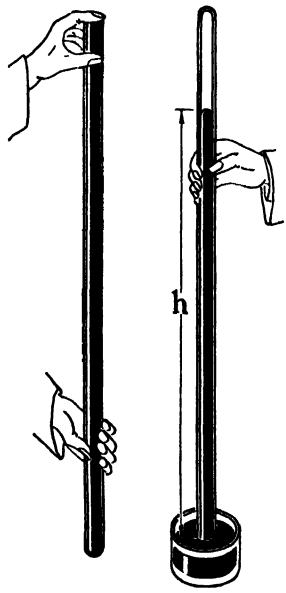


FIG. 102. The barometer. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Imagine a similar open tube of air reaching out into space to the top of the atmosphere and resting in the dish of mercury beside the closed tube. The short column of mercury in the closed tube has the same weight as the air in the long column. As the air pressure varies, the height of the mercury column changes. If the air is lighter, the mercury falls. There is a definite relation between the mercury reading and the weather. Low barometers usually indicate storms, while high barometers usually mean clear weather. In a storm area the cyclonic effect produces a partial vacuum and the barometer falls. In clear weather the air is usually dense and contains less water vapor.

Mercury is used in barometers for the following reasons:

1. Its specific gravity (see p. 247) is 13.6. It is the heaviest liquid known at ordinary temperatures. This makes a short column possible. Were water used, the barometer would need to be about 35 feet high.
2. Mercury does not wet glass.
3. Mercury is quite easily visible.
4. Mercury boils at 357° C. and freezes at —39° C. so that it can be used over most of the earth.

It is possible to make a water barometer and there is an interesting story in connection with the first one ever made. Otto von Guericke, the burgomaster of the city of Magdeburg, while studying atmospheric pressure, erected a long tube closed at

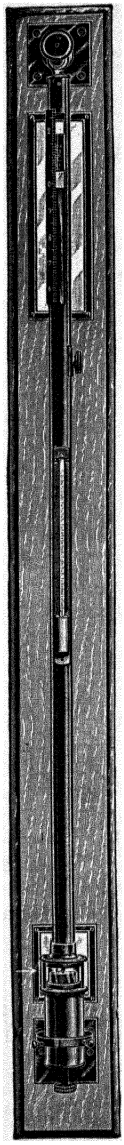


FIG. 103. A barometer. (Courtesy, Central Scientific Company.)

one end and reaching from the cellar to the roof of the house. A wooden image was placed in the tube so that it floated on the water. On fine days this weather prophet would rise above the house tops, while in foul weather—at its approach, in fact—it would retire below the roof. The superstitious citizens of Magdeburg thought that von Guericke was in league with the devil. We must remember that the experiment was performed in the year 1650.

Another type of barometer, the aneroid, consists of a cylindrical box with a flexible cover. Most of the air in the box is removed. The flexible cover rises and falls as the air pressure varies, its motion being transmitted to a pointer by means of levers. This type of barometer is both sensitive and portable. Because the atmospheric pressure decreases with altitude (about 0.1 inch per 100 feet) aviators use a modified form of the aneroid to measure height. A good altimeter can measure a height change of as little as 2 feet. Fig. 104 illustrates a common type of aneroid barometer.

COMPRESSED AIR

Compressed air is capable of exerting great force and is put to work in many devices. We are familiar with the signs on the rear of some trucks and buses—"Caution: Air Brakes." Railroad trains and trolleys would be unable to travel with safety at high speeds if they were not equipped with air brakes to enable them to stop quickly. Compressed air is used to spray paint, to sand-scour the outside of stone buildings, and to perform many other tasks in industry. It is one of our cheapest and most efficient tools.

When underwater tunnels and the foundations for bridges are being built, huge tanks called caissons are used. These are heavy and bottomless, resting on the bed of the river. In the upper part are two or more chambers, each sealed. Men go down into the first and remain until they are accustomed to the slight increase of pressure which is maintained there. Then they descend to the next chamber for a further increase in pressure. When they have become accustomed to this pressure they go to the floor of the caisson where they work under great pressure on the floor of the river, removing mud and laying the foundations for the structure. Air under high pressure is continually forced into the caisson to keep the water out (Fig. 105).

Men cannot work more than a few hours a day under such pressure and are unable to work at this occupation for many years.

They frequently succumb to a condition known as "caisson bends." Under such great pressure an excessive amount of air is forced into the blood. Nitrogen cannot be removed by body cells so that when a man comes to the surface too rapidly, the nitrogen, being unable to escape from the blood through the lungs rapidly enough, bubbles out into the blood vessels. This is why men cannot leave a submerged submarine and rise to the surface of the water unless special means are provided. Helium mixed with air has been found helpful as a preventive of "bends."

BUOYANCY

The principle of buoyancy is described in Chapter 17. At this point we shall illustrate it as follows: 10,000 cubic feet of air under ordinary conditions of temperature and pressure weigh about 800 pounds. Suppose that we have a balloon of 10,000 cubic feet capacity which weighs 500 pounds. If this is filled with 10,000 cubic feet of air at normal pressure it will weigh a total of 1300 pounds. Since it displaces only 800 pounds of air, the balloon will not rise, because the buoyant force is not great enough. However, if the balloon is filled with 10,000 cubic feet of hydrogen weighing only 56 pounds, the total weight will be 556 pounds instead of 1300 pounds and the balloon will rise in air. The balloon will have a lifting power of 244 pounds or the difference between the air displaced and the weight of the balloon and hydrogen. Had we used helium instead of hydrogen the lifting power would be slightly less, since 10,000 cubic feet of helium weighs about 100 pounds. In this case the lifting power would be 200 pounds.

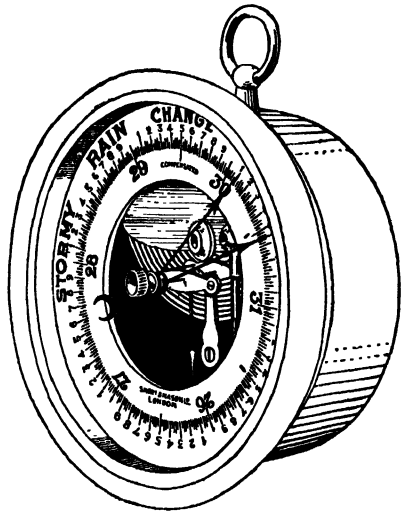


FIG. 104. An aneroid barometer. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

Now let us consider two other phenomena. Suppose our balloon without its load rises so high that it reaches air, which, because of its rarity, weighs only 556 pounds per 10,000 cubic feet. The balloon will stop rising and will float at that level. If the sun shines on the balloon, causing it to expand, the balloon will be larger than 10,000 cubic feet, will weigh less per cubic foot than the air, and will rise higher. Or if, with the coming of night, the gas is cooled, shrinking to less than 10,000 cubic feet, the balloon will sink. In the stratosphere flight of Stevens and Ander-

son, the bag was initially only one-third inflated so that upon rising to higher altitudes the expansion would increase the lifting power. They began the ascent before sunrise. Why?

Balloons are large bags filled with hydrogen or helium to which a basket is attached. They depend upon the wind for motive power and di-

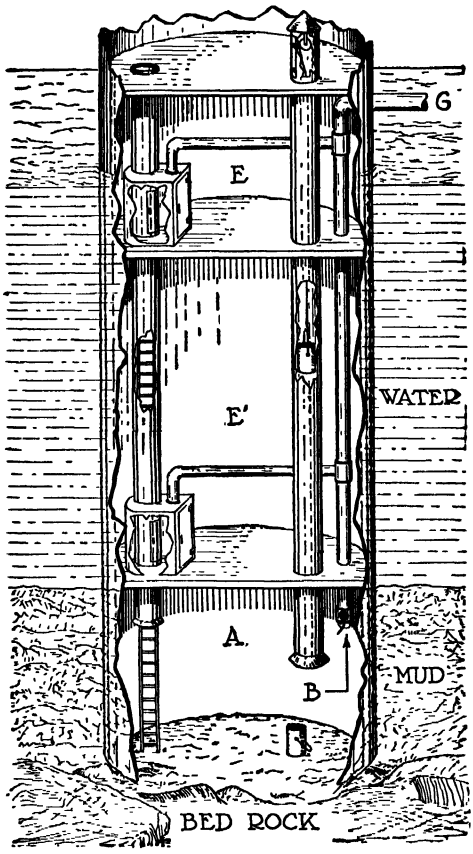


FIG. 105. A caisson. E and E' are compression chambers. The workmen operate in chamber A. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

rection of flight as they cannot be steered. When they are released from the ground they rise until they displace a weight of air equal to their own weight.

The balloonist can cause a balloon to rise higher by emptying sand

bags which are carried as ballast. He may cause the bag to descend by opening the valve in the bag, thus allowing the gas to escape. Since the balloon weighs less after some gas is removed, why does the balloon descend? (This question is left as an exercise for the student.)

Although blimps and dirigibles are maintained in the air by rigid gas compartments, they are propelled by motors. When they wish to descend air is pumped into reserve tanks, thus increasing the weight. The hydrogen or helium is not disturbed.

AIRPLANES

Airplanes are different in principle from balloons, being heavier than the air displaced. They are propelled by motors and maintained aloft by the pressure of the air beneath them. The action resembles that of a kite floating in the wind. By means of whirling propellers, an artificial wind is maintained to keep the plane in the air. This wind is deflected by the wings so as to exert a force nearly perpendicular to the wing surfaces. The slope and curvature of the wings have been carefully calculated to produce forces which support the plane.

The first successful power flight was made by Orville and Wilbur Wright in 1903. Since that time great progress has been made in the operation of heavier-than-air machines. A discussion of the forces which support the airplane will be found in Chapter 21.

REFERENCES

Glathart: "Foley's College Physics," Philadelphia, The Blakiston Company.
Humphreys: "Physics of the Air," New York, The McGraw-Hill Book Co.
Margenau, Watson, and Montgomery: "Physics," New York, The McGraw-Hill Book Co.
Milham: "Meteorology," New York, The Macmillan Co.
Tarr and Von Engeln: "New Physical Geography," New York, The Macmillan Co.
Stratosphere Flights, *The National Geographic*, 1935.

QUESTIONS AND PROBLEMS

1. Why do balloons tend to rise when the sun heats the enclosed gas?
2. What is meant by fractional distillation?
3. Why are some mountains snow-covered in summer, while adjacent valleys are uncomfortably warm?
4. If you were 12 miles up in the atmosphere, could you see to read a book? Explain?
5. Can you suggest a way by which a submarine could descend into the water?
6. If you open a bottle of ammonia at one point in a room, within a few seconds the odor is detectable everywhere. Explain.

7. A balloon and contents weigh 500 lb. It displaces 800 lb. of air. What is the lifting power?
8. Why do we use a straw to suck lemonade?
9. What does a mercury barometer indicate?
10. Why not use the aneroid barometer exclusively and discard the mercury barometer?
11. A tank of air at atmospheric pressure has the pressure tripled. How will the volume change? Answer: Reduced to one third.
12. Five hundred cc. of air is heated from 0° C. to 50° C. How will the volume change? Answer: Increase of 91 cc.
13. Mercury is 13.6 times as heavy as water. How high would a water barometer be? Answer: 1033.6 cm. at standard conditions.
14. Five hundred cc. of gas at 0° C. and 1 atm. pressure will have what volume if the pressure is increased to 3 atmospheres and the temperature remains constant? Answer: 166 cc.
15. Would water boil at 100° C. on Mars? Explain.

Visual Aid

"Liquid Air," General Electric Co.

Topics for Discussion

Dirigibles
Liquid Air
Heliocopters
Airplanes
Priestley
Stratosphere Flights
The Jet-propelled Plane

Experiments

1. Oxygen. Heat a mixture of equal parts of potassium chlorate and manganese dioxide in a pyrex test tube. Collect some of the gas in bottles and test it by glowing splints and by red-hot picture wire. (Consult any chemistry text.)
2. Nitrogen. The reader may consult any chemistry text for a method of production.
3. Carbon Dioxide. Place a small amount of limewater (calcium hydroxide) in a shallow dish and expose it to the air for about an hour. White calcium carbonate will be formed and the limewater will turn milky. This proves the presence of carbon dioxide in the air. To prove the statement, place some hydrochloric acid on marble chips and cause the gas which is evolved to pass into limewater. To show the presence of carbon dioxide in the breath, bubble the expired air into the limewater.
4. Water. A glass of ice water is sometimes covered with a film of moisture which has condensed from the air. Dew is another illustration of water condensed from the air.
5. Dust. Allow the sunlight to shine through a tiny slit into a darkened room. Dust particles will be seen floating in the beam.
6. Weight of Air. Balance two corked flasks on a pan balance. Uncork one and heat it until it is quite hot. Remove it from the flame and quickly cork it. When it is cool, replace it on the pan. Is there still a balance? Explain.

7. Boil a few cubic centimeters of water in a flask, remove it from the heat, and tightly tie a sheet of rubber over the mouth. Explain what happens.
8. Purchase a toy model airplane and examine the wing structure.
9. If liquid air can be secured, perform some of the common experiments.
10. Study the principle of the aneroid by soldering the short arm of a lever to the top of a sealed can of vacuum-packed coffee. The changes in atmospheric pressure will be observed on a scale at the end of the long arm.

12. WINDS AND WEATHER

To talk of the weather, it's nothing but folly,
For when it rains on the hill, it shines in the valley.

—DENHAM

Some of the most interesting of natural phenomena are those atmospheric features which we call weather. Man has always used the weather as a topic of conversation; consequently many false ideas have arisen in past generations. Many people believe that winters in past decades were more severe than the present winters. Actually, scientific records indicate that this belief is open to question. It is commonly believed that storms always occur during the equinoxes, that a period of mild weather called "Indian Summer" always occurs in late fall, that explosions of gunpowder cause rain on July Fourth, that if the groundhog sees his shadow on February Second, six weeks of winter will follow, that aching corns indicate rainy weather, that thick onion skins indicate a cold winter, that if it rains on Easter Sunday it will rain for the next four Sundays. None of these beliefs has a basis of fact. We cannot predict the weather for more than a few hours in advance.

Many interesting couplets about the weather have been handed down from generation to generation in past years. It may be of interest to list a few:

Evening red and morning gray
Send the traveler on his way.
Evening gray and morning red
Send the rain upon his head.

When the wind is in the south,
The rain is in the mouth.

Mackerel sky and hairy tails
Make the sailors furl their sails.

A rainbow in the morning
Makes sailors take warning,
A rainbow at night
Is the sailors' delight.

There is a definite relation between varying air pressure and the weather. As the sun heats an area of the earth, the air over this area becomes warmer and less dense. Consequently, a great mass of air rises into

the upper atmosphere and is replaced by cooler air from the surrounding areas. Over a large cool area, which may be several hundred miles distant from the warm area, the air, being more dense than the surroundings, sinks to the ground and flows outward. Between these two areas, air is in horizontal motion. *This horizontal movement of air from the region of high pressure to a region of low pressure is called a wind. The currents of air moving vertically constitute calms.* These circulations of air are the principal causes of weather.

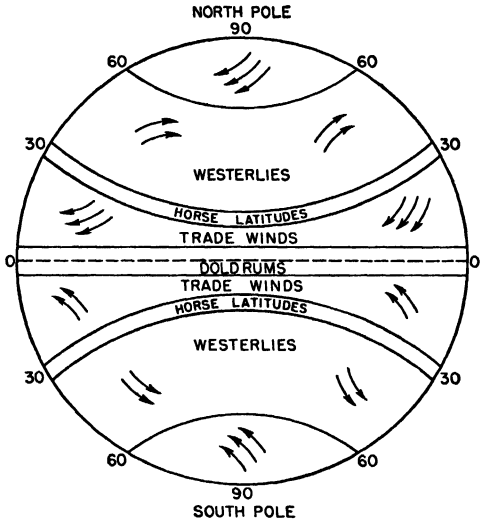


FIG. 106. Wind belts of the world. The rising air of the doldrums flows north and south and gradually drops at the "horse latitudes." This air returns as the trade winds. Another part of the upper air forms the prevailing westerlies.

Weather is greatly influenced by belts of prevailing winds. There are on the earth four large regions of rather constant wind motion known as *planetary wind belts*. Separating the wind belts are regions of little or no wind called *calm belts*. Because each belt merges gradually into the adjacent belts and also because air movement is modified by the unequal heating of land and ocean masses, no definite boundaries can be given for each belt, so that the latitudes noted in Fig. 106 are only approximate. In the northern hemisphere the belts shift about 5 degrees northward in summer and about 5 degrees southward in winter.

Of all regions, the equatorial zone receives the greatest amount of heat from the sun. This is partly due to the approximately equal days and nights, but primarily it is due to the fact that the equator receives direct rather than slanting rays of sunlight. A beam of sunlight one foot square

striking the ground from directly overhead heats one square foot of ground, whereas the same beam striking the ground from an angle distributes the same heat over several square feet, so that each square foot receives correspondingly less heat.

The result is a rather steady upward flow of air. Because the air is moving upward over a great area, no wind is felt, hence the equatorial zone is a belt of calms, called the *doldrums*. Most of the equator lies over water, and, as there is more water vapor per unit volume in warm air than in cold air, the rising air over the equator is "saturated with moisture."

As the air reaches an altitude of a few thousand feet it expands, and, in expanding, becomes cool. As the air cools some of the water vapor condenses, subsequently there are almost daily downpours of rain over the equator. At the equator the weather varies little from day to day. The mornings and nights are usually cool, although at many locations along the seacoast the night temperatures are nearly as high as those in the daytime. The temperature and the humidity rise during the forenoon after which a heavy rain falls. Because of the heavy rainfall and the high humidity, commercial activity in these regions is rather limited. Many persons are unable to live in the tropical regions because of the unfavorable climatic conditions.

Winds

As has been stated, air moving from a region of high pressure to one of low pressure constitutes a wind. Winds are strong when the difference between the high and low pressures is great. If the pressure difference is not great we have gentle breezes of from 1 to 5 miles per hour. An average "high" is about 30.0 inches on the barometer and a "low" averages 29.5 inches. If the pressure drops to 29 inches, there is danger of a hurricane. (At Philadelphia the highest pressure on record is 31.02 inches and the lowest 28.54 inches.)

An interesting type of wind is the breeze along the coasts. Land absorbs heat and loses heat more rapidly than water. During the summer day the land is being warmed by the sun. As the warm air rises, cooler air from the ocean flows toward the land, giving us the afternoon sea breeze. At night the land cools more rapidly than the water so that the cool air flows out from the land. This is the night *land* breeze. Anyone who wishes to sleep in comfort at the seashore in summer should have a room with a window on the landward side to secure the night land breeze. In winter the land cools more rapidly than the water so that winter resorts are often located near the seacoast in order to secure a more moderate climate.

Monsoons are the seasonal winds which occur in various parts of the world, especially in India. Much of India has a dry winter and a rainy summer season. From October to March the wind blows from the north-

east since the land is cooler than the water. Because it is cool dry air sweeping down from the mountains, there is little rainfall. In June the air flows in from the sea and produces a very heavy rainfall which sometimes reaches a high value of 80 inches per year.

TRADE WINDS. Air is continually moving toward the equator, replacing the rising air of the doldrums. This results in a belt of steady winds known as the trade winds on either side of the equator. The trade winds become warmer as they approach the equator and the rainfall is rather infrequent. The winds sweeping over large land areas cause evaporation of the water and produce desert areas in parts of Australia, Western South America, and Western Africa. The Sahara is in the trade wind belt. On the other hand, if the trade winds blow from the sea over the land we may have great precipitation, as in Brazil and the East Indies. Some mountainous islands in the trade wind belt have heavy rainfall on the eastward side and a desert region on the westward side.

Were it not for the rotation of the earth, the trade winds would blow directly toward the equator from the north and south. However, because the earth is rotating on its axis from west to east, the winds acquire a westerly direction, coming from the northeast and southeast. (Winds are named from the direction from which they come, hence Northeast and Southeast Trades.) A point on the earth at the equator is moving about 25,000 miles in 24 hours, more than 1000 miles an hour. A point on the earth at latitude 45 degrees is moving only about 700 miles per hour, while a point near the pole has very little motion.

Since the moving air *tends to retain the speed of the point whence it comes*, the winds moving over the earth's surface from latitude 45 degrees toward the equator lag behind the earth, thus acquiring a westerly direction of flow. The direction of air flow is stated by Ferrel's Law: *To one facing the equator, moving wind and water are deflected toward the right in the northern hemisphere and toward the left in the southern hemisphere.*

An illustration of this effect is furnished by the merry-go-round. Suppose that a person on the moving platform decides to walk across the platform directly toward a point in the building. Because the platform is moving ahead as he walks across, he will walk diagonally across the platform. Another illustration is to rotate an earth globe counter-clockwise while a chalk line is drawn from the pole directly toward the equator. The chalk line will be curved.

ANTITRADE WINDS. As the heated air rises to a height of about 6 miles at the doldrums it is cooled by expansion and deflected eastward by the rotation of the earth. This air flows poleward in the upper troposphere, forming antitrades. These winds are very complex due to irregularities of temperature. Some of this moving air gradually settles to the earth forming two calm belts known as the "*horse latitudes*." Because the air is dense

and there is little water vapor, rainfall is infrequent in these belts. Some of the region is desert.

Some of the air flows farther north and forms the polar air currents which seem to circle the pole and return southward. This polar air is a partial cause of the blizzards in the prevailing westerlies belts.

PREVAILING WESTERLIES. Some of the air drifting poleward drifts down to earth in the temperate zones, forming the prevailing westerlies. The direction of air flow is due to the fact that the antitrades are flowing poleward, that is, from the equator to points which are moving more slowly. This has the effect of deflecting the air eastward, hence the term *prevailing westerlies.*

The movement of the prevailing westerlies, a belt of irregular storms, is influenced by topography and other conditions. During the winter the United States lies almost entirely in the prevailing westerlies belt. During the summer the southern tier of the states lies in the horse latitudes. South of the equator the belt is almost unbroken by land so that the winds are strong and steady, being referred to by sailors as the "roaring forties" (40 degrees south to 50 degrees south latitude).

STORMS

The belts of prevailing westerlies are characterized by a succession of storm areas which are carried eastward by a general movement of air. These storm areas are regions of rising air currents and are known as *lows* because the decreased pressure results in low barometer readings. Lows are small circular replicas of the doldrums. As the air in a low rises it becomes cooled, frequently to such an extent that precipitation of rain or snow results.

In addition to the prevailing westerlies drift, a current of cold air moves down from the poles. As this cold air layer moving toward the west meets the warmer equatorial air drifting toward the east, a circulation of air called a *cyclone* results. A cyclone is a storm several hundred miles in diameter which moves eastward across the United States and Canada. A cyclone may be a feeble whirling mass of air or it may assume the dangerous speed of a hurricane or tornado. Since the center of a cyclone is a calm (low), air blows toward this low from all directions where the pressure is higher (high). For this reason a cyclone in the central part of the United States is forecast on the eastern coast by the easterly winds which blow from the Atlantic. An east wind means that a storm area is moving from the west. Winter storms generally move about 700 miles per day, while the summer disturbances travel only about 500 miles per day.

TORNADOES, HURRICANES, AND TYPHOONS

A tornado is a rapidly whirling funnel of uprushing air in the center of which there is a very low pressure (Fig. 107). The tornado itself usually

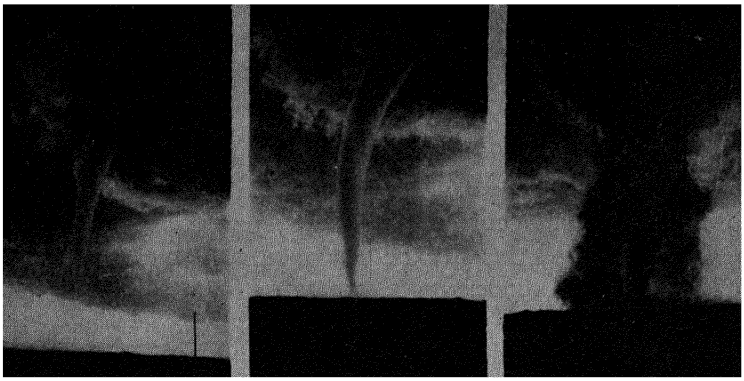


FIG. 107. A tornado. (Photos by Mrs. Roy Homer. Courtesy, Menzel: "Our Sun," Philadelphia, The Blakiston Company.)

travels about 25 miles per hour but the whirling air has a speed which has been estimated at from 100 to 500 miles per hour. When the center of a tornado passes over a building in which there is air at normal pressure, an explosion may result causing the walls of the building to be blown outward. Tornadoes are of short duration and cover a narrow path not over a few hundred feet wide. The region between the Rockies and the Appalachians seems to be best suited for the development of such storms. The exact cause of tornadoes is not known, but it is believed that currents of air blowing in opposite directions at about the cloud level develop a tremendous whirl. It is estimated that tornadoes take the lives of about 300 people each year. Unfortunately they arise too rapidly to be forecast successfully.

Destructive storms covering *large* areas are called typhoons and hurricanes. Many hurricanes develop in the West Indies and move west, then northwest and north. After a hurricane reaches the belt of prevailing westerlies, it usually moves out to sea. The most disastrous hurricane ever recorded along the Atlantic seaboard of the United States occurred on September 21, 1938. A typical Caribbean hurricane suddenly shifted its course and struck southern New England with tremendous force. Combined with the storm was an exceptionally high tide, a spring tide (see p. 45). The combined effect of the storm and water destroyed hundreds of millions of dollars worth of property and caused the death of several hundred people.

PRECIPITATION IN A LOW

Rain or snow starts at about the center of a low or very slightly in advance of it and continues until the low has moved well past. However, rain or snow do not necessarily accompany every low. Sometimes the sky is clear, sometimes overcast, sometimes there are scattered showers.

Numerous conditions contribute toward making rainfall. The most important factor is that water vapor must be cooled to a temperature below the saturation point.

THUNDERSTORMS

We are all familiar with the afternoon or evening thunderstorms which frequently occur on a hot day during which there has been little or no wind. Intense convection currents have been set up as a result of these conditions. Warm air rises, reaches the condensation point, and forms a cumulus cloud. If the condensation is rapid, a cumulo-nimbus cloud is formed. Cold air rushes down in the rear to replace the rising warm air, forming a squall and a violent wind. Just before the storm, the barometer falls due to the rising air. As the center of the storm approaches, gusty winds are noticed and a heavy downpour of large raindrops occurs, finally settling down to a steady rain. When the storm reaches the observer the barometer begins to rise as the cold descending air rushes forward. After a lightning flash, the small electrically charged drops coalesce and we have a violent downpour of rain or hail. The passage of the thunderstorm is accompanied by a rapid fall in temperature.

Thunderstorms cannot occur unless there has been a great evaporation of moisture with resulting high humidity. They may occur at any time of day and in any season, even during the winter, although the temperate zones do not have thunderstorms very often in winter because high humidity and rapid evaporation are usually absent.

High Pressure Areas (Anticyclones)

There are also regions of cool descending air known as "high" areas because of the high air pressure and the high barometric reading. In the center of the highs and lows the motion of the air is vertical. Usually highs that follow lows bring clear weather while lows that follow highs cause stormy conditions. Winds about a low area shift in a counter-clockwise direction and those about a high area shift in a clockwise direction.

Humidity

The amount of moisture in the air depends upon the temperature. By moisture in this connection we mean invisible gaseous water vapor, rather than rain, fog, or water in any liquid state. (See Appendix IV for the relationship between temperature and maximum water vapor content.)

The *absolute humidity is expressed as the amount of water vapor present either as grains per cubic foot or grams per cubic meter. More commonly we use the term relative humidity. Relative humidity is the amount of water vapor in unit volume of space compared to the total amount that could be contained in unit volume under the same conditions*

of temperature and pressure. It is expressed as a percentage. For example, Appendix IV shows that at a temperature of 69° F., the saturation amount is 18.14 grams per cubic meter. If the amount actually present is 9.07 grams per cubic meter, the relative humidity is 50 per cent. Or, if the saturation amount at 70° F. is 8 grains per cubic foot and the amount actually present is 2.4 grains per cubic foot, the relative humidity is 30 per cent.

Even in air which seems very dry, as air over a desert, there is some water vapor. The desert in northern Africa has an average relative humidity of 10 per cent. Because of the low water vapor content, the temperatures on the Sahara desert often range from 130° F. in the daytime to below freezing at night. Water vapor acts like a blanket to prevent excessive heating of the earth in the daytime and to check excessive radiation of heat at night.

Water vapor also prevents excessive evaporation. During the summer of 1949 part of the United States experienced a drought. Plant life dried out to such an extent that it died. This was due to the excessive evaporation from the leaves. Plants such as cacti whose habitat is a dry region are protected against excessive evaporation by having small leaves (spines and needles) and few stomata.

It is correct to state that the air is saturated with moisture. We must remember, however, when we speak of a cubic meter of air holding a certain amount of water vapor, that we really mean a cubic meter of space. *One must not forget that water vapor is a colorless gas and not a liquid.* It is incorrect to say that the "air is full of water." If we look into a teakettle when steam is issuing from the spout, we see nothing but water. The water vapor above the water is invisible. When the steam issues from the spout it changes to water and becomes visible.

CONTROL OF BODY TEMPERATURE

The amount of water vapor surrounding us has such a great influence on our comfort that we frequently confuse temperature with humidity. We are endowed with several methods for increasing or decreasing body heat in order to maintain a rather constant temperature of about 98.6° F.

One of these methods is the evaporation of water, called perspiration, from the skin. When the humidity is high, perspiration does not readily evaporate from the skin, just as clothes fail to dry when hung out on a day having excessive humidity. As a result, body heat is not dissipated. We feel warm, damp, and uncomfortable. In warm weather much moisture comes to the skin. Most physicians feel that a humidity of about 40 per cent at a temperature of 68° F. is most satisfactory. To attain this condition is one of the aims of air-conditioning apparatus (see p. 178).

MEASUREMENT OF HUMIDITY

Some materials are quite sensitive to moisture. They may shrink, stretch, or change color with changes of humidity. Devices which are reasonably accurate for measuring relative humidity can be made from them. One such device, the hair hygrometer, is made by fastening one end of a long hair to a rigid box and the other end to a wheel kept under tension by a spring. As the hair stretches, the spring curls it around the wheel. As the hair shrinks the spring unwinds. A long human hair which has had its oil removed by alcohol is frequently used. Human hair changes its length by $\frac{3}{120}$ when transferred from dry to saturated air. Such devices are not very accurate and are really *humidiguides*. They indicate the humidity but cannot predict the weather. Their value as weather prophets depends upon the fact that the humidity is usually greater in a low pressure area than in a high pressure area. They are often made in the form of novelties, one of which is the familiar little doll which moves in and out of a house as weather changes are expected. The chemical garden is another illustration of the effect of humidity.

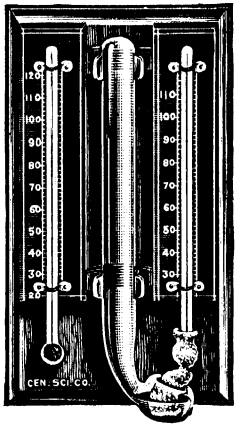


FIG. 108. Wet and dry bulb hygrometer. (Courtesy, Central Scientific Company.)

Relative humidity may be measured to an accuracy of within 5 per cent by wet and dry bulb thermometers. There are several forms of this apparatus on the market (Fig. 108). The dry bulb measures the actual room temperature. The bulb of the other thermometer is covered by a wick which is soaked in water. In very dry air, moisture evaporates rapidly from the wick, lowering the bulb temperature. If the humidity is high, there is a slow evaporation and only a slight depression of the thermometer. If the air is saturated, both thermometers will read the same since no evaporation can take place. It is important to emphasize that the difference in temperature is not a direct measure of the relative humidity. Tables must be used for a humidity determination. (See Appendix III.)

PRECIPITATION

DEW. After sunset some of the heat of the land is radiated out into space. As the air immediately in contact with the ground becomes cooled below the saturation temperature, moisture is often condensed as dew on the ground. Many people use the expression, "The dew is falling." Dew does not fall, but is produced by condensation of water vapor on objects because of the cooling of the air around the objects. In fact, dew may rise

from the earth! Dew is not often found on cloudy nights, because the clouds act as a blanket to hinder the radiation of heat from the earth. On windy nights the air does not remain in contact with the ground long enough to reach the dew point. *The temperature at which the air becomes saturated is known as the dew point.*

A person wearing spectacles often finds that the glass becomes covered with a film when he goes from cold air into a heated building. The lenses are at a temperature below the dew point of the room and the water condenses. We often find dew condensed on a glass of ice water on a summer day when the humidity is high. The air immediately in contact with the glass has been cooled below the dew point and water condenses on the surface. Since the dew point is a measure of the amount of water vapor in the air, we can calculate the relative humidity by determining the dew point (see p. 181).

FROST. Frost is composed of ice crystals which are formed when the dew point is below the freezing point of water. The water vapor then changes directly to ice crystals. Contrary to popular belief, frost does not kill plants. The killing is due to the unequal and sudden expansion of the sap which takes place on freezing. Hoar frost is formed when very humid air is in contact with objects which are below the freezing point; it covers trees, fences, and higher objects, and is thicker than ordinary frost.

FOG. Fog is formed when rather humid air in gentle horizontal motion is cooled below the dew point. Dust particles aid in the formation of fogs, which accounts for the fogs which form in London and other cities on clear mornings after work has started in the factories. Fogs over the ocean south of Newfoundland are due to warm moisture-laden air blowing from the Gulf Stream across the cold southward-moving Arctic Drift which passes under the Gulf Stream in that locality (see p. 99). The individual fog particles are of submicroscopic size, they may coalesce to form larger particles which fall as rain, or they may evaporate as the air becomes warmer. An interesting use of fog is in the study of charged particles such as electrons and alpha rays. This use is discussed in Chapter 13.

RAIN AND HAIL. Rain is formed by rapid condensation of water vapor. The character of the storm determines the size of the drops. Rapid summer convection currents form large drops, while the whirling currents of winter air or strong winds produce small rain particles. Raindrops freeze, forming sleet when falling through air which has a temperature below 32° F. Hail is produced during storms when drops of water are carried by the convection currents into a stratum of air cold enough to freeze them. As they become heavy they fall back into lower altitudes and become covered with water, and upon being hurled upward again, receive another coat of ice and snow. The hailstones soon grow so large that they are too heavy for further tossing upward and they fall to the ground. The

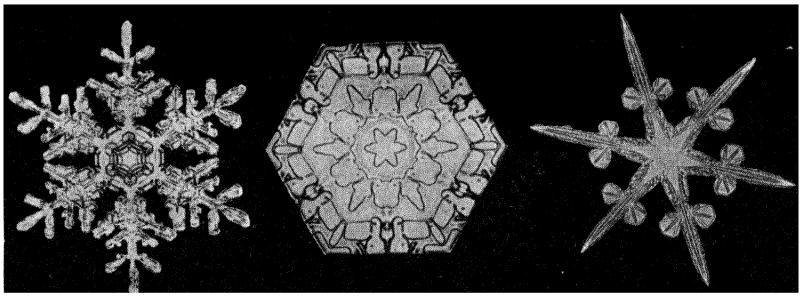


FIG. 109. All snowflakes are hexagonal crystals. (Courtesy, Science Service.)

size of the stones may be as much as an inch in diameter. By slicing a hailstone one may see the successive layers of ice.

SNOW. Snow is the result of condensation at a temperature below 32° F. In other words, rain forms and falls as liquid water, sleet forms as a liquid but freezes before it reaches the ground, snow crystals are formed in freezing air and reach the ground in a crystalline state. Each snowflake grows into a beautiful six-pointed crystal as it is being formed. The flakes are crystals of ice in which the atoms are arranged in a definite order. Snow is produced by a direct freezing of water vapor. Over one hundred thousand separate flake forms, all variants of the six-pointed crystal, have been noted. Our knowledge of snowflake patterns is largely due to the work of Wilson Bently of Jericho, Vermont, who made a hobby of photographing the flakes under a microscope. Fig. 109 shows a few of his pictures. Snowflakes can be produced in the laboratory.

CLOUDS. It may seem strange to describe clouds in connection with precipitation, but clouds actually consist of water droplets, snowflakes, or ice crystals sustained in the air by convection currents or wind. There are three basic types of clouds—*cirrus*, *stratus*, and *cumulus*. The name nimbus is applied to a cloud from which rain is falling. Cumulus clouds are the light, fluffy, flat-bottomed clouds which often appear during an afternoon. They have a top which shines in the sunlight. Such clouds are formed by condensation of moisture as the temperature of the rising air falls below the dewpoint, usually a mile or so above the ground. The cumulo-nimbus is the towering shower cloud of the thunderstorm type (Fig. 110). Cirrus (curl) clouds consist of ice particles and are often 5 or 6 miles high (Fig. 111). As a rule they are thin, beautiful, feathery in form and sometimes cause the haloes around the moon and sun. Cirro-cumulus clouds, 2 to 4 miles high, give the appearance of a "mackerel" sky (Fig. 112). Stratus clouds, as the name suggests, seem to be in layers or streaks. They may be rather close to the earth and are often accompanied by rain. Fog is a stratus cloud on the earth. The nimbo-stratus clouds are the usual rain clouds (Fig. 113).

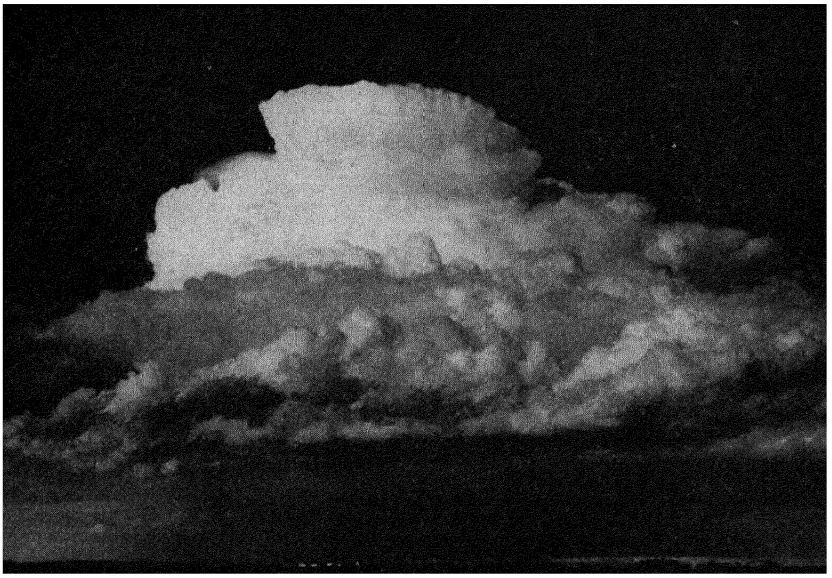


FIG. 110. Cumulo-nimbus cloud. (Courtesy, U.S. Weather Bureau and H. T. Floreen.)



FIG. 111. Cirrus clouds. (Courtesy, U.S. Weather Bureau and J. W. Johnson.)

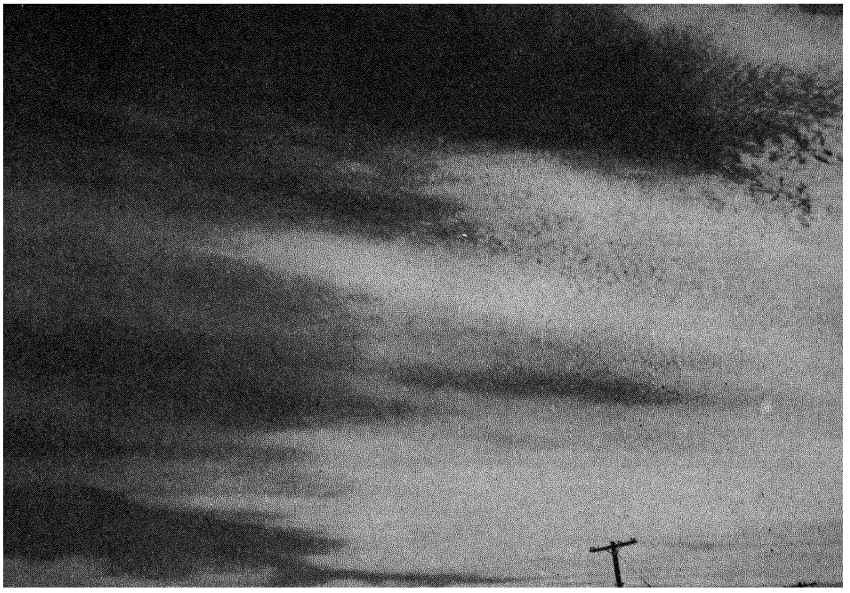


FIG. 112. Cirro-cumulus clouds. (Courtesy, U.S. Weather Bureau and U.S. Army Photo Section.)



FIG. 113. Nimbo-stratus clouds. (Courtesy, U.S. Weather Bureau and C. F. Brooks.)

Weather

The term weather includes atmospheric conditions, such as temperature variations, pressure changes, winds, clouds, and precipitation. A very close correlation has been found to exist between variations in solar radiation and weather. Several stations have been established to study the hourly variations in solar radiation. One of these stations is in California, one in Chile, and one in Africa. They must be located where there is a maximum of sunshine and a minimum of dust and haze.

Another cause of weather irregularities is the polar air. Many of the storms which sweep over the United States seem to originate in Alaska. From "Greenland's Icy Mountains" weather receives further stimulation. Low pressures which leave the United States as gentle breezes become fiendish storms after passing south of Greenland. This may be due to the continual high pressure existing on Greenland.

Air Masses. Modern weather study makes use of the theory of air masses. An air mass is a large body of air having rather uniform characteristics throughout a horizontal layer. North America and the adjacent oceans are the sources of nine distinct air masses, of which four—Tropical, Arctic, Polar, and Superior—are important in the United States. These air masses originate in tropical and polar regions and are carried along by the circulation of the atmosphere. Much of our weather is due to the effect of cold masses moving over warm ground, and warm masses moving over cold ground.

The air masses which are common in North America include polar, tropical, and arctic air masses which originate over the continent—(cP), (cT), and (cA)—and the polar and tropical masses which originate over water—(mP) and (mT). As these masses move over the surface of the earth they are modified by the temperature of the region over which they pass. If the air mass is warmer than the surface over which it moves the letter *w* is added, hence (cTw). Likewise the letter *k* is used to represent a layer colder than the surface over which it passes (cPk). The cold air masses occurring in the United States originate in the Arctic regions. They are cold and relatively dry because they have overlain frozen surfaces for long intervals. Consequently, continental polar air from Canada brings clear weather with good visibility. As these masses move southward over the warmer land, the air of the mass becomes warmer (cPk). The warm air masses are usually of oceanic origin since the continent in the region of Central America is of small area. There are, however, continental tropical (cT) air masses which produce the dry hot air lying over the southwestern part of the United States. This partly explains the scanty rainfall of the states in that region. In case this air moves northward it causes the extreme heat and droughts of the Central Plains States.

A typical maritime tropical air mass (mT) such as one which originates

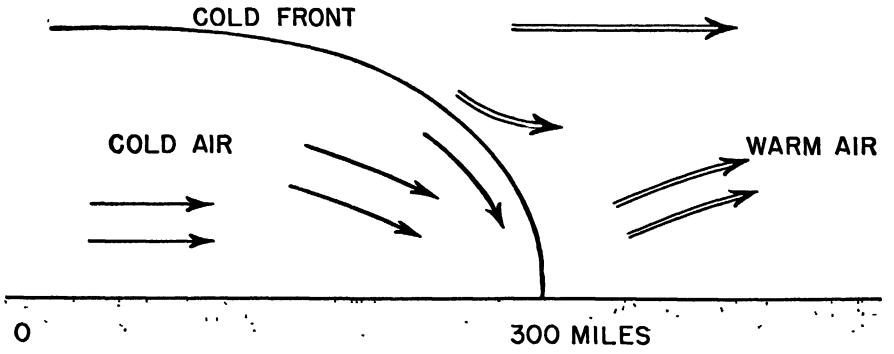


FIG. 114. A cold front. In some cases the warm air moves toward the cold air mass. The cold mass always tends to underrun the warm air.

in the Gulf of Mexico usually is accompanied by high temperature and humidity. The weather is often foggy or there may be drizzle. The air is oppressive and muggy. On the other hand, a typical maritime cold air mass (mP) along the coast usually is accompanied by rising temperatures, increasing humidity, and heavy showers of short duration.

As these air masses move over the surface of the earth, two or more of them may meet. They do not mix readily since the air layers have different densities. The boundary between them is called a *front*. If a dense continental polar mass moving from the northwest meets a maritime tropical mass moving from the southeast, the cold layer tends to slide under the warmer layer. The boundary of a cold polar mass moving into an area occupied by a warm mass is a *cold front*. This motion of the masses produces the *cyclonic* air motion.

Fig. 114 illustrates the action when the cold air is displacing the warm air—a *cold front*. In contrast, Fig. 115 illustrates the action of a warm air mass producing a *warm front*.

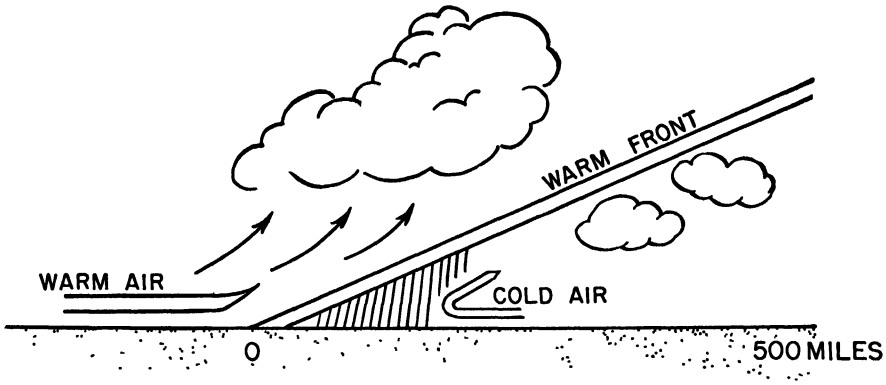


FIG. 115. A warm front. The actual conditions are only partially illustrated by this simplified drawing. The warm air mass overruns the cold air.

WEATHER MAPS

Each day the Weather Bureau issues a chart giving weather predictions and weather conditions for the entire country. The map is marked with black lines (isobars) drawn through locations of equal barometric pressure. The pressure is shown in millibars rather than in inches. (One inch equals 33.86 millibars.) The other weather conditions are given in a symbol system at each station on the map.

It will be helpful to emphasize some important facts about the two maps shown in Figs. 116 and 117. On the first map, that of February 11, a maritime polar mass (mP) lies in the region of the state of Idaho. The weather is moderate there.

A continental Arctic mass (cA) lies over North Dakota. As would be expected, the weather is clear and cold in that part of the country. A continental polar mass (cP) exists in Texas. A cold front exists over New England and the Atlantic seaboard.

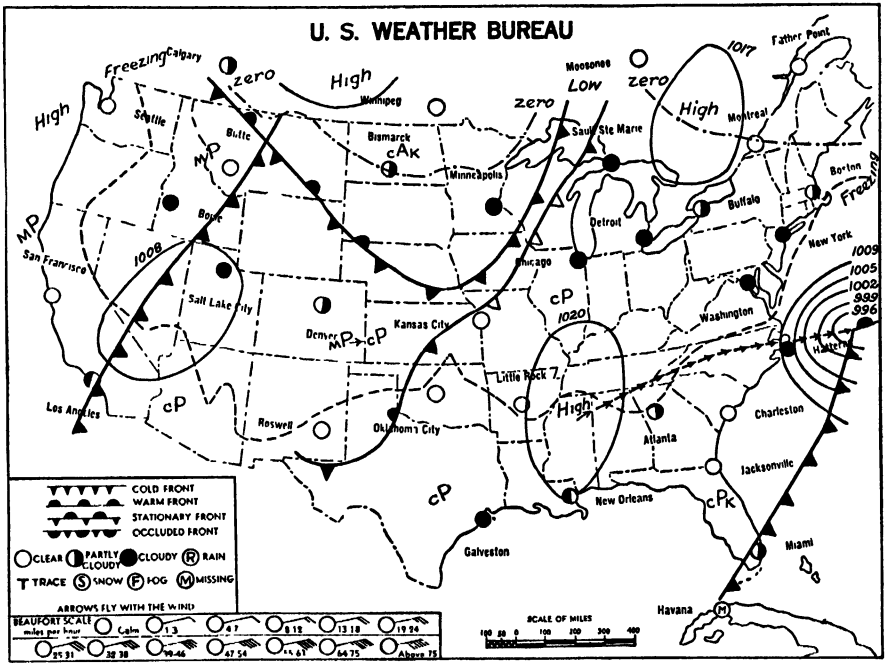
On the following day, February 12, the maritime polar mass (mP) has moved to Wyoming. Illinois has a continental polar mass. The eastern part of the country has a high pressure area.

Several fronts are shown—a stationary front in the northwest, a cold front in the west central states, and a warm front in the east central states.

WEATHER FORECASTING. The Weather Bureau receives two weather reports each day from a network of several hundred stations covering the entire North American Continent. Such reports give barometric pressures, temperatures, wind velocity and direction, precipitation, and type of weather. In addition, reports are also received from vessels in coastal waters.

The tremendous advances in aviation during the years 1940–1949 have made necessary an extensive airway meteorologic system. The study of the weather over the continents and oceans requires many upper air observation stations. In addition, each airport must prepare complete information on the flying conditions over a large area. Meteorologists at the terminals receive reports from the planes en route, and by additional air observations prepare charts for a quick analysis of the weather. The invasion of Normandy in 1944 was timed to coincide with a forecast of the weather over the English Channel. Airway reports include visibility, precipitation, fog, haze, thunderstorms, and temperature.

GENERAL WEATHER INDICATIONS. The United States lies in the belt of *prevailing westerlies*, hence the storm areas usually travel from west to east. The weather forecasts are based largely on the weather to the west and to the south of us. Numerous factors, such as proximity to the cyclonic and anticyclonic areas and differences in temperature, pressure,



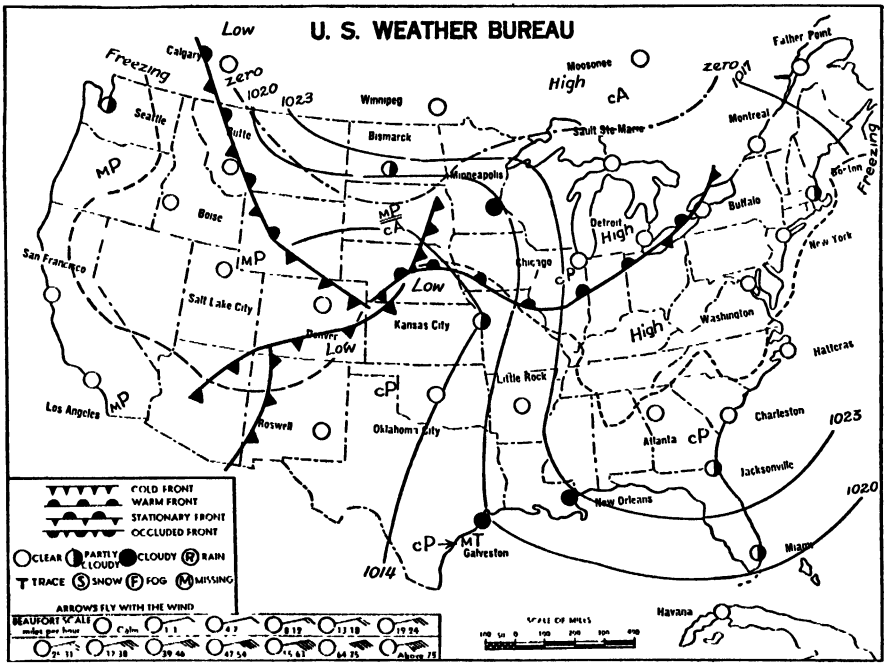


FIG. 116. (*Top*) A weather map (February 11).
FIG. 117. (*Bottom*) Weather conditions 24 hours later (February 12).

and topography, must be considered in making the prediction. It must be remembered that many changes take place in the air masses as they progress across the continent. If polar air lies over southern Canada, and the most of the United States is covered with warm air, the temperature lines are crowded together on the map. These warm and cold fronts in close proximity are essential factors in the development of lows.

About 60 per cent of low barometer areas are first noticed in the northwest. These lows usually move eastward and pass into the Atlantic Ocean off the coast of New England.

By means of the weather predictions fruit growers and farmers can protect their crops from frost and heavy rainfall, firewardens can guard against forest fires, and floods and hurricanes can be anticipated.

Although accurate weather forecasting is impossible for more than a few hours in advance, there are certain phenomena which do seem to give information concerning imminent weather changes.

We quote from the weather map as follows:

"When the wind sets in from points between south and southeast, and the barometer falls steadily, a storm is approaching from the west or northwest and its center will pass near or north of the observer within 12 to 24 hours, with winds shifting to northwest by way of south and southwest. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest and its center will pass near or to the south of the observer within 12 to 24 hours with wind shifting to northwest by way of north."

The wind and barometer indications for the United States are generally summarized in Table 9 (prepared by the Weather Bureau.

The Weather Bureau performs excellent service in forecasting weather. Some curious mistakes often occur. On the occasion of the inauguration of President Taft on March 4, 1909, the Weather Bureau predicted fair weather. They felt safe in making the prediction inasmuch as the entire country had a fairly high pressure. Consequently, thousands of people flocked to Washington for the inauguration. On the evening of March 3, a small low developed in the Carolinas, so that by the morning of the inauguration, the streets of Washington were covered ankle-deep in slush, and rain was falling. The visitors suffered much inconvenience, and as a result, the newspapers subjected the Weather Bureau to a good deal of friendly ridicule.

Why are east winds an indication of rain, and is this method of forecasting accurate? A low is the center of low air pressure; air is flowing into it from all directions. The low moves eastward. As it arrives within approximately 500 miles to the west of us, we begin to notice the movement of air toward it (east wind). The Eastern United States and Eastern Canadian winds are moisture-laden but, since this air becomes warmer and

Table 9

WIND AND BAROMETER INDICATIONS

Wind Direction	*Barometer Reduced to Sea Level*	*Character of Weather Indicated*
SW. to NW.	30.10 to 30.20 and steady	Fair with slight temperature changes, for 1 to 2 days
SW to NW.	30.10 to 30.20 and rising rapidly	Fair, followed within 2 days by rain
SW. to NW.	30.20 and above and stationary	Continued fair, with no decided temperature change
SW. to NW.	30.20 and above and falling slowly	Slowly rising temperature and fair for 2 days
S. to SE.	30.10 to 30.20 and falling slowly	Rain within 24 hours
S. to SE.	30.10 to 30.20 and falling rapidly	Wind increasing in force, with rain within 12 to 24 hours
SE. to NE.	30.10 to 30.20 and falling slowly	Rain in 12 to 18 hours
SE. to NE.	30.10 to 30.20 and falling rapidly	Increasing wind, and rain within 12 hours
E. to NE.	30.10 and above and falling slowly	In summer, with light winds, rain may not fall for several days. In winter, rain within 24 hours
E. to NE.	30.10 and above and falling rapidly	In summer, rain probable within 12 to 24 hours In winter, rain or snow with increasing winds will often set in when the barometer begins to fall and the wind sets in from the NE.
SE. to NE.	30.00 or below and falling slowly	Rain will continue 1 to 2 days
SE. to NE.	30.00 or below and falling rapidly	Rain with high wind, followed, within 24 hours by clearing, and in winter by colder
S. to SW.	30.00 or below and rising slowly	Clearing within a few hours, and fair for several days
S. to E.	29.80 or below and falling rapidly	Severe storm imminent, followed, within 24 hours, by clearing, and in winter by colder
E. to N.	29.80 or below and falling rapidly	Severe northeast gale and heavy precipitation, in winter, heavy snow, followed by a cold wave
Going to W.	29.80 or below and rising rapidly	Clearing and colder

expands as it approaches a low, it rises and becomes cooled below its saturation point. Hence we see that an east wind heralds the approach of a storm area.

AIR CONDITIONING

It can no longer be said of the weather that "everybody talks about it but nobody does anything about it." The scientific business of air conditioning (artificial weather making) is now very important. Unsatisfactory atmospheric conditions lower human efficiency, initiate illness, destroy property, and cause great discomfort. In winter, the air needs to be

heated and humidified. In summer, we require cool air which has moderate humidity. At all times we need circulating, clean air. For these reasons, office buildings, theaters, railroad coaches, department stores, and homes are being equipped for controlled air conditions.

Air conditioning has been defined as the science or process of maintaining any desired temperature, purity, moisture content, and air motion within an enclosure. Man's first attempt at air conditioning was an open fire in a cave. This was followed by fireplaces, stoves, furnaces, and electric heaters. These raised the temperature, but did not attempt to improve other factors. Until comparatively recently, few attempts were made to provide proper humidity. Many people have attempted to increase humidity by placing pans of water on the stove and by using water jackets in the hot air furnace. It was impossible to provide proper humidity by such hit-or-miss methods. It would be necessary to evaporate several gallons of water each day to provide proper humidity by such devices.

In the ordinary home in the winter, cold air having a rather low humidity is heated without the addition of moisture. *This means that the relative humidity is lowered. For example, if we bring outdoor air having a relative humidity of 70 per cent at 41° F. into the room, the vapor density table, Appendix IV, shows that the room contains 70 per cent of 6.76 Gm. of water vapor per cubic meter, or 4.732 Gm. If we heat this air to 69° F. without the addition of moisture, the relative humidity is now only 4.732/18.14 or 26 per cent. We have lowered the humidity by heating the air.*

Conversely, if we have air at 69° F. and 70 per cent humidity (12.79 Gm./cu. m.) and cool the air to 50° F. and again increase the temperature without the addition of moisture, the vapor density table tells us that the amount of moisture has decreased to 9.33 Gm./cu. m. The relative humidity is now 51 per cent.

Most authorities agree that the best conditions for comfort are a temperature of 68° F. and a humidity of 40 per cent.

Body warmth is influenced by humidity and air circulation as well as by temperature. This is determined by the rate of evaporation of moisture from the body surface. Thus we are cooler in hot, circulating dry air than in nearly saturated air at a lower temperature. For example, air at 90° F., and 20 per cent relative humidity is more comfortable than air at 75° F., and 70 per cent relative humidity. Conditioning engineers use the term *effective temperature* to include all the factors just mentioned. We have all been aware of discomfort when sitting in a closed theater which was not air conditioned. The feeling of lassitude and depression is due to a combination of high temperature, high humidity, and a poor circulation of air in the room. On the other hand, a low humidity causes a rapid evaporation of perspiration.

AIR-CONDITIONING EQUIPMENT. Three types of air conditioning are in use: ice, steam jets, and mechanical refrigeration. Some railroads are using all three in an attempt to determine the most satisfactory and economical process. In the ice system used on the Pennsylvania Railroad, water is cooled by spraying it over cakes of ice. The cold water is pumped into cooling tubes, over which the air of the car flows. This method is probably the most economical, but the necessity for frequent icing is a disadvantage. In mechanical refrigeration[1] a refrigerant such as "Freon" is used to chill the evaporator surface. The air is blown over this surface. In the "steam-jet" method a steam jet produces a vacuum of about 29 inches in an insulated chamber. Water is sprayed into the chamber, and because of the rapid evaporation, the water becomes chilled and is passed through cooling pipes over which air flows.

In all cases, air having a high humidity is cooled below its dew point so that the air leaving the apparatus has a lower *absolute* humidity than it had when it entered. As this air is circulated through a building, the humidity is low enough for evaporation of perspiration to take place rapidly. During cold weather, air is passed over heated pipes as it leaves the humidifier so that the temperature and humidity are both raised.

The problem of dust removal is a vital part of air conditioning. If the air is bubbled through cold water, the dust is removed at the same time the humidity is lowered. Many large office buildings furnish relief for hay-fever sufferers by removing the dust and pollen from the air. Not only must the air be cleaned and cooled, but it must be circulated by large fans.

Some of the important users of air conditioning are hospitals, theaters, flour mills, bakeries, and paint shops. Any restaurant which can advertise that it has an air-conditioned room is certain to increase its patronage. Many large department stores have air conditioned all or part of the plant.

Unfortunately, the cost of complete home air conditioning is still beyond the purse of the average home owner. Perhaps it may be possible to bring the cost down and if this can be done we shall be able to produce the type of weather we want by a flip of a switch. We *are* doing something about the weather.

REFERENCES

Bentley, Alwyn, and Humphreys: "Snow Crystals," New York, The McGraw-Hill Book Co.

Blair: "Weather Elements," New York, Prentice-Hall, Inc.

Brooks: "Why the Weather?", New York, Harcourt, Brace and Co.

Free and Hoke: "Story of the Weather," New York, Robert M. McBride and Co.

Humphreys: "Physics of the Air," New York, The McGraw-Hill Book Co.

Kendrew: "Climates of the Continents," New York, Oxford University Press.

[1] Mechanical refrigeration is often spoken of as electric refrigeration. (See p. 310.)

Milham: "Meteorology," New York, The Macmillan Co.
Piston: "Meteorology," Philadelphia, The Blakiston Company.
Tannehill: "Hurricanes," Princeton, Princeton University Press.
Van Cleff: "Story of the Weather," New York, D. Appleton-Century Co.
"Air Conditioning Systems for Passenger Trains," Pennsylvania Railroad.

Topics for Discussion

Humidiguides	Hurricanes	Sargasso Sea
Air Conditioning	The Climate of the Tropics	Typhoons
Tornadoes	Monsoons	Air Mass Analysis

Questions and Problems

1. Explain the cause of: the Great American Desert; the Sahara, the Australian Desert.
2. Explain why moderate humidity is more comfortable than high humidity regardless of the temperature.
3. Is low humidity in schoolrooms harmful?
4. Why does an east wind usually indicate the approach of rain?
5. What does the wet bulb read if the relative humidity is 76 per cent at a time when the temperature of the air is 80° F.? Answer: 74° F.
6. Why is there, usually, no frost on a windy night?
7. Explain the frequent fogs off the coast of Labrador.
8. Why does the Gulf Stream moderate the climate of England but not that of Canada?
9. Why is it incorrect to say that dew rises or falls?
10. Describe three methods of conditioning the air.
11. What are: the doldrums? the horse latitudes?
12. Describe the wind cycle which causes the trade winds.
13. Why do the trade winds blow from the northeast instead of from the north?
14. What is: a cyclone? a typhoon?
15. Explain the causes of a thunderstorm.
16. What is meant by: relative humidity? absolute humidity?
17. What causes. snow? frost? sleet? hail?
18. What is meant by air conditioning?
19. What is: a hygrometer? a humidiguide?
20. Explain why we may lower the humidity by "washing" the air with cold water.
21. What is the origin of the prevailing westerlies? Why do they move toward the northeast?

Experiments

1. Use an air convection apparatus. Hold a smouldering stick over a lighted candle under one opening and then cover the other opening of the convection apparatus. How does this explain highs and lows?
2. Put two or three drops of water on a wooden block. On this, place a watch glass and fill it with ether. Fan it vigorously until the ether has evaporated. The crystal should freeze to the block. Explain.
3. Determine the relative humidity of the room by the dew point method. Place water and a small piece of ice in a clean, shining, metal can, the outside of which must be perfectly dry. Stir the water carefully. The instant that a film of water appears on the outside of the can, read the temperature of the water. Remove the ice, continue to stir, and note the temperature at which the moisture just dis-

appears. Perform this test several times. An average of the readings is the temperature at which the air in the room would be saturated with moisture. Suppose that the average reading is 59° F. By referring to Appendix IV, we see that at 59° the maximum weight of water possible is 12.71 Gm. per cubic meter. Suppose the actual temperature of the room, however, is found to be 80.6°, and at this temperature there can be as much as 25.49 Gm. of water vapor present per cubic meter. In other words, at a certain time the temperature of the air in the room is 80.6° and so there may be possibly 25.49 Gm. of water present, but we find that there are actually only 12.71 Gm. present.

$$\text{Relative humidity} = \frac{\text{Weight of water vapor found per cubic meter}}{\text{Weight of water vapor possible per cubic meter}}$$

$$= \frac{12.71}{25.49} = 50 \text{ per cent}$$

NOTE: During the winter, the absolute humidity in some schoolrooms may be so low that the dew point is below 32° F. In this case no moisture will condense on the can and the relative humidity must be determined by the use of ether.

4. Determine the relative humidity by the wet and dry bulb thermometer (see Appendix III).
5. Procure a weather map and answer the following questions about a city east of the Mississippi, about a city along the Gulf of Mexico, and about some location in the Far West.
   What type of air mass covered the region?
   What was the temperature?
   What was the pressure?
   Was it raining?
   Had there been rain within 24 hours?
   What was the wind direction?
   What was the probable weather for the following day?
   This exercise is more profitable if maps for three consecutive days are studied and the weather then forecast. A fourth map can be used to check the accuracy of the forecast.
6. Collect hourly data as to temperature, pressure, and sky for an entire school day. Make a forecast of the weather for the following day. On the following day, try to see why you missed your prediction or why your prediction was correct.
7. Secure information concerning the various types of air-conditioning apparatus. Visit the local theater, the hospital, the department store. Secure information from your local railroad agent about air-conditioned trains.
8. Study the air masses on the maps given you.

13. THE ATOM AND ITS RADIATIONS

All things the world which fill
Of but one stuff are spun.

The Atom

Men have always wondered about the constituents of substances. We know that we can cut an iron wire into many small pieces. Is there a limit to which we can subdivide or is the wire so constructed that there is no limit to the possibility of subdivision?

The Theory of Limits in geometry teaches us that if we cut a line in half, there is a possibility of continuing to divide it in half forever. Some of the ancient Greeks taught that all objects were composed of small individual atoms, which were indivisible. This means that the iron wire can be subdivided only to the extent that the atoms are isolated. On the other hand, Aristotle taught that one could chop a substance into finer and finer bits, never reaching an end.

Sir Isaac Newton also believed that all materials were composed of small hard particles which could not be divided. In 1806 John Dalton, an English chemist and schoolmaster, put forth the atomic theory of matter. From his experiments, he concluded that each element was composed of ultimate, indivisible particles and that the particles of different elements differed in weight. Moreover, he concluded that the atoms combined to form molecules (little heaps) and that these molecules were the building stones of chemical compounds. Unfortunately, these atoms are not visible to the eye, because of the limitations of the eye and of the microscope. Most experimental evidence leads us to believe that an atom is about 10^{-8} cm. in diameter. This means that an atom compares to a baseball as a baseball compares to the earth. We can study the properties, but we have never observed the actual appearance of these tiny bits of matter.

The ability to see a tiny object placed under a compound microscope depends not only on the magnifying power but also on the property known as the resolving power of the instrument. The resolving power is defined as the ability of an optical instrument to enable the eye to distinguish as separate two objects which are close together. Although the resolving power increases as the color of the light used to illuminate the object changes from yellow to violet (the resolving power increases as the wave length of the light decreases), it is not possible to see an object

Table 10

PERIODIC SYSTEM OF THE ELEMENTS

	A I B	A II B	A III B	A IV B	A V B	A VI B	A VII B	A VIII	B	
1	1 H 1.0080								2 He 4.003	
2	3 Li 6.940	4 Be 9.02	5 B 10.82	6 C 12.010	7 N 14.008	8 O 16.0000	9 F 19 00		10 Ne 20.183	8
3	11 Na 22.997	12 Mg 24.32	13 Al 26.97	14 Si 28.06	15 P 30.98	16 S 32.066	17 Cl 35.457		18 A 39.944	8
4	19 K 39.096	20 Ca 40.08	21 Sc 45.10	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.93	26 Fe 55.85 / 27 Co 58.94 / 28 Ni 58.69		18
	29 Cu 63.54	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74 91	34 Se 78.96	35 Br 79.916		36 Kr 83.7	
5	37 Rb 85.48	38 Sr 87.63	39 Y 88.92	40 Zr 91.22	41 Cb 92.91	42 Mo 95 95	43 Ma	44 Ru 101.7 / 45 Rh 102.91 / 46 Pd 106.7		18
	47 Ag 107.880	48 Cd 112.41	49 In 114.76	50 Sn 118.70	51 Sb 121.76	52 Te 127.61	53 I 126.92		54 Xe 131.3	
6	55 Cs 132.91	56 Ba 137.36	Rare Earths	72 Hf 178.6	73 Ta 180.88	74W 183.92	75 Re 186.31	76 Os 190.2 / 77 Ir 193.1 / 78 Pt 195.23		32
	79 Au 197.2	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 209.00	84 Po 210 *ca.*	85 Ab 211.		86 Rn 222.	
7	87 Fa 224 *ca.*	88 Ra 226.05	89 Ac 227 *ca.*	90 Th 232.12	91 Pa 231.	92 U 238.07	93 Np 239 *ca*	94 Pu 239 *ca.* / 95 Am 241. / 96 Cm 242.		

RARE EARTHS

57 La 138.92	58 Ce 140.13	59 Pr 140 92	60 Nd 144.27	61 Il 146 *ca.*	62 Sa 150.43	63 Eu 152.0	64 Gd 156.9
65 Tb 159.2	66 Dy 162.46	67 Ho 164.94	68 Er 167.2	69 Tm 169.4	70 Yb 173.04	71 Lu 174.99	

as small as the atom is believed to be by means of the ordinary microscope.

The unaided eye cannot distinguish as discrete points two objects which are less than $\frac{1}{100}$ inch apart. By the use of the modern compound microscope, points separated by a distance of $\frac{1}{100,000}$ of an inch may be observed as discrete. Things become visible because of their disturbing effect on light waves. If an object is smaller than the wave length of visible light, it cannot be detected. By using the ultraviolet microscope, which gives a magnification of 2500 diameters, we may observe objects separated by a distance of four millionths of an inch. The electron microscope (see p. 349) gives magnifications of as much as 100,000 diameters. Its resolving power makes it possible for us to observe objects 80 billionths of an inch apart.

BROWNIAN MOTION. One approach that scientists have made to the actual observations of atoms, molecules, and their motions is by the study of the Brownian motion in colloids (see p. 259). In 1827 a botanist, Robert Brown, placed under a microscope a small dish containing pollen in water. He noticed that the grains were in constant motion. Later, Perrin made colloidal suspensions of very small particles, each one containing several thousand atoms, constantly moving about in the liquid. The dust particles floating in a beam of sunlight also show this motion. It is possible to produce a colloidal suspension (see p. 259) of metals, such as gold, by allowing electric sparks to pass between two electrodes of the metal immersed in acidulated water. A very inexpensive piece of apparatus which can be placed on the microscope stage is now for sale. The cell is filled with smoke and illuminated by an arc lamp. It is possible to view the motions of the particles of smoke.

For convenience, the scientist makes use of the exponential number system of writing very large and very small numbers; e.g., one thousand is written 10^3, one million is written 10^6, and one millionth is expressed as 10^{-6}. Using this notation, the diameter of the atom is about 10^{-8} cm. There are about 6×10^{23} molecules in 2 Gm. of hydrogen. One cubic centimeter of a gas at 0° C. and 76 cm. pressure contains 2.7×10^{19} molecules.

PERIODIC TABLE

In 1869 the Russian scientist Dmitri Mendeléeff (Fig. 118) discovered certain relationships among the elements. He set them up in the form of a table. In his time the table contained 63 elements.

At present hydrogen is the first element in the table and curium is number 96. Elements with similar properties occur at intervals of 8, 18, or 32 as we progress along the table. For example, in column one, sodium (11), potassium (19), rubidium (37), and cesium (55) have similar properties. One column is occupied by the inert gases, helium (2), neon (10),

argon (18), krypton (36), xenon (54), and radon (86). This interesting similarity occurs quite generally. Of the elements, the seven metals, iron, copper, silver, tin, lead, gold, and mercury, were known in early times and were believed to be the only metals possible because of the sacred number, seven. Elements 93, 94, 95, and 96 are produced in the laboratory by the methods of artificial radioactivity (see Chapter 27). They do not exist in nature.

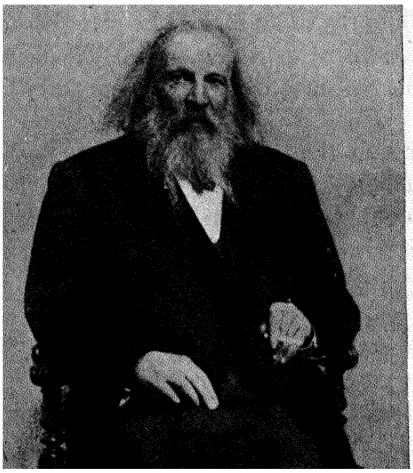


FIG. 118. Dmitri Mendeléeff (1834–1907). Discoverer of relationships among the elements. (Courtesy, Jones: "Inorganic Chemistry," Philadelphia, The Blakiston Company.)

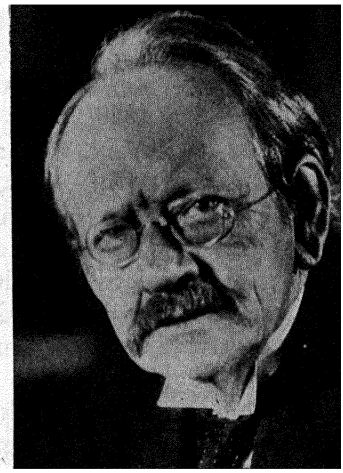


FIG. 119. J. J. Thomson (1856–1946). Discoverer of the electron; one of the originators of modern atomic theories. (Courtesy, Science Service.)

ATOM MODELS

Up to the beginning of the twentieth century, the atom was believed to resemble an elastic ball with a hard kernel somewhat like a toy balloon with a bean inside. In the period 1895–1897, a new epoch in the study of atoms was begun. During this period, J. J. Thomson (Fig. 119) discovered the electron; Henri Becquerel discovered that uranium was radioactive (emitting rays); and Konrad Roentgen discovered x-rays.

In order to study the electron, Thomson caused the cathode rays (those coming from the negative electrode) to move rapidly through a large evacuated tube (Fig. 120). By the use of a magnet, he proved that the cathode rays were a stream of negative particles (electrons) which constituted a current of elecricity (see p. 366). Robert Millikan, an American physicist, carried this work forward by the famous "oil-drop"

experiment, receiving the Nobel prize for his work. This experimenter sprayed small charged drops of oil into the space between condenser plates (Fig. 121). These drops were strongly illuminated and were moved up and down by applying high voltages (see p. 365). By means of this experiment, the amount of electrical charge contained in one electron was determined. (An electron has a charge of 1.6×10^{-19} coulomb.)

C. T. R. Wilson passed x-rays into a cloud chamber and photographed the tracks left by the electrons which were produced. If a gas is suddenly allowed to expand, it cools. If the expanding gas is saturated with water vapor and if it contains dust particles or ions, a fog may form around the particles. When electrons or alpha rays (helium ions) were passed

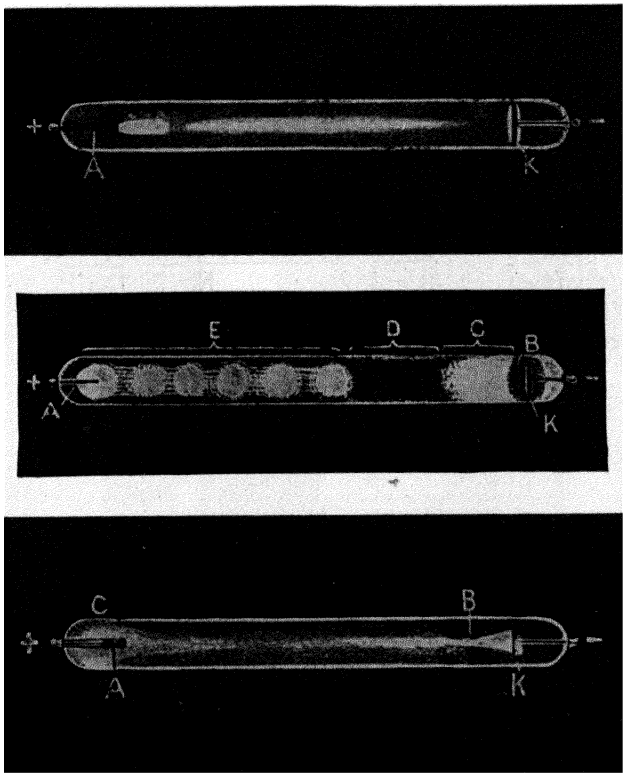
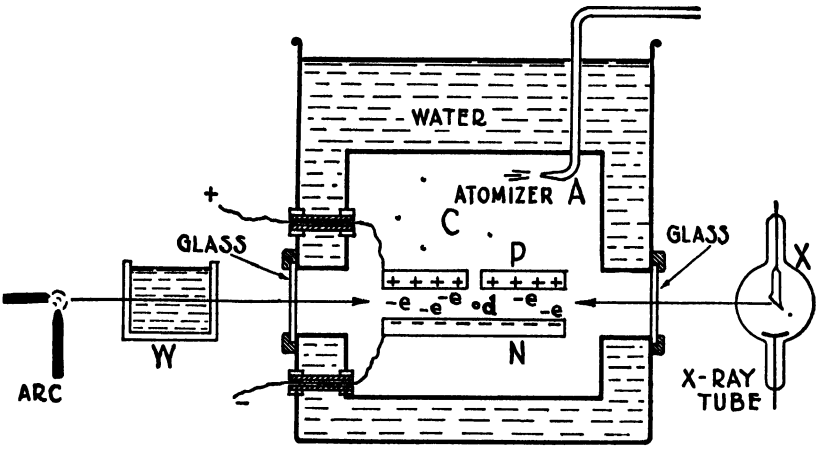


FIG. 120. Photographs showing the appearance of electrical discharge in air at reduced pressures. (*Top*) At a pressure of a few centimeters, a glow of light fills the tube. (*Center*) At a pressure of a few millimeters, we find a series of colored bands usually of a bright orange shade. (*Bottom*) When the pressure is reduced to less than .001 millimeter, the color in the tube has almost disappeared and in its place we find that the glass is shining with a yellow fluorescence, due to the impact of the stream of cathode rays (electrons) which are striking the walls. A and K are the anode and cathode, respectively. (Courtesy, Watson: "A Textbook of Physics," New York, Longmans, Green and Co., Inc.)

through the cloud chamber, ions were left in the trail and a fog formed on these ions as a thin white track. These tracks could be photographed. Figs. 122 and 123 illustrate a laboratory form of the apparatus. The tracks shown are those due to the passage of alpha rays. The tracks due to the electrons would be very irregular because of the small mass of the electrons.

At first, it was believed that electrons were small divisions of an atom with electrical charges on their surfaces. We now believe that an *electron is a particle of negative electrical charge.* The atom also seems



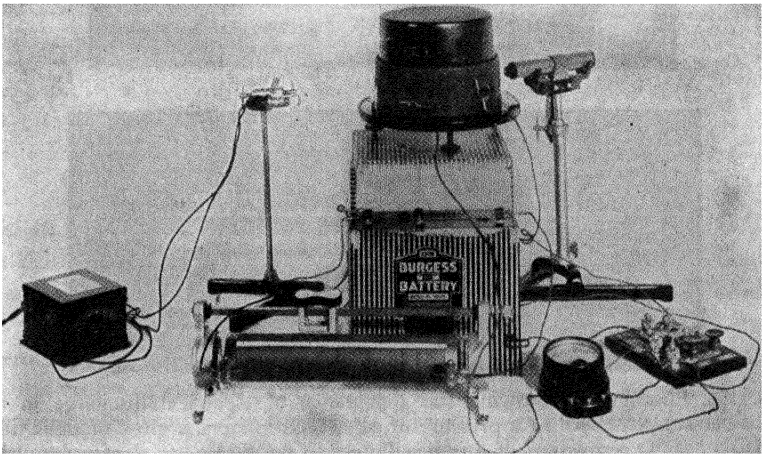


FIG. 121. (*Top*) A diagrammatic sketch of the oil-drop apparatus. P and N are the condenser plates. W is a heat absorbing water cell. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.) (*Bottom*) The oil-drop apparatus in operation. (Courtesy, Central Scientific Company.)

to contain a positively charged particle, the proton, which is 1835 times as heavy as the electron. These two units, with the addition of a neutron having about the mass of a proton but with no electrical charge, are believed to be constituents of every element in nature. Unfortunately, we do not yet know the exact nature of electrified particles. Nevertheless, with the discovery of the electron, it became evident that the atom was not the simple "chunk" of matter that scientists had believed it to be.

At present, we believe that the atom is composed of protons, electrons, and neutrons.[1] When we comb our hair on a dry day, the hair, being attracted to the comb, sometimes stands on end. This is due to positive charges of electricity which have been induced on the hair by friction with the comb. If a rubber rod is stroked with cat's fur, the rod acquires

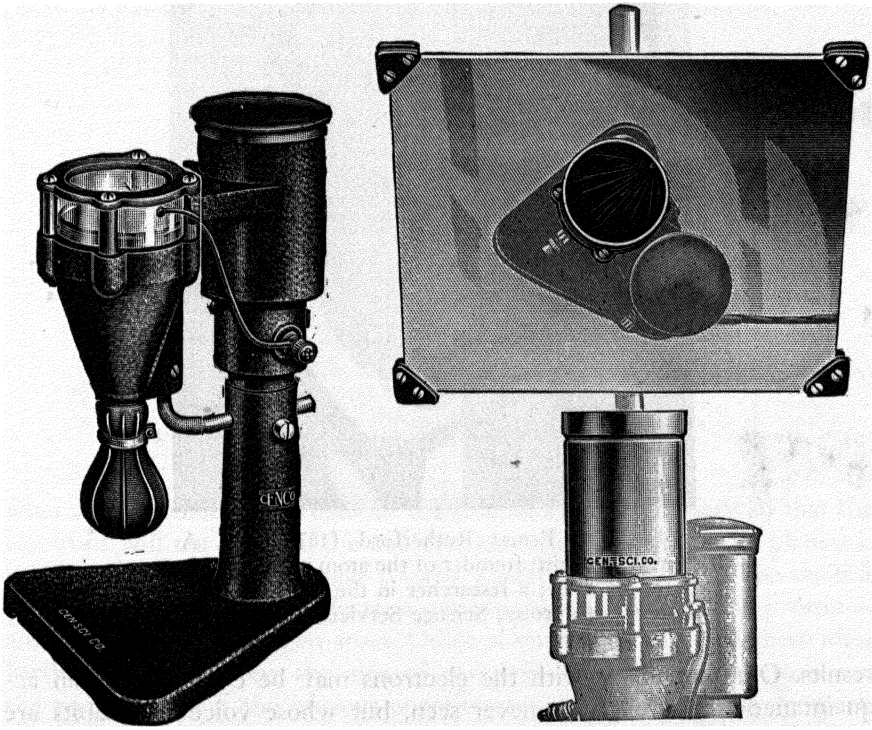


FIG. 122. (*Left*) A cloud chamber apparatus. When the bulb is pressed and suddenly released a cloud fills the glass chamber. A small piece of polonium in the chamber emits alpha particles which show tracks as they move through the fog. Electrons can be used instead of alpha particles. (Courtesy, Central Scientific Company.)

FIG. 123. (*Right*) The large mirror gives a view of the tracks produced by the alpha particles described in Fig. 122. (Courtesy, Central Scientific Company.)

[1] Hydrogen atoms do not contain neutrons.

an excess of electrons and the fur has too few. If one walks across a rug and then touches a metal doorknob, a spark is often noticed passing between the hand and the knob. The spark is a current of electricity caused by the electrons passing from the hand to the knob. The body was charged by friction. The various theories of the constitution of the atom have given rise to several atom models. At this point, it must be emphasized that any model is merely an attempt to visualize our experimental

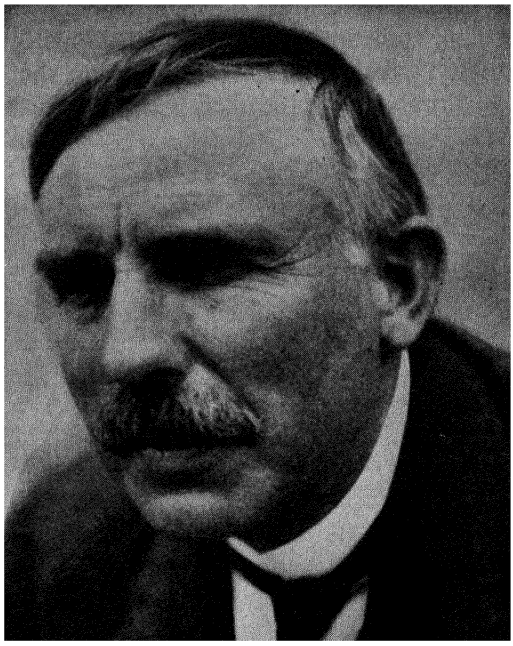


FIG. 124. Ernest Rutherford (1871–1937). A British physicist; founder of the atom model which bears his name; a researcher in the field of radioactivity. (Courtesy, Science Service.)

results. Our familiarity with the electrons may be compared to an acquaintance whom we have never seen, but whose voice and habits are familiar. We are prone to form a mental picture of such a person, although it may be far from the correct one. We can see the tracks that an electron makes in a cloud chamber; we find that the electrons are deflected by a magnet; we see fluorescence caused by their motion; we can hear the "noise" made by their collisions in a radio tube. By these means we form our mental picture of electron characteristics.

The first electrical model of an atom was devised by J. J. Thomson

himself. He thought of the atom as a ball of positive electricity, in which the electrons were distributed like seeds in a pumpkin. This model was abandoned when experiments indicated that the atom contained a small hard kernel of positive charge, the rest of the atom being practically empty space except for electrons.

The British scientist Ernest Rutherford (Fig. 124) was the next to try his hand at atom building. He pictured the atom as a tiny solar system, with nucleus and electrons. At the center is the heavy core or nucleus having a positive charge. The electrons revolve around this core some-

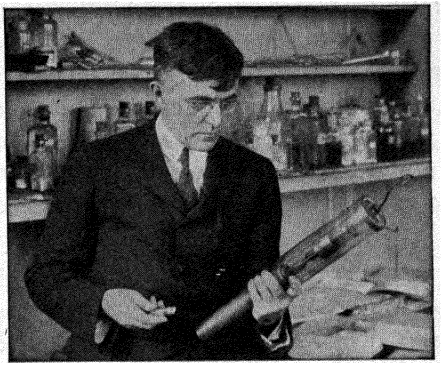


FIG. 125. Irving Langmuir (1881–). A brilliant American scientist. He has made many discoveries in the field of vacuum tubes and thin films. His discoveries cover many fields of modern life. (Courtesy, General Electric Company.)

what as the planets revolve about the sun. Motion is necessary so that the electrons will not fall into the nucleus, just as revolution of the planets is necessary to preserve the solar system. Like the solar system, the atom is mostly empty space. One electron outside the nucleus and one proton as a nucleus form a hydrogen atom. Other scientists have carried these ideas further by introducing the idea of neutrons. If two electrons surround the nucleus, and if the nucleus contains two neutrons and two protons, the atom is helium. The element uranium (atomic weight 238.07) is believed to contain 92 protons and 146 neutrons in the core and 92 electrons outside the core. Each element is given an atomic number from 1 to 96, which represents the number of electrons surrounding the core. Such a model indicates that every object, including such materials as glass, wood, iron, and silver, is composed of electrical charges. This is a startling statement.

According to the best evidence, the mass of an electron is 9×10^{-28} Gm. and its diameter is about 10^{-13} cm. The diameter of a proton is about 10^{-16} cm. If the nucleus were the size of an orange, the electron would be 5,000 miles distant.

Another interesting model, which is very important in chemical theories of the atom, is the Lewis-Langmuir atom (Fig. 125). In this theory, devised in 1916, hydrogen is portrayed as having a nucleus and a stationary electron. According to this model, fluorine (atomic number 9) has seven electrons at the corner of the cube, two electrons inside the cube, and a nucleus of nine protons and 10 neutrons. No motion except vibration is necessary in this model. When fluorine combines with hydrogen (Fig. 126), the lone electron on the hydrogen atom fits into the vacant corner in the fluorine atom, forming a molecule of hydrogen fluoride (HF). Similarly, a sodium atom has one electron in its outermost shell. When sodium combines with chlorine, this lone sodium electron fits into a space in the outermost shell of chlorine, forming a molecule of sodium chloride. In a sense, the electron binds the two atoms together. The theory also states that when hydrogen fluoride is dissolved in water,

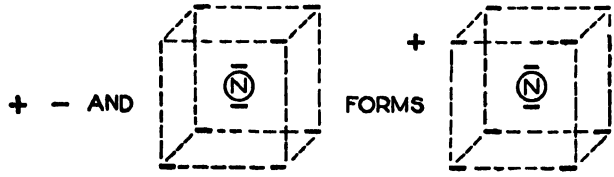


FIG. 126. Hydrogen combines with fluorine to form hydrogen fluoride. An illustration of the use of the Lewis-Langmuir theory.

the hydrogen nucleus may split away from its electron, so that the hydrogen is positively charged. The fluorine is negatively charged. These charged particles are called ions (see p. 208).

From what has been said up to this point, the reader may feel that our knowledge of the atom is still very deficient. This is certainly true. It is indeed surprising that we have made any progress whatever, when we realize that there are only a few instruments that help us reveal the secrets of the atom. We know that the atoms of a tungsten filament emit white light when the filament is heated. In the spectroscope, this light becomes a continuous spectrum (rainbow). If a current of electricity is passed through a tube containing neon gas (see p. 143), the neon atoms emit light of a type which the spectroscope separates into a line spectrum. When the molecules of a compound such as carbon dioxide are caused to emit light, a band spectrum is formed. Under the proper conditions, as we shall see presently, atoms also emit gamma rays, x-rays, ultraviolet

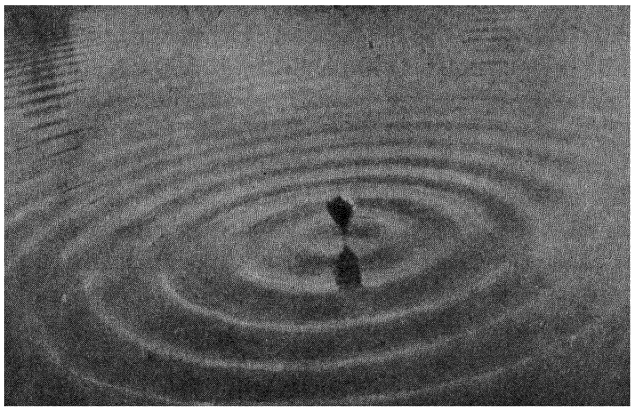


FIG. 127. The bobbing of a top in water. Note that a wave is produced each time the top moves up and down. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

rays, heat rays, and electrical radiations. *All of these emissions of energy are called radiations. From a study of these radiations, we gain our knowledge of the structure of the atoms which emit the energy.*

ENERGY

We are conscious of an entity about us which we call energy (Chapter 21). We are warmed by the sun; we read by electric light; we hear by the energy of sound; the energy contained in food furnishes us with the ability to carry on our work. Man has always wondered how the energies of heat and light reach us from the sun. Perhaps the following illustration will be helpful in considering the problem. If a friend were asleep in a boat out on a lake and we, standing on the shore, wished to attract his attention, we can think of several ways of making our presence known. We might call, thus sending sound waves through the air, or we might drop a stone into the water so that the spreading waves would lap against the boat. We might throw some object against the boat. A little thought shows us that these various methods really consist of two types, transmitting waves through some medium or shooting objects through space. In considering the methods by which the various radiations are transmitted from one point to another, the scientist must consider these two types.

WAVES

In order to explain the origin and progress of waves, we can use as an example the bobbing of a top connected to a fish line (Fig. 127). Each time the top moves up and down, a wave starts out into the water. The

number of waves sent out per second (frequency) is determined by the rapidity with which the top is operated. The frequency is determined by the source of the waves. If a chip is floating on the water, it will be seen to move up and down, yet to remain in about the same location. This indicates that the water itself did not move away from the top but that the water wave carried energy in all directions. The water is the medium which transmits the energy.

Newton thought of light energy as being transmitted by means of corpuscles. Since light casts sharp shadows, the idea of waves of light seemed improbable to him. Because of Newton's prestige, the idea of corpuscles continued to be prevalent until 1801. In that year, Thomas Young, a youth of 26, presented a paper before the Royal Society in which he offered the theory that light energy travelled in waves.

This paper provoked a great deal of discussion. A classic illustration of the narrowness of some scientists of that day is the criticism of Lord Brougham as reported in the *Edinburgh Review:* "We now dismiss, for the present, the feeble lucubrations of this author in which we have searched without success for some trace of learning, acuteness, and ingenuity, that might compensate for his evident deficiency in the powers of solid thinking." Despite such criticisms, the wave theory was soon accepted as the correct one.

Various difficulties were apparent, especially the necessity of a medium to transmit the waves. The idea of a medium, called *ether,* was introduced. In the interval from 1850 to 1900, scientists devoted a great deal of work to the study of the ether. (The word *ether* does not refer to the chemical compound of that name.) The substance was supposed to fill the entire universe, penetrating even solid materials and the atoms themselves. Ether was supposed to be a sort of jelly-like substance, so light in weight that no experiment could detect it. Waves of energy travelled through ether from the sun and stars, much as a wave travels in water or a rope. When an electric lamp is turned on in a room, it is assumed that the atoms of the filament absorb energy, with the result that the vibrating electrons in the atoms send out waves in the ether to our eyes. The energy in these waves excites the retina of the eyeball, giving us the sensation of light. Today, we doubt the existence of the ether as an actual material substance, but we still think of *waves in space.* Because of the greater ease of explanation, we shall continue to discuss the various forms of electromagnetic radiations by the wave method.

Various experiments with *polarized light* (see p. 359) and *interference* (see p. 336) seem to indicate that light certainly is a wave motion. One can readily observe a form of interference, called diffraction, by viewing a bright light through the slit between two nearly closed fingers. A series of fine lines will be noticed in the slit. A single filament lamp is best for the purpose.

QUANTA. Because of the many difficulties with the wave theory, in 1900 Max Planck, a German physicist, proposed a theory that energy was radiated in corpuscles (bullets) called quanta. There were many reasons why such a radical proposal seemed necessary. One of these was the photoelectric effect. It has long been known that if an open arc lamp shines on a polished piece of zinc, electrons are emitted from the zinc surface. Within the last few years, it has been discovered that other metals, notably sodium, potassium, and cesium, have the same property, even when illuminated by ordinary daylight. This discovery has made talking movies possible (see p. 357). We use the photoelectric cell (electric eye) in timing races, opening garage doors by the headlights of the automobile, counting objects, and operating a host of mechanical devices (Fig. 128).

Most photoelectric cells consist of a cathode plate of cesium on silver and a straight wire for an anode. When the plate is illuminated by a beam of light, electrons are released from the cathode and move to the anode wire. This completes the circuit and a current flows in the outside circuit, operating such devices as counters, doors, and burglar alarms.

In the case of automatic door openers, the light is so arranged that a person intending to move through the door intercepts the light beam with the body. The interruption of the beam closes an electric circuit and the door is pulled open.

In the photoelectric effect, the electrons are ejected in such a way that the light seems to have struck the surface in "bullets" or *quanta.* In order for the electrons to leave the surface, it is necessary that the light be of the proper frequency. Planck assumed that violet light had more energy per quantum than red light; hence it was more effective.

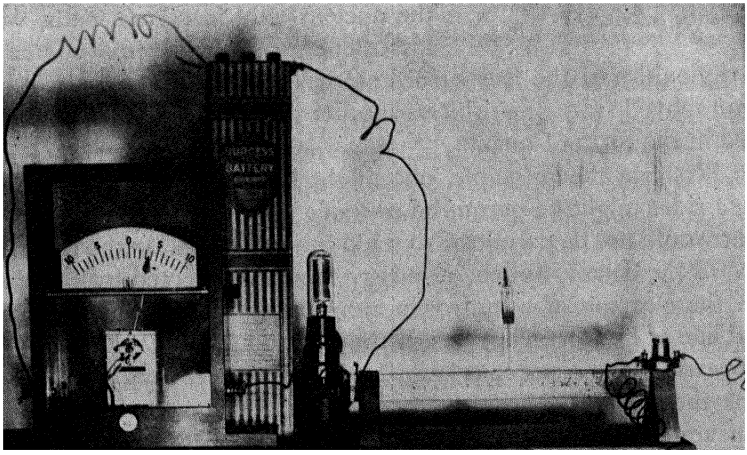


FIG. 128. A photocell in operation. A light is focused on the cell shown in the center of the figure. A current is produced which operates the galvanometer shown at the left.

The quantum theory utilizes the equation, $\text{energy}_{\text{ergs}}$ equals $h\nu$, where ν is the frequency and h is the quantum constant, 6.6×10^{-27} erg-seconds. This equation has proved to be one of the most valuable of all principles in the entire field of science.

The quantum theory placed scientists in a dilemma. Some experiments seemed to prove the existence of waves; other effects seemed to indicate that radiations were corpuscular in nature. In the words of Professor Bragg, "Waves are considered on Monday, Wednesday, and Friday; corpuscles are discussed on Tuesday, Thursday, and Saturday." Today, we believe that a beam of light has both a wave and a corpuscular nature. Sometimes the wave characteristic is more prominent. Other effects seem due to a corpuscular nature. Electrons falling on crystals give diffraction patterns similar to those of x-rays, indicating that *particles have a wave nature.*

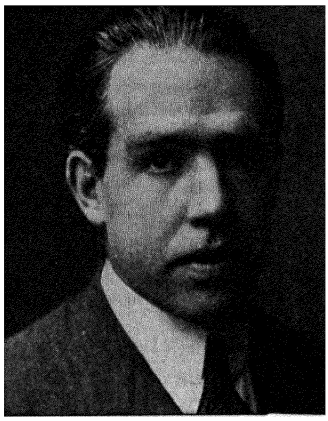


FIG. 129. Niels Bohr (1885–). A Danish physicist; one of the greatest of modern theoretical physicists; founder of the Bohr theory of the atom. (Courtesy, Science Service.)

BOHR THEORY. It has been the history of science that difficulties give rise to great advances in scientific thought. The quantum theory suggested to Niels Bohr (Fig. 129), a Danish scientist, a remarkable advance in atomic models. In 1913, Bohr, then 28 years of age, adapted the quantum principle to the Rutherford solar system atom. He advanced the principle that the planetary electrons might revolve about the nucleus only in certain paths without loss of energy. Thus he removed one of the great difficulties of the Rutherford atom. He also assumed that when an electron moved from one orbit to another nearer the nucleus, energy was emitted in the form of quanta.

To illustrate the principle, one might imagine a merry-go-round on which a rider might be permitted to move from an outer seat to an inner one but would not be permitted to stand between seats. As the rider moved in toward the center, bullets of energy would be ejected by him. In Fig. 130, if the electron of a hydrogen atom moves from orbit 3 to orbit 2, the red line of hydrogen appears. If the electron moves from 4 to 2, a blue line appears. If the transfer is from 2 to 1, ultraviolet rays leave the atom.

The theory of Bohr satisfactorily explained the line spectra of hydrogen and helium and made possible a fairly satisfactory explanation of the complicated spectra of the other elements. From this time on the

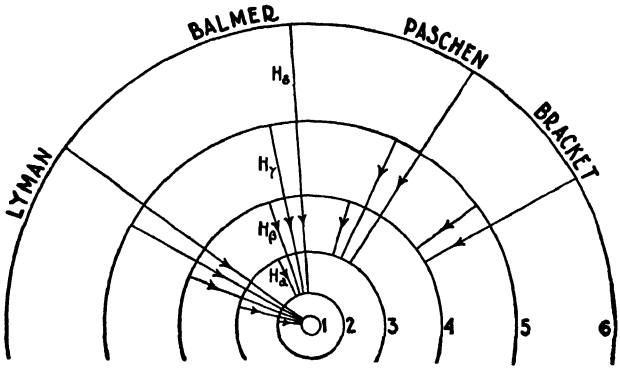


FIG. 130. The emission of light from a hydrogen atom as portrayed by the Bohr theory. As an electron moves from orbit 3 to orbit 2, there is emitted the red line of hydrogen, one of the Balmer series. The various transfers produce the different lines of the hydrogen spectrum, in the visible, infrared, and ultraviolet. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

spectroscopic study of atoms made great progress. It was found that all these radiations were of the same character and they are now grouped under the term *electromagnetic radiations* (Table 11). Each type will be discussed at an appropriate section of the text.

ELECTRONS AND WAVES. We have stated that electromagnetic waves have some particle characteristics. In addition, particles of matter seem to have wave properties. G. P. Thomson sent a beam of high speed electrons through a thin gold foil. He was able to produce a diffraction pattern on a photographic plate similar to those produced when a beam of x-rays is passed through gold foil. It is apparent that electrons moving at high speeds have wave properties similar to x-rays, or gamma rays. In fact, the wave length of an electron may be computed by the equation $\lambda = \frac{h}{mv}$ where λ represents the wave length in cm., h is the quantum constant, m is the mass of the electron, and v is the velocity in cm. per sec.

For example, an electron moving at a velocity of 10^{10} cm./sec. has a wave length of 7×10^{-10} cm. or 0.07 Ångström. This wave length is in the gamma ray region of the spectrum. It is apparent that the electron has become more complex with each passing year.

Not only does the electron have wave properties but all material particles have this property. A hydrogen atom moving about in the room at ordinary temperatures has a wave length of about five Ångströms.

ELECTROMAGNETIC RADIATIONS

The type of wave which any atom will emit depends on the amount of energy which the atom absorbs and on the subsequent motion of the

Table II

ELECTROMAGNETIC SPECTRUM

Wave Length	*Name*
10,000 m. (10^6 cm.) to 1000 m. (10^5 cm.)	Wireless and Carrier Communication
550 m. (5.5×10^4 cm.) to 200 m. (2×10^4 cm.)	Radio Broadcast
200 m. (2×10^4 cm.) to 5 m. (500 cm.)	Short-Wave Radio
5 m. (500 cm.) to 50 cm.	Ultra High-Frequency Radio
50 cm. to 0.1 cm.	Microwave Radio
50,000 A.U. (.0005 cm.) to 8,000 A.U. (.00008 cm.)	Infrared
8,000 A.U. (.00008 cm.) to 4,000 A.U. (.00004 cm.)	Visible Light
4,000 A.U. (.00004 cm.) to 100 A.U. (10^{-6} cm.)	Ultraviolet
100 A.U. (10^{-6} cm.) to 1 A.U. (10^{-8} cm.)	Soft X-rays
1 A.U. (10^{-8} cm.) to 01 A.U. (10^{-10} cm.)	Hard X-rays and Gamma Rays

electrons. If we could examine the hydrogen in the sun's atmosphere, we would find that some of the atoms were emitting energy in the form of long waves, while other atoms were sending out short-wave energy. Although all electromagnetic radiations are of the same character, differing only in frequency (vibrations per second), the various radiations are excited in different ways. Radio waves are produced by electrical methods such as those used in broadcasting stations. Bodies at high tem-

peratures produce radiations such as heat, light, and ultraviolet. The sudden stopping of electrons moving at high speeds gives rise to continuous x-radiations (Roentgen rays). All of these radiations travel at the same speed in free space, 186,000 miles per second. There is no sharp dividing line between these various wave lengths, but scientists have arbitrarily divided them into bands, depending upon the method of study of the various types. In the present chapter, we shall briefly describe the bands in order of wave lengths, reserving a detailed discussion for subsequent chapters.

A wave length is the distance from one wave crest to the next. The frequency of the wave equals the velocity divided by the wave length. The velocity of electromagnetic waves in space is 3×10^{10} cm./sec. Thus, the frequency of one of the spectrum lines of mercury is $30{,}000{,}000{,}000/0.00004 = 7.5 \times 10^{14}$ vibrations per second.

WIRELESS WAVES. The longest of the waves are the electrical radiations or radio waves. The waves used vary in length from about 10,000 m. to 550 m. (6 miles to ⅓ of a mile). Such radiations are sent out by wireless stations.

The 600 m. wave is reserved for the danger signal (SOS) of shipping.

The broadcasting band used in North America extends from 545 m. (550 kilocycles) to 199.5 m. (1,500 kc.). All broadcasting stations are crowded into this band.[2]

The short wave band extends from 199.5 m. to 2.5 m. Much modern work is being carried on at wave lengths of the order of 1 cm. These are called microwaves. (See p. 400.)

INFRARED RAYS. When materials are heated to a high temperature, as in a flame, heat energy is emitted. These waves are those which, upon striking an object, may be absorbed, giving up their energy and producing heat in the object.

LIGHT WAVES. The next band of radiations, called light or visible light, is the energy that affects the retina of the eye and the emulsion of photographic plates. It is necessary for the growth of plants (see p. 336). These waves vary in length from 8,000 to 4,000 Ångströms, that is, from extreme red to extreme violet. The entire band constitutes the continuous visible spectrum.

An Angström is a length unit named after the Swedish scientist of that name. It is 10^{-7} mm. (one ten-millionth of a mm.). This means that 8,000 Ångströms are equivalent to 0.0008 mm. or nearly 0.00003 in.

ULTRAVIOLET RAYS. Beyond the violet lies the invisible region of the ultraviolet, which extends from 4,000 to 100 Ångströms. These radiations

---

[2] A meter is equal to 39.37 in., slightly over 3 ft. An inch is 2.54 cm. A millimeter is 1/25 of an in.

affect a photographic plate and some of them produce fluorescence in minerals.

X-RAYS. X-rays are produced when electrons, which are traveling at a high rate of speed, strike a target made of a metal of high atomic weight, such as platinum or tungsten. These rays are invisible but have great penetrating power (Chapter 27).

GAMMA RAYS. The shortest wave in the electromagnetic spectrum is the gamma ray emitted by radium and associated elements. (Gamma is simply a Greek letter and has no significance except to designate the type of ray.) This radiation will also be discussed in Chapter 27.

THE NUCLEUS

Having gained some insight into the outer part of the atom, scientists began to consider the nucleus. It had been known since the discovery of the principle of radioactivity that radium and associated elements were giving out energy from the nucleus or core of the atom. It was realized that the outburst of energy from the nucleus could not be controlled by any known means.

Within the last 10 years, scientists have learned to produce "bullets" which have sufficient velocities to shatter nuclei. One such source is the "neutron gun," constructed of a mixture of beryllium and radon. Another device is the cyclotron (Fig. 288), of which there are many in operation. This latter instrument gives high speeds to helium ions, protons, and deuterons (ions of heavy hydrogen) and shoots them against atoms. In Chapter 27, some interesting results of this modern warfare will be discussed.

When one views the marvellous results of modern experimentation and tries to imagine the possibilities of the future, one feels as Newton did when he said, " . . . I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

REFERENCES

Bazzoni: "Energy and Matter," New York, The University Society.
Eddington: "Nature of the Physical World," New York, The Macmillan Co.
Eidinoff and Ruchlis: "Atomics for the Millions," New York, The McGraw-Hill Book Co.
French: "The Drama of Chemistry," New York, The University Society.
Frisch: "Meet the Atom," London, Sigma Book, Inc.
Hecht: "Explaining the Atom," New York, The Viking Press.
Hull: "Modern Physics," New York, The Macmillan Co.
Jauncey: "Modern Physics," New York, D. Van Nostrand Co.
Jeans: "The Universe Around Us," New York, The Macmillan Co.
Lang: "Early Tales of the Atomic Age," New York, Doubleday, Doran and Co.

Millikan: "Electrons + and − ," Chicago, University of Chicago Press.
Richtmyer: "Introduction to Modern Physics," New York, The McGraw-Hill Book Co.

Questions and Problems

1. Describe two atom models.
2. What is meant by an ultraviolet ray?
3. What does "gamma ray" mean?
4. What is the Brownian motion?
5. Who is Bohr?
6. What is meant by the quantum theory?
7. How does energy reach us from the sun?
8. What is the nucleus of an atom?
9. Describe the periodic table.
10. Why can we sometimes draw sparks when rubbing a cat?
11. What is an electromagnetic wave?
12. A light wave of wave length 5000 Angstroms has what frequency? Answer: 6×10^{14}.
13. Sketch a model of a chlorine atom.

Visual Aids

"Electrons," University of Chicago Film
"Energy and Its Transformations," University of Chicago Film
"Cathode Ray Tube," General Electric Co. Film

Topics for Discussion

Quantum Theory	Cosmic Rays	Neutrons
Radium	The Ether	The Wave Atom
The Bohr Atom	Cathode Rays	

Experiments

1. It is possible to demonstrate the various radiations described in this chapter. For the electric waves, one can use one of the short-wave sets manufactured by the instrument companies. A neon light is used as a receiver so that the entire class can study the reception.
2. For the demonstration of heat waves, photograph a hot flatiron in a totally dark room, using special infrared film.
3. The visible spectrum can be studied by the spectroscope. For the ultraviolet, use an argon lamp to show fluorescence of rocks. Such rocks can be purchased from Ward's Natural Science Establishment.
4. Study the Brownian motion as described in the chapter.
5. Study cathode rays. There are oscilloscopes on the market which are inexpensive and quite suitable for this purpose.
6. Examine the luminous dial of a watch in a dark room. Use a hand lens. Scintillations can be observed.

14. MATTER ASSOCIATED WITH CHEMICAL ENERGY

If by fire
Of sooty coal th' empiric alchymist
Can turn, or holds it possible to turn,
Metals of drossiest ore to perfect gold.

—MILTON

In the present chapter, we shall discuss those phenomena of nature which involve a change in the composition of substances. Such changes are termed chemical changes, since they involve energy manifested in the chemical form. Many of our common experiences are associated with chemical changes. The digestion of food is a complicated series of chemical reactions. We see on every hand such manifestations of chemical changes as the rusting of iron, the rotting of wood, the souring of milk, the growth of plants. These are just a few examples of the changes in nature which involve a change in the molecules of the compounds formed from various elements in the earth.

The history of chemical experimentation dates back to earliest times. The Chinese and the early Hindus have left records of many studies in this field. The records of early Egypt contain many allusions to experiments in chemistry. These peoples were familiar with paints and with the properties of the materials gold, silver, lead, sulfur, iron, copper, and vinegar. The priests made use of spectacular experiments in their rituals.

After a great gap of several centuries, in which there was little or no chemical experimentation, we find the science of chemistry taken up by the Arabs in the eighth century. One of the outstanding scientists of this period was the great Geber. His work started the age of alchemy and the intensive search for a method of producing gold from base metals such as lead. Geber believed that all metals were composed of sulfur and mercury. In all ages, men had wished to be able to change metals, such as iron and lead, into the valuable metal gold. Anyone successful in this feat would have untold wealth. It had long been believed that there existed an "essence" or substance called the "Philosopher's Stone" which had the power of changing lead to gold, of curing all diseases, and of performing other miraculous feats. Many alchemists spent their lives in a search for this stone. Geber taught that the only requisite for changing base metals into gold was the purification of the metal so that the sulfur impurity was removed. To this end, the alchemists of several centuries spent their lives

in performing crude experiments of all types on ores and metallic compounds. They learned much chemistry but they never produced gold. It was natural for them to cloak their work in mystery. To this end, they performed many tricks pretending to produce gold. They used astrologic symbols for the materials so as to mystify the uneducated. Many kings were duped by them. The Emperor Rudolph of Bohemia provided funds which supported many of these tricksters in their devious experiments for the production of gold. Even as late as the fifteenth century, some of this spurious gold was minted in England and passed as pure gold coins. It is difficult to believe that even the present century has provided instances of several schemes for making gold from lead. Many investors have lost their fortunes in these fraudulent methods. One might mention the case of the famous German general, von Ludendorff, who lost his fortune in one of these confidence schemes. It may be of interest to remark, that, as a result of the work on nuclear disintegration (Chapter 27), minute quantities of elements have been changed into gold. However, the process is so expensive that it will probably never prove to be valuable commercially.

One good result of the chicanery and mysticism of alchemy was the rise of iatrochemistry—the applications of chemistry to medicine. The chemicals which had been discovered were now applied to the treatment of disease. Although no universal medicine or elixir has ever been found, the way was opened for our modern marvels in medicine.

Iatrochemistry began with Paracelsus, a Swiss chemist (1493–1541). He believed that an elixir existed which could cure all ills. Ponce de Leon came to Florida in search of this marvelous substance. Paracelsus also taught that one must continually experiment and seek new remedies for the cure of disease. He initiated the medical research which has accomplished so much in the present century. After his time, the idea that illness could be removed by incantations or be prevented by wearing a charm began to disappear. But the world was still far from our present-day methods of healing. As soon as a new drug was discovered, its effects were tried on human beings, often with disastrous results. Indeed, until the time of Pasteur and Lister and the discovery of a bacterial basis for many diseases, healing was a very unscientific art.

It is rather interesting for us to read of the medical ideas which were prevalent even as late as 1850. I shall quote from a medical treatise of that period. "As sure as the cholera will never pass a boundary line—sulphurretted hydrogen, or spread among people with sulphur in their shoes—so surely it can be said to Yellow Fever—thus far and no further. Just as we recommend fear, care, and sulphur, in Asiatic cholera, so we recommend fright, run, and charcoal, in yellow fever. The substance carrying yellow fever is of a gaseous nature, a miasma, which cannot be spread by the sick.

A few handsful of charcoal will absorb the miasma and eliminate all danger." In the same text, the virus of the honey bee was a specific for colds, fatigue, loss of hair, sour food, earache, and rheumatism. Sulfur was excellent for colds, drunkenness, sour food, snake bite, and catarrh. Lest we laugh too much, let us remember that even today many a small boy is dosed with sulfur and molasses.

Oxidation and Reduction

During all of these epochs, men had been puzzled by the phenomenon of combustion. Fuels gave off heat and changed to ash. Some metals, like tin and zinc, when heated changed to a powder, the powder being heavier than the original metal. After many theories had been proposed and discarded, it remained for Joseph Priestley (see p. 145) and William Scheele to solve the mystery by collecting a gas which was given off from heated mercuric oxide. They found that this gas, which was later named oxygen, would support combustion and that it was a gas necessary for animal life.

Oxygen, one of the most important gases of the atmosphere, is responsible for the many changes which are called *oxidation*. Iron rusts because it combines with oxygen, thus forming iron oxide. Coal burns, combining with oxygen to form either carbon monoxide, or carbon dioxide, or both.

When fuels, especially coal and the hydrocarbons, burn in an insufficient supply of air, carbon monoxide is formed. Unlike carbon dioxide, it is a very dangerous gas. It has no odor, taste, or color. When it enters the body by way of the lungs, it combines with the hemoglobin of the red blood corpuscles so that they are no longer able to carry oxygen. One should never operate an automobile in a closed garage, since part of the exhaust gas is carbon monoxide.

We drive our automobiles by the combustion of gasoline. We eat food which by oxidation provides energy for our bodies. It must be emphasized that the products of such changes are different from the original materials taking part in the process. If the oxidation is rapid, as in flames or explosions, the oxidation is called *combustion*. When mercury is heated in an atmosphere containing oxygen, the oxide of mercury is formed.

Mercury plus oxygen yields mercuric oxide.

$$2Hg + O_2 \rightarrow 2HgO$$

An interesting example of oxidation is spontaneous combustion. It often happens that a pile of oily rags or a mass of damp hay will burst into flames unexpectedly. A process of oxidation has proceeded to a point where sufficient heat has accumulated to start combustion.

In contrast to oxidation, we have the chemical change called *reduction*. This usually involves a removal of oxygen from the compound. Usually we mean by reduction such metallurgic processes as the reduction of tin

from tin ore or of iron from iron ore. Perhaps the best-known commercial application of reduction is the blast furnace for the production of iron. Iron usually occurs in nature as ferric oxide (Fe_2O_3). In the blast furnace

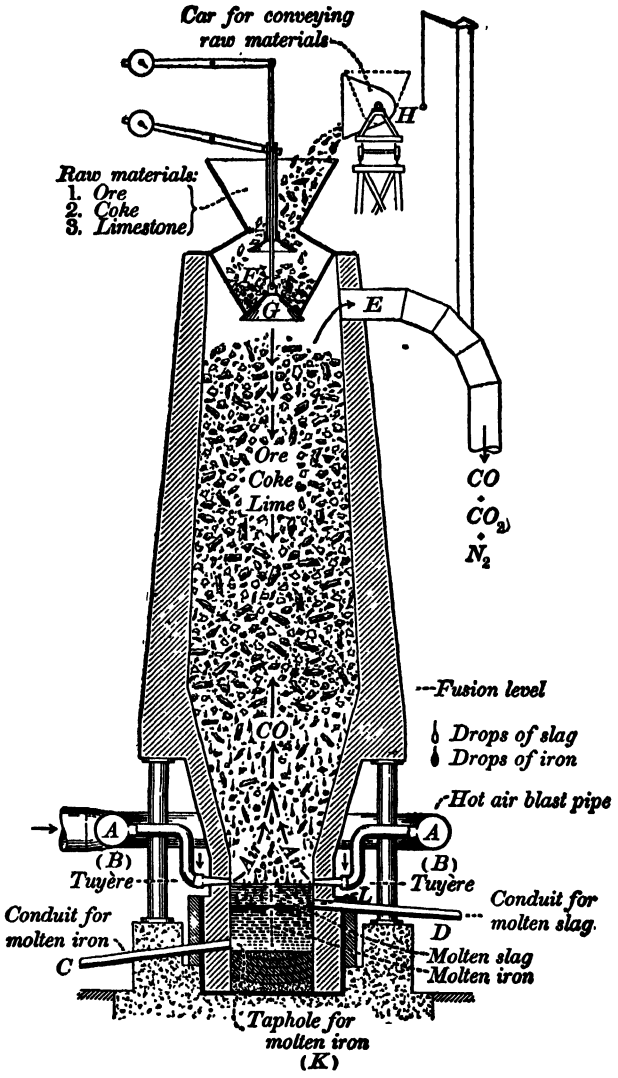


FIG. 131. The blast furnace. (Courtesy, McPherson and Henderson: "Chemistry for Today," Boston, Ginn and Co.)

(Fig. 131), limestone, coke, and iron ore are arranged in layers. The ore contains much useless material called gangue. In order to separate the metal from the gangue, limestone is used as a flux. As the mass is heated,

the coke (carbon) combines with the iron oxide according to the equation below. The molten iron is drawn off at the vent C and the molten slag at the vent D.

$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

Thermit welding of the cracks in iron or steel is a very important form of reduction. Aluminum powder is mixed with iron ore and heated. At a certain temperature, the aluminum combines with the oxygen of the iron ore, freeing the iron which flows into the crack, thus making a firm joint. The incendiary bombs used in the recent World War made use of this reaction. We may illustrate reduction by mercuric oxide. If the red powder is carefully heated in a test tube, metallic mercury will collect in the cool part of the tube.

Mercuric oxide yields mercury plus oxygen.

$$2HgO \rightarrow 2Hg + O_2$$

Symbols and Formulas

The old alchemists used to designate the then known substances by odd symbols and pictographs. Some of the symbols are of astrologic origin. For instance, the symbol for gold was ☉ (the sun), for iron ♂, for silver ☽, for water △, and for sulfur ▲. At present, we use the first letter of the name of the element and frequently the second or some other letter. For example, there are 11 elements whose names begin with the letter C. In order to distinguish them, the chemist uses two letters. C is used for carbon and Cl for chlorine. Some of the elements known in ancient times are designated by letters derived from the Latin name. The symbol for silver is Ag, from the word argentum (metal of the moon). In the formula, a symbol represents one atom. Thus O indicates an atom of oxygen, while O_2 represents a molecule containing two atoms of oxygen. A list of the known elements and their atomic weights is given in Appendix V.

The chemists have analyzed thousands of compounds and know not only what elements make up the compound but the exact proportion of each. Thus, H_2O stands for one molecule of water, which consists of two atoms of hydrogen and one atom of oxygen. We also know from the formula that water contains two parts of hydrogen and 16 parts of oxygen by weight. In other words, 18.016 Gm. of water can be made from 2.016 Gm. of hydrogen and 16 Gm. of oxygen.

The chemist has developed a system of equations, a type of shorthand, which he uses to express the changes in structure which take place in chemical reactions. When carbon burns, we know that the result is heat and carbon dioxide gas. We may write this as follows:

Carbon plus oxygen yields carbon dioxide plus heat.

$$C + O_2 \rightarrow CO_2$$

Similarly, mercury plus oxygen yields mercuric oxide.

$$2Hg + O_2 \rightarrow 2HgO$$

In thermit welding, iron oxide plus aluminum yields aluminum oxide and iron.

$$3Fe_3O_4 + 8Al \rightarrow 4Al_2O_3 + 9Fe$$

In the blast furnace, carbon plus iron oxide ultimately yields carbon dioxide plus iron.

$$Fe_3O_4 + 2C \rightarrow 2CO_2 + 3Fe$$

In some cases we find that one, two, or more elements act as a unit or radical. Some examples of such radicals are NO_3, SO_4, NH_4, and CO_3. When two or more such groups occur in one molecule, the radical is placed in parenthesis with a subscript as, for example, $Al_2(SO_4)_3$.

It is difficult for the beginner to understand these combinations of figures and symbols. The proper balancing of chemical equations can be acquired only by long experience and much laboratory experimentation. The student should not attempt to memorize complicated equations. It is more important that one understand the scientific basis for the expressions.

ATOMIC WEIGHTS

Because of the small mass of atoms—an atom of oxygen weighs only 26×10^{-24} Gm.—it is inconvenient to use these numbers in chemical calculations. To obviate this difficulty, the chemist has assigned to each element an atomic weight—a relative weight. For example, the number 1.008 is assigned to hydrogen, 16.000 to oxygen, 4.003 to helium, and 32.066 to sulfur. Each of the 96[1] elements has such an assigned weight. These numbers mean that one atom of sulfur is approximately twice as heavy as an atom of oxygen and that an atom of helium is only about one-fourth as heavy as an atom of oxygen. (An illustration of such a procedure in another field of science is the statement that one star is twice as bright as another star, without stating the actual brightness of either.) If we wish to calculate the actual weight of an atom, for example sulfur, we may calculate it by the ratio $32/16 \times 26 \times 10^{-24}$, which gives us the number 52×10^{-24} Gm. However, for most calculations the atomic weights are more satisfactory.

When atoms are combined into molecules, we make use of molecular

[1] Four elements have been added as a result of atomic disintegration studies. The total number is subject to change at any time.

weights. Obviously, the molecular weight of a compound is merely the sum of the atomic weights of the atoms composing the molecule. Carbon dioxide is composed of one atom of carbon and two atoms of oxygen. The molecular weight is 12 + 16 + 16 or 44.

VALENCE

The atoms are bound into molecules by some form of attractive force, probably electrical. Valence is the term which concerns the number of atoms which can be bound together in a molecule. Specifically, hydrogen is said to have a valence of one and oxygen a valence of two, since two atoms of hydrogen combine with one atom of oxygen to form one molecule of water. To carry the idea further, we may state that an element whose atoms combine with hydrogen atoms in a one to one ratio has a valence of one (univalent). An element whose atoms combine with oxygen atoms in a one to one ratio has a valence of two (divalent). In carbon dioxide (CO_2), we note that one atom of carbon combines with two atoms of oxygen so that carbon is said to have a valence of four. Under certain conditions, it is possible for an element to have more than one valence.

With the development of the theories of atomic structure, we now believe that the valence of an atom is determined by the planetary electrons in the outer shells of the atom. When univalent sodium combines with univalent chlorine to form table salt, a valence electron of sodium acts as the binding force to produce a molecule of sodium chloride. (Actually a sodium chloride crystal consists of a network of chlorine and sodium atoms rather than a series of separate molecules.)

IONIZATION

Many scientists have speculated as to the nature of the forces which bind atoms together. Sometimes these forces seem to be very strong, forming stable compounds such as water, while in other cases, as in carbonic acid, the forces seem weak. Some have thought that these forces were magnetic; others believed them to be electrical in nature. Even today we do not fully understand the nature of these binding forces.

Various experimenters, among them Sir Humphrey Davy, had found it possible to separate compounds by means of an electrical current. For instance, he found that by passing a current through molten sodium hydroxide (lye) he could produce the metal sodium. Moreover, he produced also potassium, calcium, strontium, and barium. He found that the metals were always deposited on the negative electrode (cathode) of his apparatus. Was there, perhaps, some charge of positive electricity on the sodium that caused it to be attracted to the negative electrode? Perhaps the atomic forces were of an electrical nature. Davy was followed by his famous pupil, Michael Faraday, who formulated the laws which govern

the separation of compounds by electricity. This process was called *electrolysis.*

Despite the great advance made by Faraday, it remained for Svante Arrhenius (Fig. 132), a Swedish chemist, to bring forth in 1884 the theory of ionization which offered for the first time a satisfactory explanation of the experimental results of the scientists who had preceded him. He assumed that there are two kinds of compounds: those which, like salt in

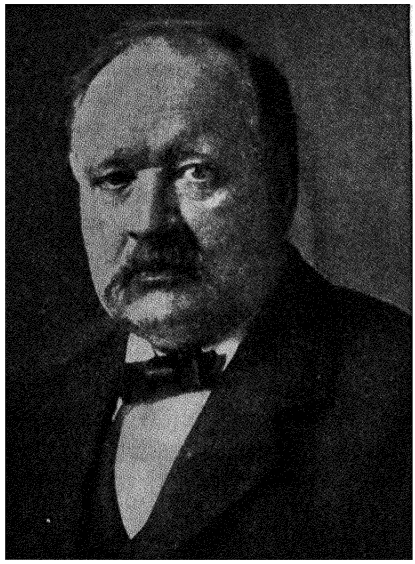


FIG. 132. Svante August Arrhenius (1859–1927). (Courtesy, Jones: "Inorganic Chemistry," Philadelphia, The Blakiston Company.)

water, conduct electricity and another type like sugar which, when dissolved in water, does not make the water a conductor. His theory assumed that if NaCl is dissolved in water, some of the molecules separate into positive ions of sodium $(Na)^+$ and negative chloride ions $(Cl)^-$. It may be that each of these ions gathers to itself several molecules of water and these units drift through the water. On the other hand, it may be that the water molecules have a great attraction for sodium atoms, tearing them away from the salt. *An ion is believed to be an atom or a group of atoms having an excess electrical charge, either positive or negative.* This charge is due to the electrons outside the nucleus of the atoms. Since a neutral sodium atom has 11 electrons, a singly charged sodium ion would have only 10 electrons. A negative chloride ion, having gained an electron, would have 18 instead of the normal 17. The water molecules themselves

ionize but little, usually acting as a medium in which ionization takes place. A positive ion has lost one or more electrons while a negative ion has gained them. An example of a group of atoms acting as an ion is the $(NO_3)^-$ radical. Since a hydrogen atom consists of a proton and an electron, a positive hydrogen ion will be merely a proton.

Ions have entirely different properties from the original atoms or molecules. For instance, when the gas, hydrogen chloride, is dissolved in water, hydrogen ions and chloride ions are formed and the solution is called *hydrochloric* acid (Fig. 133). Although chlorine gas is greenish and forms a pale yellow solution when the gas is dissolved in water, water containing hydrochloric acid, i.e. hydrogen and chloride ions, is colorless. When phenolphthalein is added to an acid solution, no visible effect is seen, but in the presence of a base it forms a red compound. Many other substances form colored compounds in the presence of acids or bases. These compounds are called indicators and are used to test solutions for the acid or basic properties. Hydrogen chloride dissolved in benzene or citric acid crystals dissolved in absolute alcohol will not form ions. Indicators do not change when added to these solutions. This indicates that ions rather than molecules are responsible for the change in color of the indicators.

If two electrodes connected to a source of electrical current are immersed in a solution containing ions (an electrolyte), the positive ions drift toward the negative electrode (cathode) and the negative ions drift toward the positive electrode (anode). If we wish to plate a spoon with

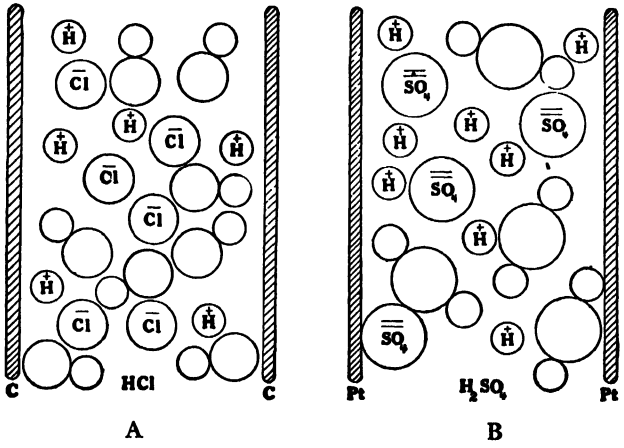


FIG. 133. Diagrammatic representation of ionization. (A) HCl is dissociated into H^+ ions and Cl^- ions. (B) H_2SO_4 is dissociated into H^+ ions and $SO_4^{=}$ ions. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

silver, we make the spoon the negative electrode of the apparatus and use a bar of silver as the anode (Fig. 134). As the current flows through the solution of some silver salt, the silver ions deposit as metallic silver on the spoon. As long as the current flows, the silver will spread itself over the spoon and the silver bar will lose silver. At the present time, many metals are deposited in this way. We have chromium plating on automobiles and on some household utensils. Gold plated jewelry and nickel plated instruments are other examples.

Similarly, if two electrodes which are connected to a source of electrical current are placed in a dilute solution of sulfuric acid, the hydrogen

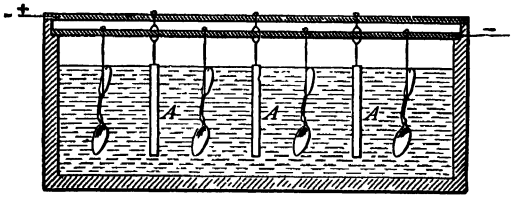


FIG. 134. Electroplating. The process of plating a spoon with silver. (Courtesy, McPherson and Henderson: "Chemistry for Today," Boston, Ginn and Co.)

ions move to the cathode and, having gained electrons, become hydrogen molecules. The $(SO_4)^-$ ions in the solution combine with water molecules to liberate oxygen at the anode. This is the electrolysis of water.

CHEMISTRY AS AN EXACT SCIENCE

Although the science of chemistry is very old, it was not until the eighteenth century that men began to work accurately by weighing and measuring the substances which they studied. A fundamental principle of chemistry was first stated by Anton Lavoisier. This law states that *in any chemical reaction, the combined weight of the substances resulting from the reaction equals the combined weight of the substances taking part in the reaction. This is the basis of all chemical equations and chemical calculations.*

In simple language, this statement means that if we burn a pound of carbon in a weighed amount of oxygen, the weight of the carbon dioxide formed exactly equals the combined weight of the carbon and oxygen used. Nothing is lost or gained.

If we wish to prepare sodium chloride, we may mix 23 Gm. of sodium and 35.5 Gm. of chlorine. At the conclusion of the experiment, we shall have 58.5 Gm. of sodium chloride. However, if we were to use 30 Gm. of sodium and 35.5 Gm. of chlorine, we would find that we had still formed only 58.5 Gm. of sodium chloride and that 7 Gm. of sodium remained.

Each atom of sodium has combined with one atom of chlorine. We know that 23 Gm. of sodium and 35.5 Gm. of chlorine contain the same number of atoms.

Acids

Some common acids are sulfuric acid (H_2SO_4) used in storage cells, acetic acid $H(C_2H_3O_2)$ in vinegar, and citric acid ($C_6H_8O_7$) in lemons and grapefruit. These substances have a sour taste, turn blue litmus red, and most of them react with some of the metals. This latter characteristic explains why tomatoes will brighten the iron or aluminum pan in which they are cooked. Acids contain hydrogen and one or more nonmetals. When dissolved in water, they dissociate into hydrogen ions and nonmetallic ions. In the case of hydrochloric acid, the equation is as follows:

$$HCl \rightleftarrows H^+ + Cl^-$$

The hydrogen ions are responsible for the properties of an acid.

Weak acids dissociate to a very slight extent, consequently, they form very few ions. The acids in tomatoes, citrus fruits, and soda water are weak. Other acids dissociate as much as 92 per cent or more, thus forming many hydrogen ions. These are strong acids, of which sulfuric, hydrochloric, and nitric acids are examples. (Of course, in a very dilute solution, such as about 0.4 per cent of hydrochloric acid, there can be but few ions present. This concentration is present in the gastric juice.) Vinegar contains acetic acid and, in addition to its aromatic flavor, is used because of its acid characteristics. Boric acid is very weak and is used as an antiseptic and eyewash. Sulfuric acid, while not as strong as hydrochloric, has the ability to destroy skin, clothing, and wood. It is a dangerous acid. *All acids should be added to water, never the reverse.*

Bases

Bases usually contain a metal and always contain one or more hydroxyl ions (OH). The (OH) group consists of an atom of hydrogen and one of oxygen which are attached to each other and act as a unit in chemical reactions. Bases have a bland taste and a slippery feeling. When they are dissolved in water, they dissociate into metallic ions and (OH) ions, the latter being negative. The (OH) ions turn red litmus blue.

$$NaOH \rightleftarrows Na^+ + (OH)^-$$

One of the strongest, and also one of the most dangerous bases is household lye (sodium hydroxide). It should be kept out of the reach of children, since they sometimes eat it because it looks like candy. Household ammonia (ammonium hydroxide, NH_4OH) is a water solution of ammonia gas (NH_3), and although it does not contain a metal, it has the

properties of a base. Limewater is calcium hydroxide ($Ca(OH)_2$), a weak base. Milk of magnesia contains magnesium hydroxide, another base. Bases combine with grease and are used for cleaning purposes (Chapter 19).

Salts

There is no more amazing experiment in science than the formation of a salt by the interaction of an acid and a base. If the experimenter adds a little phenolphthalein to a dilute solution of hydrochloric acid and then, drop by drop, introduces a dilute solution of sodium hydroxide, after a time the solution will turn pink, indicating that it is basic (Fig. 135). If more hydrochloric acid is added until the color just disappears and the solution is evaporated to dryness, the residue will be found to be sodium chloride. The neutralization of the ions of the acid by the ions of the base has produced a salt, a substance different from either the acid or the base. In the neutralization of a strong acid by a strong base, the process is that of the combination of the (H) and (OH) ions to form water. Most salts are formed when acids react with bases and consist of the metal of the base and the nonmetal of the acid. However, it must be emphasized that salts are formed in other ways as well.

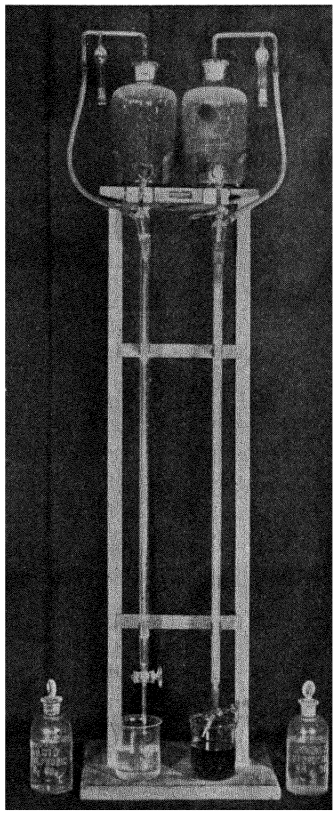


Fig. 135. Neutralization apparatus. An acid and a base are mixed to form a salt. In the beaker is an indicator whose color indicates the basicity of the solution.

Base plus acid yields salt plus water.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

Salts have a characteristic salty taste, many of them being neutral to litmus. Common household salts are table salt, washing soda, baking soda, borax, Epsom salt, sodium phosphate, and soap.

Water dissociates to a very slight extent into hydroxyl and hydrogen ions. These ions may interact with the ions of other substances. When washing soda or baking soda are dissolved in water, some molecules react with the ions of the water to produce carbonic acid, a very weak acid, and sodium hydroxide, a strong base. For this reason, the solution acts like

a base. A salt gives a basic reaction if its negative ions are derived from a weak acid and its positive ions come from a strong base.

In this connection, it is of interest to correct the fallacious idea that people afflicted with indigestion take baking soda to neutralize the excess acid in the stomach. The real effect of sodium bicarbonate is to stimulate peristalsis so that the stomach can empty normally.

Other Chemicals

In addition to the common chemicals which are classed as acids, bases, and salts, there are many others which do not come under these heads. A few are worthy of a brief description in this text.

The element chlorine, which has been mentioned as a constituent of sodium chloride, has important uses when dissolved in water. Chlorine

Table 12

Common Chemicals

Substance	*Common Name*	*Formula*
Copper sulfate.	Blue vitriol	$CuSO_4$
Iron sulfate	Copperas	$FeSo_4$
Potassium nitrate	Nitre	KNO_3
Sodium nitrate	Saltpeter	$NaNo_3$
Magnesium sulfate	Epsom salt	$MgSO_4$
Sodium carbonate	Washing soda	Na_2CO_3
Ammonium chloride	Sal ammoniac	NH_4Cl
Sulfuric acid	Oil of vitriol	H_2SO_4
Hydrochloric acid.	Muriatic acid	HCl
Sodium sulfate	Glauber's salt	Na_2SO_4
Boric acid	Boracic acid	H_3BO_3
Citric acid	Lemon juice	$C_6H_8O_7$
Acetic acid	Vinegar	$HC_2H_3O_2$

water has the property that the oxygen of the water is easily released in the atomic state in the presence of chlorine. This oxygen acts as a germicide and bleaching agent. As we have mentioned, chlorine is often used in water as a method of purification. Bleaching powder is a chlorine compound (calcium hypochlorite). Chlorine is also a constituent of some of the poison gases.

Bromine is another element used in many common chemical compounds. It finds its greatest uses in photography as silver bromide and in medicines as sodium and potassium bromide. Most of the bromine used in industry is recovered from sea water brines.

Explosives

Any chemical material which, when confined, burns rapidly and generates a high pressure is called an explosive. Gasoline explodes when mixed with the oxygen of the air and operates the gasoline engine by pushing on the pistons of the cylinders.

However, by the term "explosive" we usually mean those solids and liquids which are able to burn rapidly without the addition of oxygen. They are composed of nitrogen, oxygen, and carbon. Such explosives are used in road building, soil conservation, clearing of forest land, quarrying, and mining. However, in the minds of most persons they are associated with warfare. Modern warfare is largely a display of high-powered explosives.

The oldest explosive is gunpowder, made from potassium nitrate, sulfur, and charcoal. When ignited by a spark, large volumes of the oxides of carbon, sulfur, and nitrogen are produced. However, the rate of change in volume is slow compared to that of some of the newer explosives. Another disadvantage of gunpowder is the large amount of smoke produced.

The modern explosives produce only gases, since they contain the carbon, nitrogen, oxygen, and hydrogen atoms in the same molecule.

The basic principle of producing the modern explosive is that of nitrating some organic material. The first one produced was made by nitrating cellulose with a mixture of nitric and sulfuric acids. This material, called guncotton, is dissolved in acetone and made into rods and powder grains.

Another powerful explosive is nitroglycerine ($C_3H_5(NO_3)_3$). If glycerine is treated with nitric and sulfuric acids, an oily liquid which is dangerously explosive is produced. Every teacher of elementary chemistry should be on the lookout for schoolboy attempts along this line. The manufacture of nitroglycerine is accompanied by a great risk, as it is very sensitive to shock.

Alfred Nobel, a Swedish chemist, conceived the idea of mixing nitroglycerine with wood pulp. This made the material less dangerous to handle. The mixture is moulded into sticks called dynamite. Another development of Nobel was to mix acetone, guncotton, and nitroglycerine. This produced *cordite*, which is used in gunnery. As a result of his discoveries, Nobel acquired great wealth, which he used to found the Nobel foundation, which confers the Nobel prizes on outstanding scholars.

By nitrating phenol, the material *picric acid* is produced. This explosive has many peacetime uses.

However, the word explosive means to most persons TNT, trinitro-

toluene, a material produced by nitrating the hydrocarbon, toluene. TNT has become the standard wartime explosive due to its ease of handling—its action must be started by a primer—and to the violence of the explosion. Such a material is a bursting explosive and is not adapted for use in gunnery. Its value is in bombs and torpedoes. One cc. of TNT will produce nearly 9,000 cc. of gases in a fraction of a second. It is mixed with ammonium nitrate when used in bombs.

TNT was first used in warfare by Germany in 1914 and was so effective that the great fortifications of Belgium crumbled almost as if by magic. The armies were forced from the forts into trenches. In the Second World War, TNT was the principal explosive used in the great bombs dropped by airplanes.

The atomic bomb is discussed in Chapter 27.

Poison Gases

Despite the superiority of Germany's artillery at the outset of the First World War, both sides had reached a stalemate during the winter of 1914. In order to regain the advantage, Germany resorted to poison gas. In April, 1915, a row of tanks of liquid chlorine were laid down in the battlefield of Ypres. Waiting for a favorable wind, they released the gas and a cloud rolled over the Allied trenches. The soldiers were unprepared for such an attack and were demoralized. From that time on, poison gas was a weapon of both sides. After chlorine, phosgene was used. This gas is made by mixing chlorine and carbon monoxide in the light. Other gases were chloropicrin, sneeze gas, and tear gas, the latter two being used by police authorities of today in subduing criminals.

However, the most disastrous of all substances used as poison gas was mustard gas. Actually, the substance is a liquid and, when sprayed on the ground, it lingers, slowly evaporates, and poisons the surroundings for days. Many soldiers died from pneumonia from the effects of gas.

In this chapter, we have attempted to survey the history and fundamental principles of chemistry as a phase of science. No attempt has been made to give a complete treatment of the subject of general chemistry. Rather, we have discussed certain phases which serve as an introduction to the following chapters on the application of chemistry to our daily lives.

References

Arrhenius: "Chemistry in Modern Life," New York, D. Van Nostrand Co.
Clarke: "Marvels of Modern Chemistry," New York, Harper and Brothers.
Findlay: "The Spirit of Chemistry," New York, Longmans, Green and Co.
French: "The Drama of Chemistry," New York, The University Society.
Fries and West: "Chemical Warfare," New York, The McGraw-Hill Book Co.
Glasstone: "Recent Advances in General Chemistry," Philadelphia, The Blakiston Company.

Grady and Chittum: "The Chemist at Work," Easton, Journal of Chemical Education.
Hendrick: "Everyman's Chemistry," New York, Harper and Brothers.
McPherson and Henderson: "Chemistry for Today," Boston, Ginn and Co.
Slosson: "Creative Chemistry," Garden City, Garden City Publishing Co.

Questions and Problems

1. State five facts about each of these formulas: NaCl, H_2SO_4, Na_2CO_3, $Al_2(SO_4)_3$, $Ca(OH)_2$.
2. What are the symbols for: oxygen? carbon? sodium? nitrogen? gold?
3. How do atoms differ from ions?
4. How do acids differ from bases?
5. Why do some salts have an alkaline reaction?
6. What is the difference in structure between: hydrogen and oxygen? sodium and salt?
7. Name several common household chemicals.
8. What is meant by valence?
9. What is electrolysis?
10. What is meant by nitration of a substance?
11. Iron oxide contains 7 Gm. of iron to every 3 Gm. of oxygen. How much iron can be produced from 5,000 Gm. of iron oxide? Answer: 3,500 Gm.

Visual Aids

"Electrochemistry," University of Chicago Film
"Oxidation and Reduction," University of Chicago Film
"The Arrangement of Atoms and Molecules in Crystals," General Electric Co.

Topics for Discussion

Indicators	Explosives	Metallurgy
Ancient Drugs	Dentifrices Which Neutralize "Acid Mouth"	

Experiments

1. Acids. Place a few drops of vinegar or acetic acid in half a test tube of water. Test with litmus. Pour a few drops of this solution into a clean beaker of water and cautiously taste it. Cover a small piece of zinc in a test tube with dilute hydrochloric acid. What gas is given off? What have you learned about the properties of acids from this experiment?
2. Bases. Add a few drops of sodium hydroxide solution to half a test tube of water. Test with litmus. Feel a few drops between the fingers. (Wash your fingers with water. Do not wipe them on clothing.) State two properties of bases.
3. Salts. Dilute 1 cc. of concentrated HCl with 9 cc. of water. To 5 cc. of this diluted acid add 5 cc. of sodium hydroxide solution. (Assuming that the HCl, concentrated, is 13 Normal, a stock solution of NaOH of the same strength may be made by dissolving 52 Gm. of NaOH in 1,000 cc. of water.) Test the resulting mixture with litmus. Add, drop by drop, enough of either acid or base to make the solution neutral. Pour a few drops of the solution into a watch crystal, placing the crystal over a beaker of boiling water. When the water has evaporated, leaving crystals of the salt, compare your crystals with crystals from the stock bottle of NaCl. If possible, examine the crystals under a microscope.

4. INDICATORS. Use a few drops of each substance in the left hand column in half a test tube of water. In the case of liquid indicators, add two drops of indicator to each tube. Record the resulting color in the chart.

Substance	*Litmus*	*Methyl Orange*	*Phenolphthalein*	*Methyl Red*
HCl				
Na_2CO_3				
$Al_2(SO_4)_3$				
$NaOH$				
$NaCl$				

15. CHEMISTRY ASSOCIATED WITH LIVING THINGS

The citizen of our day uses modern science at each turn of his day's work.

—CALDWELL

Some of the interesting phenomena associated with the chemical properties of inorganic substances were described in Chapter 14. In addition, there are a great number of substances which are usually studied under the heading of organic chemistry—the chemistry of carbon compounds. Among the compounds of carbon, there are several hundred thousand connected with living matter. It is beyond the scope of this text to explore the maze of organic chemistry. We must content ourselves by describing a few substances which are common in our daily lives. Out of the nearly 500,000 compounds, there are many with which everyone is familiar. For example, the list includes such varied materials as foods, paper, rayon, soap, Bakelite, antiseptics, dyes, perfumes, rubber, Duco, plastics, glycerine, adrenaline, and penicillin.

Naturally, many organic compounds are derived directly from plants and animals. Examples are foods, enzymes, vitamins, vegetable medicines, many acids, olive oil, linseed oil, and flavoring materials. Fermentation gives us alcohol, lactic acid, and vinegar. The distillation of coal produces coal tar, which is the starting point for the production of hundreds of organic compounds.

There are certain differences between organic compounds and inorganic compounds which are worthy of note. Most organic compounds are soluble in ether and alcohol but not in water, while many inorganic compounds are not soluble in alcohol and ether. Most organic solutions are not conductors of electricity.

Organic chemistry may be said to have had its beginning in 1828. In that year, Friedrich Wöhler (Fig. 136) produced urea ($CO(NH_2)_2$), a constituent of urine, in the laboratory by heating the inorganic salt ammonium cyanate (NH_4CNO). It is interesting to note that, although the molecules of ammonium cyanate and of urea have the same number of atoms, they are entirely different substances because of the different arrangement of the atoms in the molecule. Such substances are called *isomers*.

Until that time, man had assumed that a gulf was fixed between ordi-

nary inorganic chemicals and those substances which were produced in living organisms (plants and animals). It had been assumed that some "vital force" was necessary to produce organic compounds. Accordingly, the synthesis of organic substances in the laboratory was considered to be impossible. Wöhler's discovery showed that this belief was incorrect, and the experiment opened the way for the preparation of thousands of

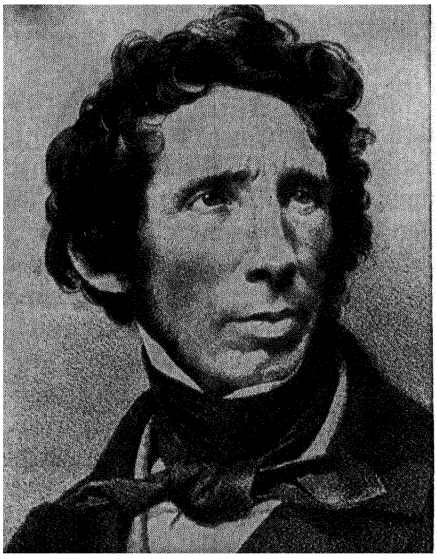
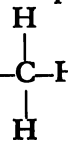


FIG. 136. Frederick Wöhler (1800–1882). A famous German chemist. (Courtesy, "Hackh's Chemical Dictionary," Philadelphia, The Blakiston Company.)

compounds, many of which were formerly found only in living organisms.

It was early discovered that the element carbon was the heart of all organic substances. In these substances, carbon has a valence of four. There are four electrons in the valence shell. The atom can form four bonds. This means that one atom of carbon can unite with four atoms of hydrogen or with two atoms of oxygen. Moreover, two atoms of carbon can unite with each other.

Since carbon does not, as a rule, form positive and negative ions, the combination of carbon with another element is called a sharing of electrons. Each bond represents two shared electrons. For example, methane (CH_4) can be represented by the structural formula



or by the

electronic formula $H:\underset{\underset{H}{\vdots}}{\overset{H}{\vdots}}{C}:H$. Each hydrogen atom shares its electron with the carbon atom, and the carbon atom shares one of its electrons with the hydrogen atom. The double dot indicates this fact. In the structural formula, each dash represents two shared electrons.

Carbon Compounds

Several hundred carbon compounds which are composed of carbon and hydrogen can be classified in four series known as the hydrocarbons. The four series are known as: the aliphatic or methane series, named for the gas methane (CH_4); the ethylene series from the gas ethylene (C_2H_4); the acetylene series from acetylene (C_2H_2); and the aromatic or benzene series named from benzene (C_6H_6). We shall describe some compounds of each series.

Methane Series	*Benzene Series*
Methane (CH_4)	Benzene (C_6H_6)
Ethane (C_2H_6)	Toluene (C_7H_8)
Propane (C_3H_8)	Xylene (C_8H_{10})
Butane (C_4H_{10})	Mesitylene (C_9H_{12})
Pentane (C_5H_{12})	
Hexane (C_6H_{14})	
Heptane (C_7H_{16})	
Octane (C_8H_{18})	

The methane series forms most of the constituents of petroleum. Methane (marsh gas) is an essential constituent of natural gas. Being found in coal veins, it is dreaded by the miners because it often causes disastrous mine explosions. It is known as "fire damp." Propane and butane are compressed in tanks and sold for house fuel. The hydrocarbons hexane to octane are constituents of gasoline.

The octane number of gasoline is a measure of its antiknock value. The hydrocarbon n-heptane knocks badly in a gasoline engine, while isooctane (2,2,4-trimethyl pentane) does not knock. The mixture of the two determines the antiknock value of the fuel. For example, a gasoline which has an octane number of 70 has a knock tendency equal to that produced by a mixture of 30 per cent n-heptane and 70 per cent isooctane. Both of these compounds belong to the methane series. One hundred octane gasoline is standard aviation fuel. Some of the new fuels have higher ratings. Triptane has an octane rating of 150.

One of the marvels of these substances is that the chemist can replace (substitute) the hydrogen atoms with other elements, thus forming new

compounds. In this statement lies the mystery of organic synthesis, the building up of complex substances from simpler ones. An example is the anesthetic, chloroform. When methane and chlorine are mixed, reactions are possible by which the compounds chloroform and methyl chloride are formed. The reaction for chloroform may be partially expressed as follows:

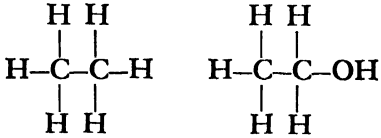
$$CH_4 + 3Cl_2 \rightarrow CHCl_3 + 3HCl$$

If methyl chloride is treated with sodium hydroxide, we form methanol. The chemist uses a graphic method of representing these reactions. It must be emphasized that the methods indicated are not always the most satisfactory ones for the preparation of the compounds.

By replacing all the hydrogen atoms by chlorine, we might produce CCl_4, which is the cleaning fluid carbon tetrachloride. (Actually, carbon tetrachloride is manufactured by a different process.) If we replace the hydrogen atoms by two atoms of chlorine and two atoms of fluorine, we produce the gas CCl_2F_2, "Freon," used in refrigeration (see p. 310).

We might think of methanol (CH_3OH) as being formed by a replacement of one hydrogen atom in methane by the hydroxyl radical OH. *This alcohol, often called wood alcohol because it was formerly distilled from wood, is a dangerous poison.* It causes blindness and even death when taken internally. It has extensive use in the preparation of varnishes and antifreeze solutions.

If we remove one hydrogen atom from ethane (C_2H_6) and replace it by chlorine, we form ethyl chloride, from which ethyl alcohol can be prepared. However, ethyl alcohol is usually prepared by the fermentation of grains. It is the alcohol which is used in beverages as well as in extracts, toilet preparations, and drugs. Pure alcohol is 200 proof. Ordinary grain alcohol is 95 per cent pure and is termed 190 proof. When ethyl alcohol is denatured by the addition of some substance which renders it unfit for drinking, it is not subject to tax. Such alcohol is used for solvents and for antifreeze solutions.



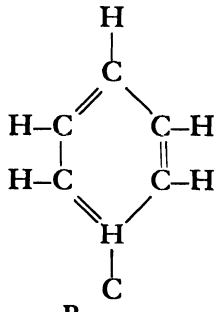
Ethane Ethyl alcohol

The benzene series is derived from soft coal. When coal tar is distilled, the chemist derives a series of compounds called aromatics. Among these are benzene, naphthalene, toluene, xylene, phenol, and anthracene. Most of these substances are well-known, naphthalene being used in moth balls

and phenol (carbolic acid) as a disinfectant and a source of many plastics (see p. 279).

One ton of soft coal yields about 60 pounds of coal tar. This coal will yield 10 pounds of benzene, 10 pounds of toluene, 25 pounds of phenols, and 50 pounds of naphthalene. From these compounds are produced several hundred intermediates, which, upon further synthesis, yield thousands of other substances. Fig. 87 shows schematically a few of the great variety of coal products.

The properties of benzene (C_6H_6)—not to be confused with the mixture of hydrocarbons used as gasoline—were first described by Michael Faraday. The chemist Friedrich Kekulé devised a structure of the compound by constructing a hexagonal structural formula. In this structural formula, each line represents a valence bond. It is worthy of note that x-ray studies justify the structural formula for benzene.



Benzene

The variety of possible substances derived from the benzene ring is almost beyond belief. About one-half of all carbon compounds are derived from benzene. When benzene is treated with nitric acid, nitro-benzene is formed, which by reduction with hydrogen forms the amine called aniline, a source of many dyes. Phenol is a benzene derivative in which one hydrogen atom has been replaced by an (OH) radical. When phenol is treated with nitric acid, we get the explosive trinitrophenol. The nitration of toluene produces trinitrotoluene (TNT). From phenol we also derive salicylic acid, plastics, acetylsalicylic acid (aspirin), and oil of wintergreen. Sulfanilamide, the well-known antidote for streptococcal infection, is also a derivative of benzene.

Other substances which are well known are rubber, ethylene, ethylene glycol (Prestone), and glycerine. Ethylene (C_2H_4) is a very interesting hydrocarbon. When mixed with oxygen, it is used as an anesthetic, replacing ether in some operations. Another commercial use for ethylene is in the ripening of fruits. If oranges are picked when still green and are subjected to an atmosphere of ethylene, the fruit develops both

better color and better flavor. A less happy use of ethylene is in the manufacture of mustard gas for warfare. Glycerine is a valuable chemical. It is used in the manufacture of nitroglycerine and synthetic resins and is an essential ingredient for skin lotions and medicines.

DYES

Dyes have been used from earliest times. Until rather recently, all dyes were of three types: vegetable dyes such as logwood and indigo; animal dyes, for example, cochineal and Tyrian purple; and mineral dyes.

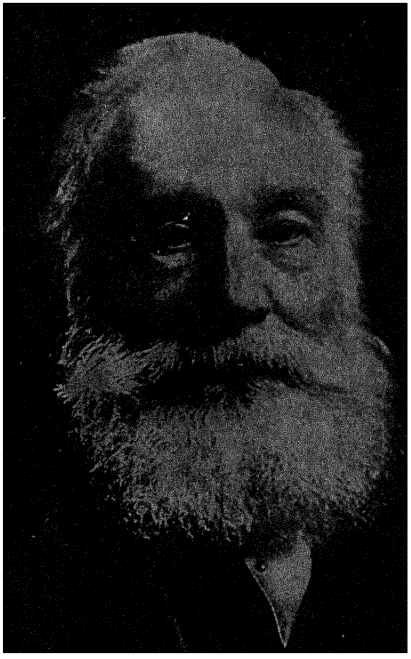


FIG. 137. Sir William Perkin (1838–1907). (Courtesy, Moore: "History of Chemistry," New York, McGraw-Hill Book Co., Inc.)

In 1856, William Henry Perkin (Fig. 137), an English chemist, was trying to produce quinine synthetically by oxidizing the dye base aniline, which is derived from benzene. To his surprise, his result was a black mass which, when dissolved in alcohol, made a beautiful violet liquid which could be used to dye wool and silk. He gave the name "mauve" to the dye. This was the first coal-tar dye ever prepared. Consequently, Perkin is called the "father of the coal-tar dye industry." The number of dyes derived from coal tar is more than 3,000.

Following up this discovery, Perkin produced the dye alizarin by the nitration of the aromatic, anthracene. Until this time, the turkey red dye alizarin had been produced from the root of the madder plant and was a French monopoly. As a result of the new method, red dye became very cheap and the madder root market was ruined.

German chemists now took up the study of dyes and produced a great variety of colors. The dye of the cochineal bug was replaced by azo-scarlet. Indigo, originally produced in India from the indigo plant, was made synthetically. Every reader of history is familiar with Tyrian purple, the symbol of royalty in the Roman empire. This dye was extracted from a sac in a shellfish along the coast of Tyre, hence the name. By analyzing this substance, scientists were able to produce a synthetic purple which was superior to the original. Each year new shades having their origin in the humble coal tar appear.

Some flavoring extracts and perfumes are composed of complex hydrocarbons. When the leaves, flowers, and bark of plants are distilled, pressed, or extracted, a group of essential oils is produced. From these oils we secure such varied compounds as camphor, menthol, lilac perfume, lemon oil, and many others. Most of the extracts and perfumes are now produced synthetically.

DRUGS AND MEDICINES

Man has always sought for methods of relieving pain and curing illness. Consequently, the search for medicines has been carried on since the dawn of history. Many human interest stories have come down to us in connection with methods of healing the sick.

The ancient Egyptians were familiar with such remedies as castor oil, aloes, peppermint, anise, juniper berries, and wormwood. Mixtures of these medicines were used for many purposes, including such serious diseases as cancer, tuberculosis, and kidney disease.

The drug opium, derived from the juice of the white poppy, has been known for 6,000 years as a remedy that would relieve pain. Opium is one of the drugs classed as alkaloids. These occur in dicotyledonous plants. Some other examples are nicotine from tobacco, atropine from the belladonna plant, cocaine from coca leaves, strychnine from nux vomica, and quinine from chinchona bark.

In the seventeenth century, quinine came on the scene as an invaluable medicine for the treatment of the dreaded malarial fever. Quinine and the two synthetic drugs plasmochin and atabrine have the property of killing malaria protozoa in the blood stream. They are specifics for malaria and travelers in the tropics use them daily. A synthesis of quinine was announced in 1944.

We all know the drug aspirin (acetylsalicylic acid) which is prepared

from phenol. This synthetic substance, together with the compounds salol and sodium acetylsalicylate, relieves congestion, neuralgia, headache, and rheumatism. It is necessary to guard against excessive use of these drugs. They affect the digestion and slow up the heart action if taken in large quantities. Some other synthetic drugs which we know are novacaine (an important drug replacing cocaine), mercurochrome, salvarsan, adrenaline, and ephedrine.

For years, the goal of the research pharmacologist has been to produce synthetic drugs which would prove to be specific cures for each disease caused by bacteria and protozoa. At present, nearly every disease due to protozoa can be cured by a synthetic drug. Even the diseases due to streptococcus and staphylococcus seem to be yielding to the synthetic drugs sulfanilimide and others prepared from aniline. Each day brings new cures of bacterial diseases by the amazing products of the chemical laboratory.

It is said that the most common American disease is constipation. We have become a nation of drug users in attempting to alleviate the condition. Many purgatives have the property of causing more water to enter the intestine. Probably the most common of these drugs is magnesium sulfate (Epsom salt). The presence of this salt in the intestine causes water to flow in through the walls due to osmotic pressure (see p. 258). A strong salt solution in the intestine and water outside the wall produce an osmotic pressure which tends to dilute the salt solution.

Other drugs, such as calomel and castor oil, are intestinal stimulants due to their irritating properties. Such drugs must be used with caution. In addition, there is a whole series of vegetable drugs which have the property of causing peristalsis of the intestinal tract. Some examples are cascara sagrada, rhubarb, senna, and aloes. Another type of purgative includes jalap, podophyllum, and gamboge. It is important to emphasize that no drug will cure the difficulty. Most of them will in time cause the intestine to become less active so that stronger doses must be taken.

Many persons have the impression that all vegetable drugs are harmless. This is entirely wrong. Some of the most dangerous drugs are of vegetable origin, e.g., the alkaloids just mentioned. Phenolphthalein, the essential ingredient of many laxatives, is a mild poison and will in time cause intestinal irritation.

RUBBER

A discussion of rubber rightly belongs in this chapter on the chemistry of carbon, since it is a member of this class of compounds. Rubber is contained in the juice of certain plants found mainly in the tropics. Rubber trees are raised in great numbers in the East Indies. When cuts are made in the bark of these trees, a milky liquid which can be coagulated flows out. The juice is an emulsion of particles of rubber in water.

When Columbus discovered America, he found the natives using a strange gummy substance. They made the substance into elastic balls. In 1731, La Condamine discovered the natives of Brazil playing with similar balls. This gum was investigated by the French but little attention was paid to it. It received its name by mistake. Priestley is reported to have discovered that a wad of the gum would erase pencil marks. On that account, he called it *rubber.*

The coagulation of rubber is brought about by various methods. When such chemicals as acetic acid or alum are added to the latex, a soft mass of crude rubber is formed. In order to make the rubber suitable for use, it must be vulcanized, a process discovered by Goodyear. In vulcanization, the crude rubber is mixed with compounds of sulfur. Other chemicals are added to give color to the material.

Rubber slowly oxidizes and becomes brittle. It is attacked by strong acids, the halogens, and by oils. Properly made rubber fabricated with cotton makes one of the toughest and most durable materials known. The modern automobile tire is an example.

Synthetic Rubber

For a long time, chemists had wished to produce rubber in the laboratory. They knew that when raw rubber (caoutchouc) $(C_5H_8)_x$ is heated, it decomposes into the liquid, *isoprene* (C_5H_8). Although isoprene was well known, it seemed impossible to reverse the process and polymerize the material into rubber. During the First World War, both Germany and Great Britain polymerized isoprene into a rubber-like material but the product was not durable. Not until 1931 was a synthetic rubber developed for commercial purposes. In its production, coal and lime are heated in an electric furnace, forming calcium carbide. When this material comes in contact with water, the gas acetylene is formed. A polymer of this gas called vinyl acetylene is mixed with hydrogen chloride and the product, *chloroprene,* results. Chloroprene gradually polymerizes to a yellow elastic material resembling vulcanized rubber. It is called *neoprene.* It should be emphasized that neoprene is not the same chemical compound as natural rubber.

Another source of synthetic rubber is butadiene, derived from ethyl alcohol. Butyl rubber has its source in isobutylene, which is derived from crude petroleum and natural gas.

The shortage of natural rubber which was created when Japan conquered the East Indies stimulated the production of synthetic rubber in the United States and Great Britain. Synthetic rubber is now produced in several ways.

All synthetic rubbers are deficient in rebound resilience. In automobile tires, this has the effect that considerable heat is generated in the

tire as it bounces over the road. Probably the best synthetic rubber for innertube use is *butyl*. This is usually mixed with considerable natural rubber and under this condition is very satisfactory.

References

Delmonte: "Plastics in Engineering," Cleveland, Penton Publishing Co.
French: "The Drama of Chemistry," New York, The University Society.
Lowy, Harrow, and Apfelbaum: "Organic Chemistry," New York, John Wiley and Sons.
Powers: "Synthetic Resins and Rubbers," New York, John Wiley and Sons.
Richardson and Wilson: "Fundamentals of Plastics," New York, The McGraw-Hill Book Co.
Simonds: "Industrial Plastics," New York, Pitman Publishing Co.
Whitmore: "Organic Chemistry," New York, D. Van Nostrand Co.
Williams: "Introduction to Organic Chemistry," New York, D. Van Nostrand Co.

Questions and Problems

1. What is the benzene ring?
2. For what was Perkin famous?
3. What was Wöhler's contribution to chemistry?
4. What is the difference between an organic and an inorganic compound?
5. Describe the production of natural rubber.
6. What does the term "synthetic rubber" mean?

Topics for Discussion

The Benzene Ring	Cathartics	Dyes
Synthetic Rubber	Patent Medicines	Polymerization[1]

Experiments

1. Place a little calcium carbide in a test tube and cautiously add a few drops of water. The gas emitted is the hydrocarbon acetylene C_2H_2. This gas is used in the oxyacetylene torch.
2. Consult a text on organic chemistry and write the equations for the production of several drugs.
3. Prepare the gas methane by dropping water on aluminum carbide. *Proceed cautiously.*
4. Preparation of Iodoform. Place 25 milliliters of a 20 per cent solution of potassium carbonate in a 150 ml. beaker and add 5 ml. of a special denatured ethyl alcohol. Heat in boiling water to 70–80° C. and add, in small portions with vigorous stirring, 2.5 Gm. of crystalline iodine. When the brown color has disappeared from the solution (add a few more drops of alcohol if necessary), cool, filter off the yellow crystals of iodoform, and wash them with distilled water. Iodoform, at one time, was used as an antiseptic until better compounds were made available.

   The formation of iodoform is not singularly confined to ethyl alcohol. However, its ready production from ethyl alcohol provides a simple way of quickly

[1] Polymerization is a chemical process by which single molecules unite with each other to form a more complex compound having different properties than the single molecules.

differentiating between the highly poisonous methanol (wood alcohol) and the less harmful ethyl alcohol (grain alcohol).

5. PREPARATION OF AN AZO DYE (Orange II). Dissolve 1 Gm. of sulfanilic acid in 2 ml. of a 10 per cent solution of sodium hydroxide in a 150 ml. beaker. Add to this solution 2 ml. of a 20 per cent sodium nitrite solution. Cool the solution to 5° C. by the addition of a few lumps of ice and packing the beaker in ice. When the solution is 5° C. or less, add slowly, with constant stirring, 5 ml. of 4N hydrochloric acid. Allow a lapse of 2–3 minutes and pour the contents of the first beaker *into* 10 ml. of an 8 per cent β naphthol solution contained in a second 150 ml. beaker. Allow the mixture to warm to room temperature. Note the formation of a highly colored compound, Orange II. *Be sure to thoroughly wash out both beakers when finished as some of the materials are explosive if allowed to become dry*. Orange II represents an azo compound which can dye cloth if properly applied.

16. NUTRITION

Nothing to do but work,
Nothing to eat but food.

—KING

FOODS

One of the most important problems of our daily lives is that of foods. A healthful diet must contain the proper amount of the various food substances; it must be adapted to the climate, to the age of the individual, to the amount of work done by him, and it must be present in digestible form (Fig. 138). Although the natives in tropical countries usually live on readily available fish and fruits, the peoples of the temperate zones have always been compelled to plan for their food supply. Early man obtained food mainly by hunting and fishing, but as civilization progressed, he became a tiller of the soil and later a herdsman. Modern life utilizes both animal and vegetable products in the diet. Food substances are often classed as carbohydrates, fats, and proteins.

CARBOHYDRATES

Among the most important of the foods used by both plants and animals is the great group of carbohydrates. This group, including sugar, starches, and cellulose, is composed of carbon, hydrogen, and oxygen. Perhaps the best known of the sugars is sucrose ($C_{12}H_{22}O_{11}$) which is extracted from sugar cane and sugar beets. Cow's milk contains lactose (milk sugar). In honey and fruits, we find levulose and its isomer, dextrose ($C_6H_{12}O_6$).

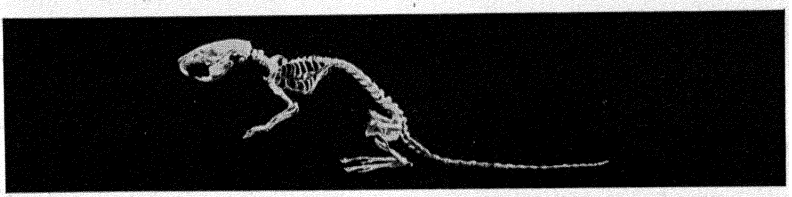
Most plants contain the carbohydrates glucose, starch, and cellulose. Starch grains in potatoes, wheat, corn, and oats are enclosed in cells having rather tough walls of cellulose. Consequently, it is necessary to cook the vegetables to break down the cell walls, so that the digestive juices can act more readily on the starch itself. In bread making, the flour is mixed with water, sugar, fat, and yeast. A group of enzymes (see p. 234) produced by the yeast plants cause the sugar to ferment to alcohol, liberating carbon dioxide. The gas causes the loaf to expand, and upon baking we obtain a light spongy mixture of digestible starch, protein, and fat. The alcohol is expelled during the baking process.

FATS

These substances are found in both the solid and liquid state. They are classified as fats of animals, such as lard, butter, and tallow, and the vegetable fats, which include palm oil, cocoanut oil, peanut oil, cottonseed oil, corn oil, and olive oil. The liquid fats contain olein. In the presence of a catalyst such as nickel dust (see p. 130), olein will combine with



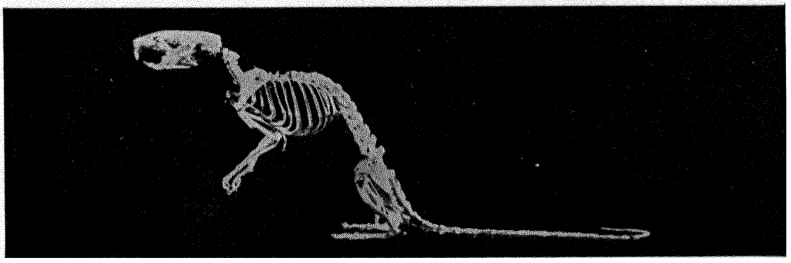
This rat ate only meat, potato, bread, and butter. He weighed 89 grams.



His bones also show the effect of poor diet.



This rat ate plenty of milk and vegetables, besides meat, potato, bread, and butter. He weighed 194 grams.



His bones are strong and well formed.

FIG. 138. Growth may be controlled by diet. Food made the difference in these twin brothers, 6 months old. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

hydrogen atoms to form the solid fat *stearin*. Crisco and Spry are made in this way (see p. 268). Oleomargarine is composed of beef fats, oils, and milk churned together.

There are some inedible fats, such as linseed oil and tung oil, which are used in the manufacture of paints and varnishes.

The body has the ability to store fats in the muscles of the various organs so that the animal can endure periods of famine. Animals such as bears and woodchucks, which hibernate in winter, store great layers of fat in the summer which sustains them in the winter. Humans who eat to excess store unwanted fat. Fats are a valuable food and are rather expensive.

PROTEINS

Proteins are complex substances which are essential for growth in the body. Some familiar ones are meats, egg albumin, the protein in beans and peas, the gluten of wheat, and the casein of milk. It is certain that the chemical changes in the synthesis of proteins are some of the fundamental characteristics of life. So far the chemist has made some progress toward the synthesis of proteins.

Proteins contain carbon, hydrogen, nitrogen, oxygen, and sometimes phosphorus and sulfur. The foul odor of spoiled proteins is due to the nitrogen and sulfur compounds formed during decomposition. Plants are able to synthesize proteins, but animals must obtain their protein materials from their food. Proteins, upon digestions, break down into amino acids, which are utilized in the human body by being absorbed into the blood and then synthesized into tissue substances, protoplasm, and cell membranes (Fig. 139).

Foods that are rich in proteins tend to exert an acidic effect on the body because a number of the end products are acids. On the other hand, fruits and vegetables generally exert an alkaline effect, due to the fact that they contain salts of calcium, sodium, and potassium. The acids are burned up in the body and the salts (e.g., sodium citrate) exert a basic effect in the body. It is interesting that in this way some of the acid fruits have an alkaline effect in the body.

DIGESTION

Carbohydrates, fats, and proteins supply all the energy used by the body. If a carbohydrate such as dextrose is oxidized, carbon dioxide and water are formed according to the equation

$$C_6H_{12}O_6 + 6O_2 \text{ yields } 6CO_2 + 6H_2O.$$

When a fat such as stearin undergoes oxidation, the reaction is as follows:

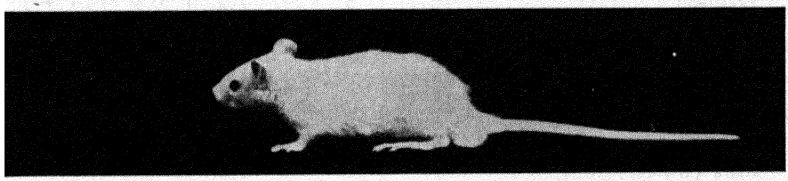
$$2C_{57}H_{110}O_6 + 163O_2 \text{ yields } 114CO_2 + 110H_2O.$$

The oxidation of a protein molecule is much more complicated. Beside carbon dioxide and water, nitrogenous wastes and urea are produced.

We eat a great variety of chemical compounds in our foods, many of them being very complex and insoluble in water. Digestion is necessary



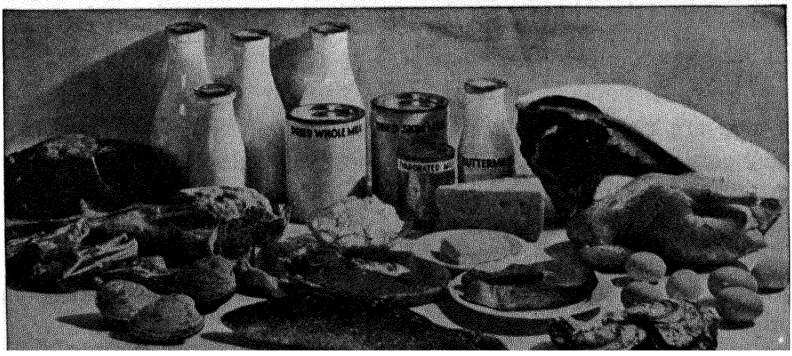
This rat had good protein but not enough. It weighed 70 grams.



This one had enough protein but of a poor kind. It weighed only 65 grams.



This one had good protein and plenty of it. It grew normally and weighed 193 grams.



Good protein foods: Milk, all forms–Eggs–Poultry, all kinds–Cheese–Meat, lean, all kinds–Fish–Shellfish.

FIG. 139. Protein for building muscles and all tissues. Rats from the same litter, 11 weeks old. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

Table 13

FOOD VALUES, PERCENTAGE BY WEIGHT

	Protein	*Carbohydrate*	*Fat*	*Crude Fiber*	*Ash*
Beans, navy (dry)	22.5	61 0	1 8	4 4	3.5
Lettuce	1 2	1.0	0 3	0 7	0.9
Peas (green)	5 8	10.6	0 5	1 7	1.0
Tomatoes	0 9	3.3	0 4	0 6	0.5
Apples (winter)	0.3	11.2	0.3	1.2	0.3
Oranges	0.8	8 5	0.2		0.5
Bread (white)	9 2	51 1	1.3	0 5	1.2
Oatmeal	16 1	67 5	7 2	0 9	1.9
Rice (polished)	6 9	77 4	0 3	0 2	0.4
Walnuts (English)	12 5	5 0	51 5	1 4	1.7
Beefsteak (grilled)	25 2		21 6	.	1.0
Eggs	13.4		10 5	.	1.0
Butter...	1 0		85 0		3.0
Cheese (American)	29 0	0 3	36.0	.	3.4
Milk (whole)	3 3	5 0	4 0	.	0 7
Molasses	2 1	69 3		.	3 2
Olive oil			100		.

to break foods into a few simple substances which are soluble in water. In order for us to derive benefit from our food, it must pass through the intestinal walls into the blood.

When we consider that our body cells are too small to be seen without the aid of a microscope, and when we realize that these cells must convert molecules of food into molecules of body substance and in addition must oxidize food for body energy, we can readily understand why digestion is important. Digestion is made possible by a set of catalysts called enzymes.

ENZYMES

These are catalytic substances present in all living cells. They are organic compounds and play a part in most physiologic processes. A number of enzymes have been produced in a pure state. When they are analyzed, they are found to be proteins or to resemble proteins.

The enzymes in the digestive tract aid in the digestion of food. Examples of such enzymes are pepsin, rennin, lipase, and trypsin. Zymase, found in yeast, converts glucose to alcohol and carbon dioxide. The enzyme sucrase, which is found in tissues, hydrolyzes sucrose to glucose and fructose.

Enzymes are interesting because each one has a specific function in a physiologic process. Only a very small amount of the enzyme is needed to produce the desired chemical change.

SALIVARY DIGESTION. The principal digestion taking place in the mouth is the conversion of starch to sugars. Starch molecules are very large, the smallest starch molecule having the probable formula ($C_{1200}H_{2000}O_{1000}$). Such molecules are either insoluble or very slightly soluble in water, depending on their size, but even the smallest are too large to pass through the intestinal wall. To change starch to sugar in the laboratory, it is necessary to boil it with hydrochloric acid for 20 to 30 minutes. In the mouth, we can convert starch to maltose in less than 60 seconds at body temperature. Two enzymes, ptyalin and maltase, act as catalysts to bring about this astonishing change.

GASTRIC DIGESTION. The gastric juice contains three enzymes which are important: rennin, which curdles milk; pepsin, which changes complex proteins to simple proteins known as peptones and proteoses; and a small amount of lipase, which converts emulsified fats (see p. 268) to fatty acids and glycerine. There is half of one per cent of hydrochloric acid in gastric juice. One of its several functions is the control of protein digestion. It also aids in the digestion of sugars.

Simple sugars, alcohols, and some drugs (aspirin being one) are absorbed into the blood directly from the stomach, but the large mass of food is retained for one or more hours, being passed into the intestine very gradually.

INTESTINAL DIGESTION. Digestive juices from three sources carry on intestinal digestion. Pancreatic juice is secreted by the pancreas, a small gland lying behind and below the stomach. It contains sodium carbonate, which neutralizes the hydrochloric acid; trypsin, which splits any undigested proteins to peptones; steapsin, which digests fats; and amylopsin, which digests carbohydrates.

Bile secreted by the liver does not contain any enzymes, but it accelerates the digestion and solution of fats.

Intestinal juice is formed in the walls of the intestine itself. It contains erypsin, which splits peptones into amino acids, and three enzymes, maltase, sucrase, and lactase, which complete carbohydrate digestion.

Other substances, such as iron, calcium, and phosphorus, are also needed in digestion.

VITAMINS

For many years, the students of food chemistry had been faced with the dilemma that despite the fact that they were able to analyze foods and could determine their composition with seeming great precision, these food elements alone did not suffice for satisfactory nutrition. They were aware that an animal may be fed all the basic foods in a pure form and yet will not grow or develop properly.

The history of nutrition has provided some very puzzling problems.

Table 14

VITAMINS

	Sources in Diet	*Other Sources*	*Deficiency Effects*	*Results from Use*	*Chemical Nature*
A	Carrots, spinach, prunes, butter, liver, beans, turnip greens	Fish liver oil, β-Carotene, Synthetic vitamin A	Loss of appetite, eye trouble, colds and respiratory ailments, xerophthalmia, night blindness	Good appetite, resistance to infection	Vitamin A esters
D_2 D_3 D_4 D_5	Sea foods, a very little in vegetables	Cod liver oil, irradiation of ergosterol and fats, yeast	Rickets, bad teeth, constipation	Proper metabolism of calcium and phosphorus, good bone structure	D_2 (called Calciferol) Viosterol
E	Cereals, lettuce, spinach, milk, eggs, meat	Wheat germ, oil, and lettuce leaves	Reproductive sterility in rats	Fertility and cell growth	Group classed as tocopherols
C	Peppers, spinach, peas, tomatoes, lemons, oranges, raw milk, liver	By synthesis	Scurvy, colds, poor bone structure	Resistance to infection, good bone structure, growth	Ascorbic acid
B_1	Whole cereals, vegetables, oranges, prunes, milk, egg yolk, liver	Baker's yeast	Beriberi, colds, poor digestion, nervous instability	Good appetite and digestion, resistance to infection	Thiamine hydrochloride
B_2 or G	Green vegetables, oranges, eggs, apples, milk, lean meat, liver	Brewer's yeast, liver extract	Anemia, bad digestion, bad skin, leg stiffness, pellagra	Good digestion, good nutrition, good skin	Riboflavin
B niacin	Whole wheat, liver, yeast, pork, veal, brown rice	Nicotinic acid	Pellagra		Nicotinic acid
B_6	Wheat, lettuce, spinach, milk, yeast	Pyridoxine	Rat pellagra		Pyridoxine hydrochloride

During the American occupation of the Philippine Islands, the army officers tried to better the prison fare by substituting white polished rice for the brown rice which had been the standard prison fare. Within a short time beri-beri, a nervous paralysis, broke out and was only checked when the diet was changed.

It has long been known that sailors who lived for long periods on a diet which contained no fresh vegetables or fruits developed scurvy, which could be checked by drinking fruit juices. Because of this fact, sailing vessels were often called "lime juicers" because of the lime juice they carried to combat scurvy.

Again, many infants who had been fed with the most expensive foods developed rickets, a disease of the bones, while other youngsters who lived on very cheap food did not have this difficulty.

Consequently, food chemists began experiments in feeding laboratory animals, particularly rats, with the result that certain substances were discovered to be present in foods in such small amounts that they escaped detection by laboratory analysis. These substances were called vitamins because they seemed essential to the well-being of living organisms. Our daily requirement of these substances is a very small amount indeed. A vitamin is a chemical substance which is necessary in small amounts for the proper functioning of the body. It must be obtained from outside sources.

As was mentioned in connection with enzymes, complicated chemical changes must take place in the body without the benefit of high temperatures or strong reagents. Each vitamin serves specific catalytic functions in the body, thus enabling chemical changes to take place quickly under ordinary conditions. It may be that the vitamins are necessary links in the formation of essential enzymes, especially those concerned with oxidation.

It will be of interest to describe some of the vitamins. Many have now been identified as definite chemical compounds. In such cases, we shall give both the older name and the newer chemical name. Much of the uncertainty and mystery has been removed from the subject of vitamins since some have been synthesized.

VITAMIN A promotes growth, helps to maintain a healthy respiratory tract, prevents an eye disorder called xerophthalmia, maintains the integrity of the epithelial and nerve tissues, and aids in reproduction. It has long been known, for instance, that milk and eggs (good sources of vitamin A) are helpful in the dietaries of tubercular patients. Vitamin A is fairly stable but is partially destroyed by cooking at high temperatures in the presence of air. The carotenes in carrots and other vegetables change into vitamin A in the body (Fig. 140).

Vitamin A deficiency is not of great importance in any locality where

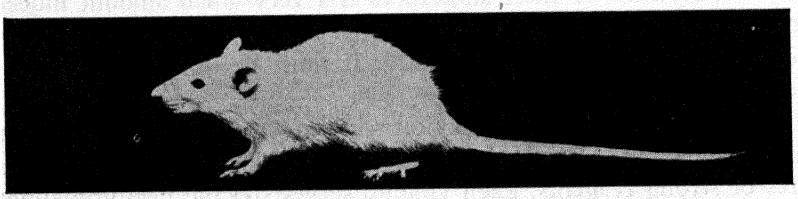
vegetable and dairy products are plentiful. A quart of milk provides all the vitamin A needed by very young children.

VITAMIN B. There are at least 10 vitamins listed under the name of vitamin B. Some of these are not completely identified.

VITAMIN B_1(thiamine) aids digestion and appetite, maintains the integrity of the nerves, and prevents beri-beri. In past generations, winter dietaries did not contain much vitamin B_1. Fatigue, loss of appetite, rheumatism, and nervousness were common complaints in late winter. Spring tonics were popular. With the coming of fresh fruits and vegetables, the disorders cleared up, to the underserved credit of patent medicines and



This rat had no vitamin A. It weighed only 56 grams. Note the infected eye, rough fur, and lack of vigor.



This one had plenty of vitamin A and weighed 123 grams. It has bright eyes and sleek fur and is vigorous.



Foods rich in vitamin A: Butter and cream—Whole milk—Cheese, made from whole milk—Eggs—Liver, all kinds—Cod-liver oil—Other fish-liver oils—Salmon, red—Green and yellow vegetables—Yellow fruits—Tomatoes—Olives.

FIG. 140. Vitamin A for growth, and the prevention of certain infections. Rats from the same litter, 11 weeks old. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

the old time remedies. Vitamin B_1 is not very stable at high temperatures. It can be produced from rice polishings and by synthesis. The chemical formula is now known (Fig. 141).

VITAMIN B_2, called *riboflavin*, is an important factor in general bodily vigor and growth. This vitamin has been prepared in the laboratory. Its chemical name is riboflavin mononucleotide.

The B vitamin called *niacin* both prevents and cures the disease pellagra. Its chemical name is nicotinic acid. Because the public confused



This rat did not have enough vitamin B. The lack of muscle control is called spastic paralysis.



The same rat 24 hours later, after receiving a food rich in vitamin B. Already it has recovered muscle control.



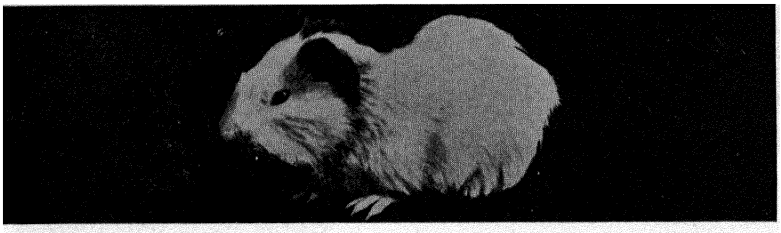
Good sources of vitamin B: Milk, all forms—Fruits—Vegetables—Whole grains—Nuts—Beans, peas, and other legumes—Liver and other edible organs —Egg yolk—Lean pork—Oysters.

FIG. 141. Vitamin B for good appetite and good muscle tone. Female rat, 24 weeks old. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

this name with nicotine, the vitamin is called niacin. Vitamin B_{12} seems to be effective in the treatment of pernicious anemia.

Some other B vitamins which are at present of less importance are pyridoxine (B_6), pantothenic acid, inositol, biotin, and choline. Their value in the human dietary has not been fully studied.

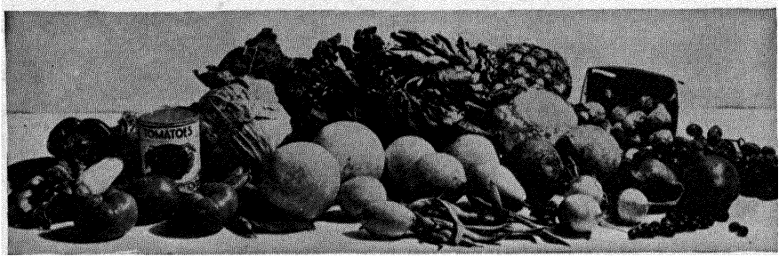
VITAMIN C. The history of vitamin C goes back to ancient Greece. Since the beginning of history, armies have been scourged by scurvy. The disease manifests itself by swelling of arms and legs, rotting of the gums, and loss of teeth. It was early noticed that fresh vegetables and fruit juices prevented and cured scurvy. The modern use of orange, tomato, and other fruit juices has made this disease rather rare among most peoples (Fig. 142).



This one had no vitamin C and developed scurvy. Note the rough fur and crouched position due to sore joints.



This one had plenty of vitamin C. It has sleek fur and is healthy and alert.



Good sources of vitamin C: Fresh fruits, especially citrus fruits–Tomatoes, fresh and canned–Fresh vegetables, especially cabbage–Sprouted legumes.

FIG. 142. Vitamin C for healthy gums and teeth. Guinea pigs of the same age. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

VITAMIN E. In 1922, it was found that a substance present in certain leafy vegetables aided reproduction in rats. The best natural source of vitamin E, as it is now called, is wheat germ oil. Thus far the knowledge of the action of this vitamin is not complete.

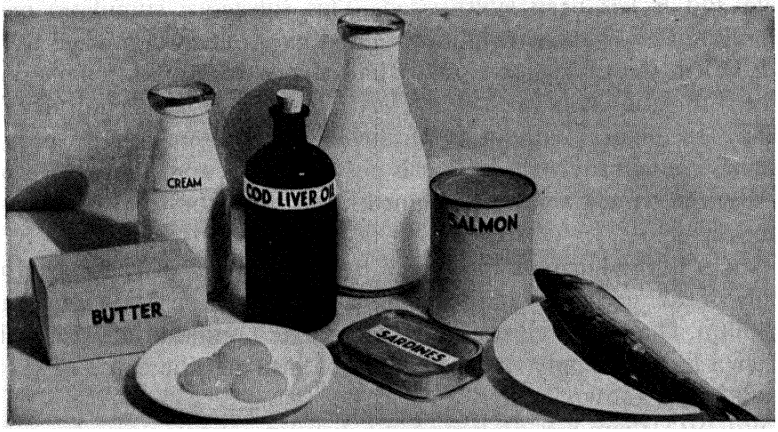
VITAMIN D. This compound is called the antirachitic vitamin. It causes calcium and phosphorus to be deposited in bones and teeth. The compounds of calcium and phosphorus which are carried in the blood stream are converted into bone in the body, provided vitamin D is present. If



This rat had no vitamin D. Note the short body and bowlegs—typical signs of rickets.



This one had plenty of vitamin D. Its bones are strong and straight.



Foods that supply vitamin D: Fish-liver oils—Certain other fish oils—Oily fish, such as herring, sardines, salmon—Small amounts in milk, cream, butter, eggs.

FIG. 143. Vitamin D for good bones and teeth. Rats from the same litter, 20 weeks old. (Courtesy, Bureau of Home Economics, U.S. Dept. of Agr.)

there is a deficiency of vitamin D, rickets result. The nervous system is affected first, then the muscles, skull, and sternum. Arm and leg bones are affected last. In very young infants, the soft spot on top of the head hardens late and other skeletal deformities develop (Fig. 143).

Actually, there are several vitamins belonging to the vitamin D family. Vitamin D_3 is found in cod liver and halibut liver oil and in egg yolks. When the organic sterols, such as ergosterol, which are present in many animal tissues, are irradiated by ultraviolet light, the vitamin D_2 is produced. It is now common practice to irradiate milk and other food products containing sterols in order to produce the vitamin in the food.

The K vitamins are chemicals which assist in blood clotting. They have been produced in a pure form just recently. They occur in the green leaves of vegetables and are formed in the intestines by bacterial action.

VITAMIN X, the newest of the vitamins, is found in lettuce, egg yolk and meats. Grass and alfalfa are excellent sources. It plays an important role in the palatability of foods.

HORMONES

The third class of body catalysts, the hormones, are manufactured in a set of ductless glands. From these glands, the hormones find their way into the blood stream. They influence activities of the body.

ADRENALINE is an important hormone of the adrenal glands. It has the property of constricting the blood vessels. Two similar substances (which have been synthesized) are ephedrine and benzedrine.

THYROXINE comes from the thyroid gland. Its chemical formula is known and it has been synthesized. This substance stimulates energy metabolism. Goiter is the condition caused by an undernourished thyroid gland. When the thyroxine is taken into the body, it takes effect slowly but the stimulation lasts for weeks. Herein lies part of the danger of taking reducing medicines without a physician's supervision. Most reducing medicines contain thyroxine and it is possible to accumulate such an overdose that the tissues will be consumed. Death may be the result of such a practice.

INSULIN is the hormone produced by tiny groups of specialized cells (islands of Langerhans) in the pancreas. Its function is to start sugar metabolism. Diabetes mellitus is the pathologic condition in which there is either a limited supply or a total lack of insulin. The cause of the deficiency is not known.

Until 1932, there was no hope for a diabetic patient, since the real nature of diabetes was not understood. With the discovery of insulin by Banting and Best, the hormone can be given by injection to diabetics, enabling them to eat a normal diet. One source of insulin is beef pancreas.

There are many hormones which control various organic activities of plants and animals. They represent fascinating problems to the physiologist and when they are present in abnormal amounts they cause profound changes in body functions.

References

Beery: "Chemistry Applied to Home and Community," Philadelphia, J. B. Lippincott Co.
Berman: "Glands Regulating Personality," New York, The Macmillan Co.
Borsook: "Vitamins," New York, The Viking Press.
Eddy: "What are the Vitamins?" New York, Reinhold Publishing Corp.
Gordon: "Nutritional and Vitamin Therapy," Chicago, Yearbook Publishers.
Sherman: "Chemistry of Food and Nutrition," New York, The Macmillan Co.
Sherman and Smith: "The Vitamins," New York, Chemical Catalogue Co.
Summer and Somer: "Chemistry and Methods of Enzymes," New York, Academic Press.
Williams: "What to do about Vitamins," Norman, University of Oklahoma Press.

Questions and Problems

1. Name and describe the classes of food.
2. What are hormones?
3. What is meant by the term vitamins?
4. Describe the process of starch digestion.
5. How is a fat digested in the body?
6. Why is it difficult to digest half-cooked starch?
7. What is beri-beri?
8. Explain the process of bread making. Why do we use yeast?

Topics for Discussion

Vitamins Hormones Basic Foods
Intestinal Digestion

Experiments

1. Fermentation of Sugar. For this experiment, use a 20 per cent solution of sugar or use one part of Karo and three of water. Add one yeast cake, which has been broken into bits. Set aside in a warm (about 75°–80° F.) place for a day. Carbon dioxide gas is generated and alcohol is formed. The alcohol can be distilled off and recognized by its odor. It can be further identified by adding strong acetic acid and concentrated sulfuric acid to a little of it. A fruity odor results. This experiment not only demonstrates the changing of one organic compound into another, but also illustrates the work of yeast.
2. Test for Sugar. To a few cc. of any sugar except sucrose add a little Benedict's reagent. Heat to boiling and note color. This test identifies sugar as a group. Cane sugar, however, does not respond. Karo, honey, or bananas may be used.
3. Test for Starch. Boil a very small pinch of starch in half a test tube of water. Let it cool and when cold add tincture of iodine. Blue indicates starch; violet indicates dextrin.
4. Test for Protein. There is no test which will identify all proteins. Certain tests will identify certain organic groupings, which may or may not be present in protein. These groupings may also be present in nonprotein material. The most uni-

versal test is the Biuret test. To a little egg white, add concentrated sodium hydroxide and a very dilute copper sulfate. Warm gently. A purple color indicates protein; a red-violet color indicates partially digested protein.

5. TEST FOR FAT. Place a piece of meat fat or other fat on a piece of brown wrapping paper. Warm it in an oven. A translucent spot indicates fat.
6. Make up a balanced diet consisting of 2,500 calories for yourself for one day.
7. Make a list of vitamins and their uses.
8. Place a green plant in the dark for two days. Note the change in color.

17. WATER AND ITS APPLICATIONS IN DAILY LIFE

Pure water is the best of gifts that man to man can bring.
—AUTHOR UNKNOWN

Because of the fact that water is such an intimate part of our daily lives, we rarely think of it as an interesting substance. Actually, water is one of the most curious substances on the earth. It may exist as a vapor, liquid, or solid under ordinary conditions. It acts as no other substance in that it contracts upon cooling until the temperature of 4° C. is reached, at which point its density is greatest. One cc. of pure water at 4° C. weighs exactly 1 Gm.

As it is cooled further, it expands and freezes at a temperature of 0° C. This explains why ice floats on water. One cubic foot of pure water weighs 62.4 lb., and 1 cubic foot of ice weighs only 56 lb. About $\frac{1}{9}$ of a cake of ice floats above the surface of water.

The amount of water on the earth is enormous, over $\frac{3}{4}$ of the globe being covered with oceans. In addition, the solid crust itself contains an amazing quantity of water. Water penetrates nearly everything; even granite has about one half pint of water per cubic foot. The atmosphere contains great quantities of water and water vapor. Glaciers are composed of ice, the solid form of water. All plants and animals must have water to live. About $\frac{4}{5}$ of the weight of animal tissue is water, while some plants are as much as 95 per cent water.

Since water is such a common substance, we use it in many ways as a standard. We use the freezing point and the boiling point as fixed points for thermometer scales. It is used as a reference unit for specific heat, specific gravity, the calorie, and the British thermal unit (see p. 302).

Water (H_2O) is composed of hydrogen and oxygen. As we ignite a jet of hydrogen and hold the flame under a cool surface, we see drops of water forming. If a current of electricity is passed through acidulated water, the water molecules are separated into hydrogen and oxygen. In performing the experiment, acidulated water must be used, since pure water is a nonconductor of electricity.

WATER PRESSURE

Every swimmer is aware of the fact that water exerts a pressure due to its weight. Many pearl divers have ruptured their eardrums and have

suffered internal injuries by descending too far under water. The force of water sometimes causes dams to collapse, with loss of life and property. Submarines must be built with great strength to withstand the tremendous crushing force of the water when they are submerged. *The force exerted by a liquid on any submerged surface is equal to the density of the liquid times the area of the surface times the depth of the center of gravity of the surface.* For example, the eardrum has an area of about $\frac{1}{500}$ of a square foot. If a diver is submerged to a depth of 25 ft., the force on the drum is $\frac{1}{500} \times 62.4 \times 25$ or about 3 lb. Since pressure is defined as the force on a unit area, the pressure on the drum would be expressed as about 1500 lb. per sq. ft. Such a force may rupture the eardrum.

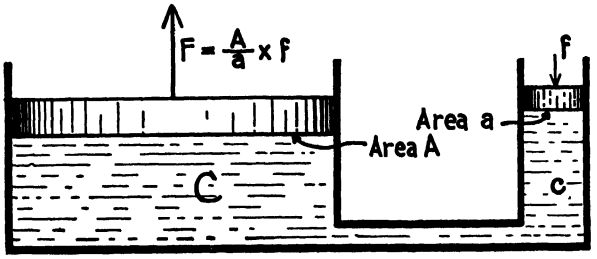


FIG. 144. Model of a hydraulic press. The small piston has area a and the large one area A. F/f equals A/a. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Many of us have thrilled to the exploits of Beebe, who descended over 3000 ft. in sea water in order to study marine life at great depths. He used a metal sphere built to withstand a great crushing force of about 1400 lb. per sq. in. His observations were made through a quartz window 10 in. thick. (The density of sea water is 64 lb. per cu. ft.)

The force exerted by confined liquids is illustrated by the hydraulic press. This powerful machine is a familiar sight at service stations, where it is used to raise automobiles for repair. The mechanism consists of a large cylinder which supports the car and a small piston which moves by the action of compressed air (Fig. 144). The two are connected by a well of oil or water. As the small piston moves down, it forces liquid into the cylinder chamber and the cylinder rises slowly. The force on the plunger (f) is much less than the weight (F) of the automobile. The law which applies to this case is:

$$\frac{\text{Weight lifted}}{\text{Force on piston}} = \frac{\text{Area of cylinder}}{\text{Area of piston}}$$

The hydraulic press acts on the principle which states that pressure applied to one point of a confined liquid is transmitted equally and

undiminished in all directions to all points of the containing vessel. If we have a hollow sphere with surface area of 10 sq. in. filled with water and if we exert a force of 1 lb. on 1 sq. in. of the surface, there will be a force of 1 lb. on each square inch or a total of 10 lbs. As we pump up a tire, the pressure applied at the valve is transmitted to all parts of the tube.

Specific Gravity

Every automobile driver is familiar with the hydrometer used to test the concentration of acid in the storage battery. When a battery is fully charged, the liquid should have a specific gravity of about 1.275, the figure varying slightly in different makes of batteries. As the battery is discharged, the specific gravity drops and may safely fall to 1.18 without causing injury to the cells of the battery. Specific gravity is the relation between the weight of an object and the weight of an equal volume of water. It is expressed by the following formula:

$$\text{Specific Gravity} = \frac{\text{Weight of a body}}{\text{Weight of an equal volume of water}}$$

A more useful form of the relation is as follows:

$$\text{Specific Gravity} = \frac{\text{Weight of a body}}{\text{Weight of a body} - \text{weight of the body in water}}$$

In a storage battery, this means that the liquid weighs 1.275 times as much as the same volume of water (Fig. 145).

As an illustration of the use of the formula, we shall solve a simple problem. A piece of brass measuring $1 \times 2 \times 4$ cm. weighs 67.2 Gm. on a laboratory balance. Its volume is 8 cc. Eight cc. of water at 4° C. weigh 8 Gm. Hence, 8 cc. of brass compares in weight to 8 cc. of water as 67.2 compares to 8, or the specific gravity of the brass is 8.4.

Table 15

Specific Gravities

Aluminum	2.7
Brass	8.4
Copper	8.9
Cork	0.2
Gold	19.3
Iron	7.9
Lead	11.3
Mercury	13.6
Oakwood	0.8
Pinewood	0.6
Platinum	21.4
Silver	10.5

Buoyancy

One of the most interesting phenomena associated with liquids and gases is that of buoyancy. Balloons and dirigibles float in air, and many objects float in water. When we are swimming, we find that it is very easy to pull ourselves out of water until we are part way out, when we seem to grow heavier. We notice this when climbing from water into a boat. As long as we are entirely immersed in the water, we can pull ourselves up easily, but when we are nearly out of the water, it is difficult to climb into the boat. Swimmers in the Dead Sea and in Great Salt Lake have difficulty in swimming because the buoyancy of the salt water pushes the feet higher than the head. Because of the buoyancy of water, ships travel the sea and animals can float and swim. In fact, the size of a ship is given in tons displacement, meaning the number of tons of water displaced by the ship when it is loaded to capacity. Buoyancy is the property of liquids and gases by which they support objects immersed in them (see page 155).

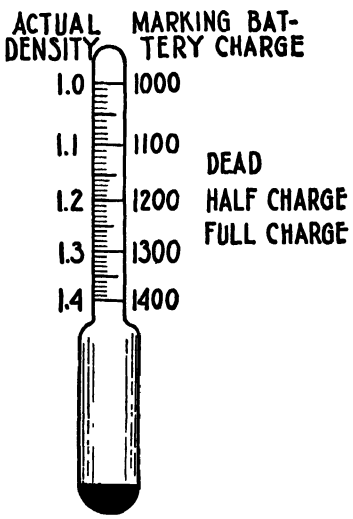


Fig. 145. Storage battery hydrometer. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

The principle of buoyancy was first stated by Archimedes, the philosopher of Syracuse, about 240 B.C. This principle may be expressed as follows: *A body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid.* A consequence of the principle is that objects which do not weigh more than an equal volume of the gas or liquid, float. In other words, objects which have a specific gravity of unity or less than unity float in water.

An interesting legend tells of the circumstances which led to the discovery of the principle. It seems that Hiero, the tyrant of Syracuse, had commissioned a goldsmith to fashion a gold crown. After receiving it, Hiero became suspicious that considerable silver had been used. He asked Archimedes if one could detect the presence of silver in the gold crown. Archimedes hit on the answer by noticing that, while submerged in the bath, his body displaced an equal volume of water. He also recognized that the force buoying up his body was the weight of the water displaced. He solved the problem by weighing the gold crown and an equal weight of pure gold, first in air, and then when submerged in water. Were the crown alloyed with silver, the apparent loss of weight should be greater than for the gold bar. We may illustrate this principle by an example. Let us suppose that the block of

pure gold weighs 20 lb. and has a specific gravity of 20. When immersed in water the block would apparently weigh only 19 lb., a loss of 1 lb. However, if the 20 lb. crown were an alloy of gold and silver having a specific gravity of 13, then the apparent loss of weight would be 1.8 lb. Thus, an adulteration could be easily detected without injuring the crown.

A 1 cm. cube of a material heavier than 1 cc. of water sinks and displaces 1 cc., or 1 Gm., of water. Because of this displacement, it seems to weigh 1 Gm. less than it originally weighed. There is a greater pressure (because of the greater depth) pushing on the bottom of the cube than on the top of the cube. If the force downward is 5 Gm. and the force upward is 6 Gm., the block experiences a buoyant force of 1 Gm., which is the weight of the water displaced (Fig. 146).

The volume of an irregular object such as a stone which has a specific gravity greater than water may be determined by placing it in a vessel that is completely filled with water. The volume of the overflow is the volume of the body. Or, by Archimedes' Principle, if we weigh the stone in air and when under water, the *apparent* loss of weight of the body as measured in grams is equivalent to the volume in cubic centimeters.

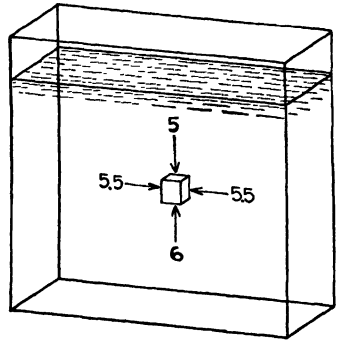


FIG. 146. The pressures on the sides of a 1 cm. cube submerged 5 cm. below the surface of water are equal. There is greater pressure on the lower surface than on the upper.

WATER PURIFICATION

The problem of securing an adequate and satisfactory supply of drinking water for cities is a serious one. Some cities, such as Philadelphia, Pennsylvania, and Columbus, Ohio, secure water from rivers. New York City maintains great reservoirs, which are carefully protected from pollution, in the Catskills. Wells are not permitted in congested communities because there is always the danger of contamination.

Water is never found pure in nature. The impurities which get into water as it flows over and through the ground may be classified roughly into suspended material, dissolved matter, and colloidal substances. Drinkable water should be free from poisonous substances and disease-producing organisms. It should have a pleasant taste and no objectionable odor. The purification processes usually include sedimentation, filtration, and chlorination.

SEDIMENTATION. In the laboratory, suspended matter is removed by filtering through filter paper. Such a method would be much too slow and

costly for large volumes of water. The usual city filtration bed consists of a large tank with outlet pipes along the floor. The bottom of the bed is covered with rocks on which are placed layers of coarse pebbles, gravel, and sand, in the order named (Fig. 147). Water flows into the bed at the top and leaves by the pipes at the bottom. At periodic intervals the flow of water is stopped and the bed is cleaned by forcing air and water through the bottom. The debris is carried off at the top.

Because of the large basins which would be required for simple sedimentation, coagulants are used in connection with the process. The coagulant such as alum reacts with the alkaline salts in the water to form a gelatine-like material which settles. It is essential that the water have the proper alkalinity. If this is not true, alkalis must be added. Many bacteria and protozoa are trapped by the coagulated mass, so that the method is also a disinfecting one.

FILTRATION. This is similar to sedimentation except that the water is passed through some porous material.

BOILING. By this process, living organic matter is destroyed and carbonate hardness is removed. In case of doubt, all drinking water should be boiled.

DISTILLATION. Distillation differs from boiling in that the steam is passed through condensers and is then collected as distilled water. This process is used whenever extremely pure water is needed. Drug stores, laboratories, storage batteries, and many industries require distilled water. The water is not very palatable, having no minerals to give it flavor.

AERATION. Water is sometimes sprayed into the air or allowed to flow over surfaces resembling shutters in order to permit a maximum quantity of oxygen to dissolve in it. The oxygen kills bacteria and helps to dispose of some of the organic matter and gases which have an unpleasant odor.

CHLORINATION. Of the various disinfection methods, the application of chlorine gas is the most widely used. Liquid chlorine is obtained in cylinders and is introduced as a gas into the chlorinator, where it is mixed with water. The resulting chlorine solution is applied to the large body of water which is to be disinfected.

Another form of the chlorination treatment is the ammonia-chlorine process. If a mixture of ammonia and chlorine is added, not only is the water sterilized, but also the chlorine taste which sometimes results when chlorine is used is prevented.

ULTRAVIOLET RAYS. An interesting way for disinfection where small bodies of water are involved is by the use of ultraviolet rays. The water flows through the apparatus in thin layers, where it is exposed to the rays from mercury lamps. Such a method is useful for swimming pools and for water which is to be used in bottled drinks.

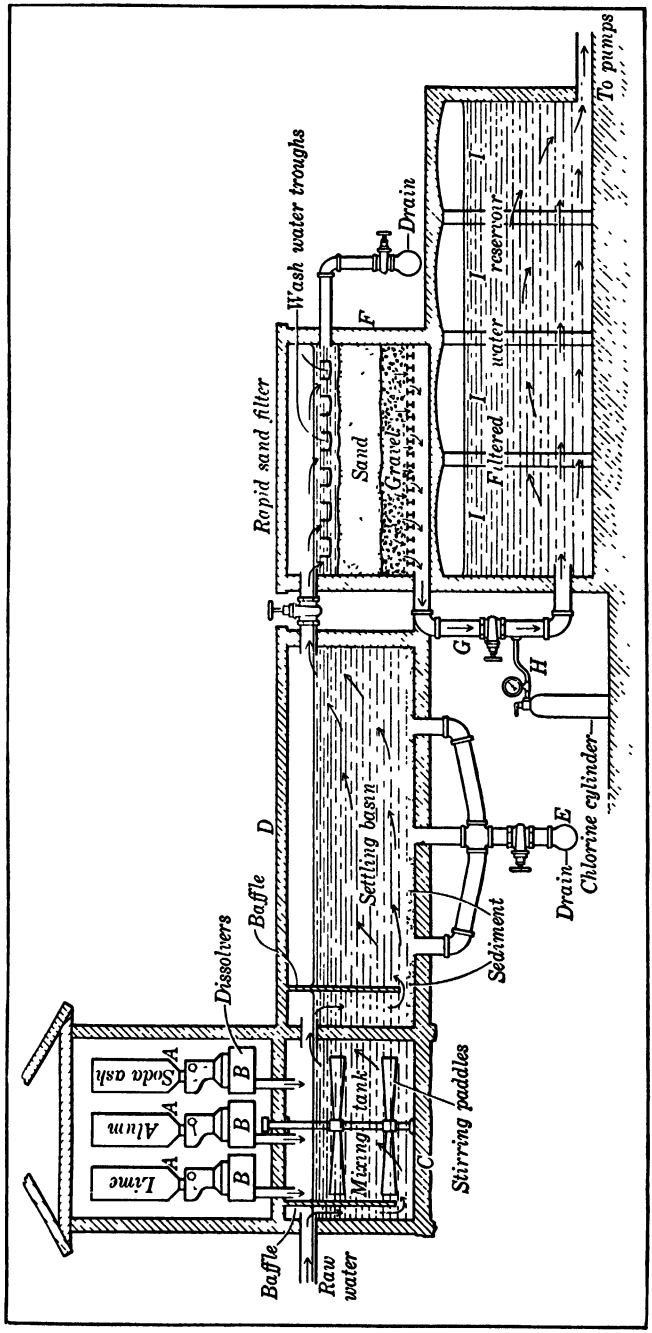


FIG. 147. Diagram illustrating the operation of a city water-purification plant. (Courtesy, McPherson and Henderson: "General Chemistry," Boston, Ginn and Co.)

WATER SOFTENING

Many water supplies, especially wells, give difficulty to the user in that the water is said to be "hard." Various minerals which are present in solution in water supplies interfere with laundry work, dyeing, tanning, and other industrial uses. Hard water is also a serious problem in steam plants, since it produces boiler scale.

The principal materials which make water hard are the bicarbonates and sulfates of calcium and magnesium. Carbonate hardness is due to the presence of calcium bicarbonate and magnesium bicarbonate. Although these compounds break down and form the carbonates when the water is boiled, such a method is unsatisfactory because the insoluble carbonates form boiler scale, which is difficult to remove. The usual softening process for carbonate hardness involves the use of lime (calcium hydroxide). If the proper amount of lime is added to the hard water, an insoluble compound is formed. The soft water can then be decanted from the softening tank.

The noncarbonate hardness (permanent hardness) of water is due to calcium or magnesium sulfates or chlorides. Boiling does not remove this type of hardness.

In Chapter 19, the chemistry of soap manufacture is discussed. Soap, when used in pure water, produces a lather which helps to remove grease and dirt from the material being washed. If soap is used with noncarbonate hard water, the soap combines with the salt, e.g., calcium chloride, to form calcium stearate, a slimy, curdy precipitate. Only when all of the calcium chloride has been removed will a lather form. Such a softening process is too expensive for water softening, since it uses a great deal of soap.

In order to soften hard water in the home, a good method is to use sodium carbonate (soda ash) or borax in the water. These materials will react with the calcium and magnesium salts to form insoluble compounds.

In the large softening plants used by cities, both soda ash and lime are added to the water for complete softening. The lime combines with the calcium bicarbonate and the soda ash combines with the calcium or magnesium sulfates or chlorides. The principal reactions can be illustrated by the following chemical equations.

Lime plus calcium bicarbonate yields calcium carbonate plus water.

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 + 2H_2O$$

Sodium carbonate plus calcium sulfate yields calcium carbonate plus sodium sulfate.

$$Na_2CO_3 + CaSO_4 \rightarrow CaCO_3 + Na_2SO_4$$

Ion Exchangers. The most important of such water softening methods is the one which uses the mineral *zeolite*. This method of softening water

involves no addition of chemicals except sodium chloride and there are no precipitates. The water is allowed to filter through a bed of the zeolite. In the process an exchange of ions takes place, the sodium ions from the zeolite replacing the calcium ions in the hard water. Likewise, the calcium ions enter into combination in the zeolite. Zeolites are silicates of sodium and aluminum. The most common type is the mineral green sand (marl). There are large supplies of this mineral in the United States. An illustration of the form of reaction follows:

Sodium zeolite + calcium sulfate → calcium zeolite + sodium sulfate

Water softened in this way is almost devoid of hardness. Many institutions, such as hospitals, hotels, and laundries, use the method to produce really soft water. A most interesting feature of this zeolite softening process is that the mineral can be restored to its original composition by passing a strong sodium chloride solution through the filter in the reverse direction. This produces a chemical reaction by which calcium zeolite reverts to sodium zeolite.

References

Beery: "Chemistry Applied to Home and Community," Philadelphia, J. B. Lippincott Co.
Brinkley: "Introductory General Chemistry," New York, The Macmillan Co.
Mason: "Water Supply," New York, John Wiley and Sons.
McPherson and Henderson: "Elementary Study of Chemistry," Boston, Ginn and Co.
Moore: "A History of Chemistry," New York, The McGraw-Hill Book Co.
Prescott: "Water Bacteriology," New York, John Wiley and Sons.
Ryan: "Water Treatment," New York, The McGraw-Hill Book Co.
Trimm: "General Chemistry," New York, The McGraw-Hill Book Co.
Turneaure: "Public Water Supplies," New York, John Wiley and Sons.

Questions and Problems

1. What is the weight of 1 l. of pure water at 4° C.? Answer: 1000 Gm.
2. How many tons of freight can be carried on a barge 20 ft. long, 10 ft. wide, and 10 ft. deep, weighing 5 tons? Answer: 57.4
3. One hundred cc. of sulfuric acid weigh 182 Gm. What is its specific gravity? Answer: 1.82
4. What is the specific gravity of a piece of wood (pine) $3 \times 6 \times 10$ cm. that weighs 108 Gm.? Answer: 0.6
5. A ring weighs 19.4 Gm. By using a balance and some water one can determine whether the ring is gold or brass. How?
6. How would you determine the weight of an irregular piece of iron without weighing it?
7. What is the specific gravity of an object that weighs 48 Gm. and displaces 8 cc. of water? Answer: 6
8. What is the weight of a piece of aluminum $3 \times 4 \times 8$ cm.? Answer: 259.2 Gm.
9. Describe four methods for water purification.

Visual Aid

"Beyond the Microscope," General Electric Co. Film

Experiments

1. Thoroughly mix 10 cc. of concentrated sulfuric acid with 200 cc. of water. Fill a Hoffman electrolysis apparatus (both tubes must be completely filled) and connect to a storage battery. Once electrolysis has started do not reverse the terminals. (Unless this precaution is observed, a mixture of hydrogen and oxygen which is explosive may be formed.) The cathode tube should contain hydrogen and the anode oxygen. Identify the two gases by placing a lighted match over the openings and cautiously allowing the gases to escape.
2. Weigh a clean, dry iron ball. Fill an overflow can with water until water runs out as additional water is poured in. Place a dry graduated cylinder under the spout of the can; immerse the ball and note how much water has run into the cylinder. Calculate the specific gravity of the ball. Judging from the amount of the overflow, how much do you think the iron ball weighs in water? Verify your answer.
3. Place in three separate tubes 20 cc. of distilled water, of faucet water, and of water containing about 3 drops of calcium chloride. Carefully add soap solution to each tube, counting the drops in each case. Shake the test tubes well after each drop of soap is added and keep adding soap until lasting suds are produced. Be careful to distinguish between suds and scum. (Soap solution may be prepared by dissolving 10 Gm. of castile soap powder in 1 l. of 50 per cent ethyl alcohol.)
4. Pass carbon dioxide through limewater until the precipitate which is formed completely disappears. Test with soap solution. Is it hard? Boil 20 cc. of the solution for 5 minutes and again test with soap. What type of hardness is this?
5. Add 3 drops of calcium chloride to 40 cc. of distilled water. Test 20 cc. for hardness. Add washing soda to another 20 cc., filter, and again test for hardness. What effect did the washing soda have on the solution?
6. Distill 50 cc. of muddy salt water and test the distillate for hardness. Is the water soft?
7. Secure a small amount of zeolite and filter hard water through it. Test the water with soap.

18. TRUE AND APPARENT SOLUTIONS

It is the part of scientific men to lift the veil from the mysteries of nature.
—HUME

One of the most common everyday experiments is that of making a solution. A lump of sugar is dropped into hot coffee. As the liquid is stirred, the sugar disappears; yet we find that the coffee is sweet. If we try the experiment with cold coffee, the sugar dissolves rather slowly.

On the other hand, if we try to dissolve a lump of marble, an object resembling sugar, we find that it is impossible to make a water solution of the rock. Why does sugar dissolve in water while marble does not? Scientists believe that water molecules moving about as clusters in the liquid bombard the sugar and break the lumps apart. For some reason the marble does not break apart under the bombardment. Perhaps calcium carbonate molecules cling too firmly to each other.

The process of solution presents many curious differences. Sugar dissolves in water but not in ether; butter dissolves in ether but not in water; one may dissolve 13 Gm. of potassium nitrate in 100 Gm. of water at 0° C. and 246 Gm. at 100° C. Alcohol dissolves in water in any proportion and the temperature rises; ammonium chloride dissolves freely in water, but the temperature falls. One liter (about one quart) of water dissolves 1298 l. of ammonia gas at 0° C. and only 710 l. at 20° C. (Fig. 148).

Most theories of the process of solution are based on the electrical properties of molecules. Some compounds have molecules called the polar type which act as if one end of the molecule has a positive charge and the other end a negative charge. Water is such a compound. On the other hand, the hydrocarbons like gasoline have nonpolar molecules.

If two polar molecules such as water and sodium chloride are mixed, the unlike charges cause the molecules to be attracted to each other and solution results. Gasoline being nonpolar does not dissolve in water but another nonpolar molecule, such as fat, will mix with gasoline.

Scientists are not agreed as to whether solution is purely mechanical or a type of chemical process. Sugar dissolved in water acts like a gas by exerting pressure. This process would appear to be mechanical. On the other hand, we often get curious color changes when materials go into solution. If we dissolve anhydrous copper sulfate, which is a gray material, in water, the solution is blue. When the salt is crystallized out of

solution, the substance retains some water of hydration and the crystals are blue (blue vitriol). Some substances like salt water conduct electricity, while others like sugar solution do not. Probably the best idea is that solutions stand midway between chemical compounds and simple mixtures or suspensions. In support of solutions as chemical compounds, there are some very common types of solutions which appear to be ac-

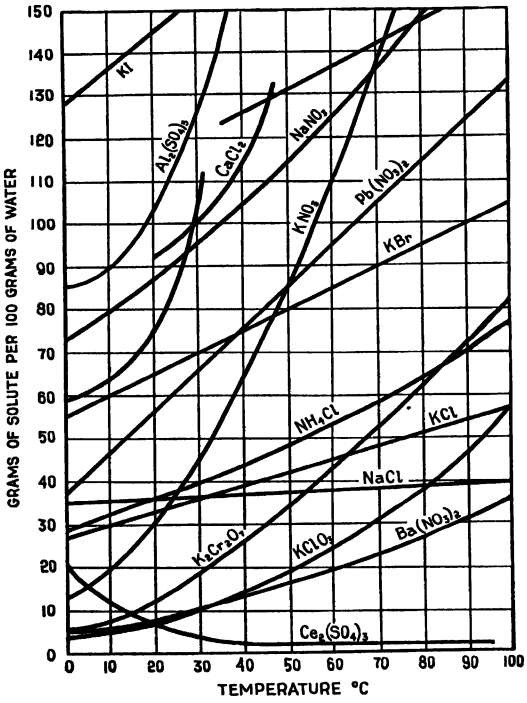


FIG. 148. Temperature-solubility curves of various salts in water. (Courtesy, Jones: "Inorganic Chemistry," Philadelphia, The Blakiston Company.)

companied by chemical reactions. When ammonia gas is dissolved in water, there is every evidence that it does react with water, forming the base, ammonium hydroxide (NH_4OH). However, no one has ever isolated ammonium hydroxide as a separate crystalline substance. Similarly, carbon dioxide gas seems to combine with water to form carbonic acid, which gives the acidity to "soda water." If we pour concentrated sulfuric acid into water, the solution becomes very hot. In these cases, we do know that chemical changes have taken place.

Some Terms Used in Solution

In discussing solutions, the term *solvent* or *dispersion medium* is used to designate the liquid, gas, or solid in which the substance is dissolved.

The dissolved substance is called the *solute*. In the case of the solution of gases in gases, liquids in liquids, and solids in solids, the predominating substance is the solvent. Gases will mix in any proportion. We have, for example, the mixture of gases in the atmosphere. In this case, we might regard the nitrogen as the solvent. Some liquids, such as alcohol and water, are miscible in all proportions. If the alcohol is less than half the mixture, it is the solute. If its proportion exceeds the water, it is the solvent. If we clamp a piece of gold to a bar of lead, the gold will penetrate slowly into the lead. We regard the lead as the solvent. The gas hydrogen will dissolve in the metal platinum. Gold used in jewelry is a solution of copper in gold.

A concentrated solution is one that contains a relatively large amount of solute. At 20° C., 100 Gm. of water dissolve 109 Gm. of sodium hydroxide. If we dissolve only 20 Gm. in 100 Gm. of water, we have a dilute solution; 90 Gm. would be a concentrated solution, 109 Gm. a saturated solution. When a hot saturated solution is allowed to cool slowly, it sometimes happens that the excess solute does not settle out of solution. Hence, the cool solution contains more solute than is usually held at that temperature. This is a *supersaturated solution.*

One commercial application of a supersaturated solution is a type of self-heating water bottle. A solution of hypo (sodium thiosulfate) is supersaturated and allowed to cool in the metal container used as the hot water bottle. If the container is shaken, some of the salt precipitates and heat is liberated.

Properties of Solutions

Solutions dissolved in water modify the properties of the water. Every housewife is familiar with the use of salt in water for cooking purposes. Salt has the property of raising the boiling point several degrees so that the starch cells and muscle tissues break down more rapidly, thus hastening the cooking.

A mixture of salt and ice melts at a lower temperature than ice alone. People scatter salt over icy pavements to speed up the melting of the ice. Calcium chloride lowers the freezing point of water and is used as a brine in the manufacture of ice. In the winter, we use materials in our automobile radiators to prevent the water from freezing. Some of the substances used are glycerin, ethylene glycol, and alcohol. Such solutions have a lower freezing point than pure water. A desirable antifreeze should not injure the radiator, should flow freely in cold weather, and should not evaporate to any extent.

OSMOSIS

A very interesting, and to some extent mysterious, effect produced by solutions is *osmosis*. If we fill and seal a sausage casing made of animal membrane with concentrated sugar solution and place it in a beaker of

water, we find that after a few hours the sausage casing will swell and even burst because of the water that has entered. During this time, very little sugar has passed into the water outside the casing. The housewife soaks dried fruits such as prunes in water to restore the water lost in drying. *Osmosis may be defined as the diffusion of solvent particles through a semipermeable membrane.* An interesting experiment within the reach of every science class is the osmosis of water in a carrot, as shown in Fig. 149. The carrot is hollowed out and the cavity filled with syrup. A cork and a glass tube are inserted. If the carrot is placed in a dish of water, the water will slowly diffuse through the shell of the carrot and pass into the syrup. As the volume of the syrup increases, the solution rises in the glass tube. The height of the liquid in the tube is a measure of the osmotic pressure.

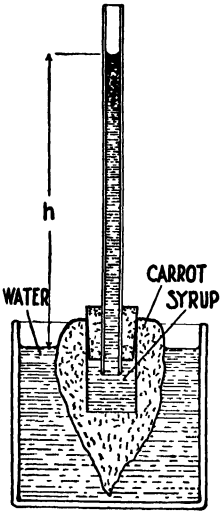


FIG. 149. Owing to osmosis, water has passed through the carrot into the sugar solution. The height (h) measures the osmotic pressure. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Osmosis is one of the most important factors in the behavior of living matter. Air passes through the lungs into the blood, and carbon dioxide passes out of the blood into the lungs by osmotic pressure. Soil water passes through root hairs into the tissue of the plant by osmosis. By this means, dissolved minerals and other food materials are carried to the plant. Should salt be thrown on the ground or should too much fertilizer be applied, the concentration of the minerals of the salt water would become greater than that of the plant protoplasm, thereby causing the moisture to leave the roots. Osmotic pressure is partly responsible for the rise of sap in trees. It must be *emphasized* that it is not the only cause. Osmosis often causes toothache. If the dentine of the tooth is exposed and a piece of candy is placed in the mouth, the saturated syrup in the mouth produces an effect on the nerve by osmotic pressure through the porous dentine.

Both the rise of the boiling point and the osmosis of solutions are best explained by the vapor pressure of water as compared with the vapor pressure of the solution. It appears that a substance such as salt, when dissolved in water, tends to hinder the water molecules from escaping from the liquid. If pure water and a solution of some substance in water are placed on opposite sides of a porous membrane, the water molecules in contact with the membrane on the water side have more freedom of motion and can diffuse freely through the wall. On the other side, the water molecules are bound to the molecules of the solute, so that neither

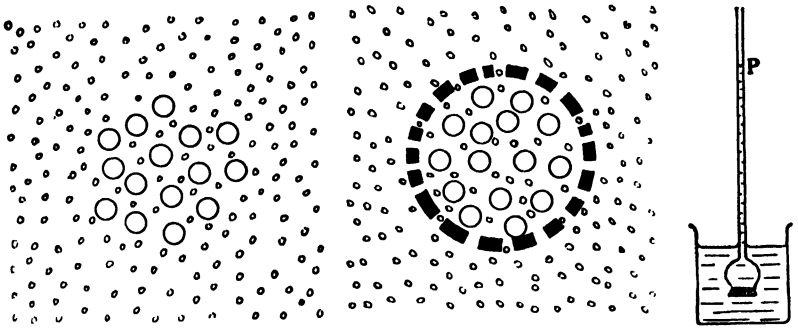


FIG. 150. Drawing illustrating the process of osmosis. (Courtesy, Heil: "The Physical World," Philadelphia, The Blakiston Company.)

water nor solute pass freely through the porous wall, because these solvent-solute clusters reduce the evaporation tendency of the water. (A less satisfactory explanation states that the pores of the wall are too small for the passage of the solution clusters but are large enough for the passage of water molecules.) Consequently, the water will pass through until the pressure set up by the height of the solution prevents further passage by equalizing the rate of water diffusion in the two directions. Figure 150 illustrates the osmotic phenomenon through a membrane separating the solution and the solvent. The large circles represent sugar molecules and the small circles water molecules.

COLLOIDS

The individual particles of the solute in a solution are too small to be seen in the microscope. They probably consist of single atoms or molecules and can pass through animal or vegetable membranes and filter paper. There is a different class of substances, very common in daily life, which has very peculiar properties. These substances are aggregations of atoms and molecules which, while invisible to the eye even with the aid of a microscope, are very large compared to atoms. They are called *colloids*. We can taste and smell some of these colloids even though we cannot see them. Every hay fever sufferer is aware of the tiny particles of plant pollen which irritate the nose and throat. We are familiar with the smell of new-mown hay and the scent of flowers. Each of these materials is composed of particles of colloidal size.

Colloid particles range in size from $\frac{1}{10}$ to $\frac{1}{1000}$ micron.[1] They may be solid, liquid, or gaseous, and are surrounded by a dispersion medium which may be solid, liquid, or gaseous. Such mixtures are often called *sols*. They cannot be filtered by the usual process. Such substances may be classified into eight groups as follows:

[1] One micron is $\frac{1}{1000}$ mm.

Table 16

CLASSIFICATION OF SOLS

1.	Solid in solid	Gold in glass (gold ruby glass) Selenium in glass (red glass)
2.	Solid in liquid	Gold in water Sulfur in water Sodium chloride in alcohol
3.	Solid in gas	Blue tobacco smoke Dust in air
4.	Liquid in solid	Water in calcium carbonate (pearl)
5.	Liquid in liquid	Emulsions such as mayonnaise Gelatins in water Jellies
6.	Liquid in gas	Fog and clouds in air
7.	Gas in solid	Seafoam candy Floating soap Gray hair
8.	Gas in liquid	Soap suds Whipped cream Foams

Almost all the processes of living tissue are concerned with colloidal dispersions. The cells, including both protoplasm and cell walls, are colloidal. The physiologist who studies such body processes as nerve action, digestion, circulation, and secretion is concerned with colloidal dispersions.

The chemistry of colloids concerns such varied subjects as blue eyes, photographic film, cheese, salad dressing, tanning, cement, rubber, glass, paint, varnish, foam, pottery, blue of lakes and blue of sky, colors of feathers and colors of paints, baking of bread, dyeing, and water purification. Truly, colloids are a part of our daily life.

We cannot see colloids directly but if the source of light is properly adjusted, we may see the diffraction pattern due to the light scattered by these tiny objects. We see clouds (colloidal water), and we notice dust particles dancing in a beam of sunlight in a darkened room. The ultramicroscope, invented in 1908, utilizes the principle of the dancing particles in the light to make the position and motion of the colloidal particles visible. A strong horizontal beam of light (Fig. 151) is focussed, by means of a system of lenses, at a point in the glass cell on the microscope stage. The particles in the colloidal solution in the cell scatter the light, thus producing a diffraction pattern. The light does not enter the microscope

directly so that only rays scattered sidewise are seen. We do not actually see the detail of the particle, but a diffraction pattern around it.

The ultramicroscope makes particles visible which are as large as 10 millimicrons in diameter. Since most molecules are much smaller than this, they cannot be seen in the ultramicroscope. It may be that some of the very large molecules of proteins can be seen by means of the ultramicroscope. The electron microscope enables us to study very small particles (see p. 349).

PREPARATION OF COLLOIDS. Colloids may be prepared by grinding, by peptization in water, by emulsification, and by electrolysis. The colloid mill is a device used to grind materials so fine that they are colloidal in size. Another dispersion method is the arcing of metals in water. If two electrodes of gold, silver, or platinum are connected to a source of electricity and the tips placed nearly in contact under acidulated water, an arc will pass and small particles of the metals scatter into the water, forming a colloidal dispersion. Such materials are called suspensoids. When an oil and a liquid such as water or vinegar are mixed in the presence of an emulsifying agent such as egg or milk casein, an emulsoid which is partly colloidal is formed. In the chemistry laboratory, one may form a colloidal mixture very simply by pouring ferric chloride into boiling water. We may form some colloids by simply mixing substances with water. If we mix glue or gelatin with hot water, a colloidal suspension is formed. We are all familiar with gelatin desserts, which are colloidal in nature.

Because of their size, colloidal particles have interesting properties. They have astonishing powers of absorption because of their large surface area. The gels contain large amounts of water—gelatin dessert contains 20 times as much water as gelatin. Foam contains many times more gas than

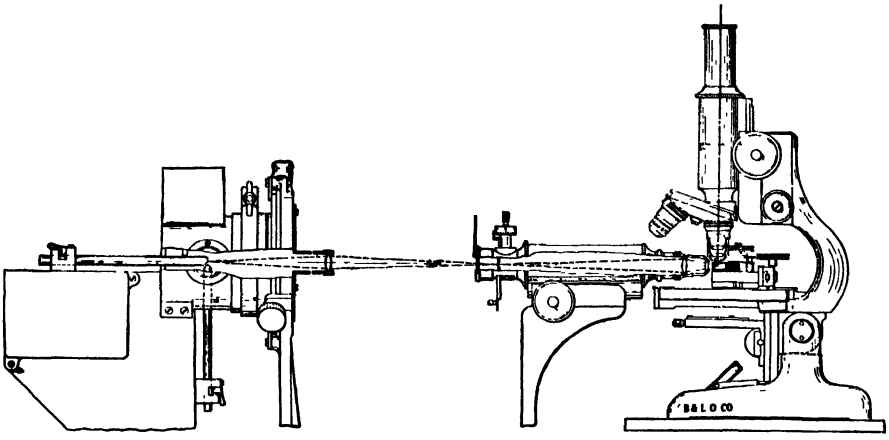


FIG. 151. Diagram of an ultramicroscope. (Courtesy, Bausch and Lomb Optical Co.)

the foaming agent. It has been discovered that many colloidal particles are electrically charged. Perhaps the most important application of the electrical charges on colloidal particles is the Cottrell process for the removal of smoke from the gases of factory stacks. Two highly charged electrodes are placed in the chimney (Fig. 152) and as the smoke passes between

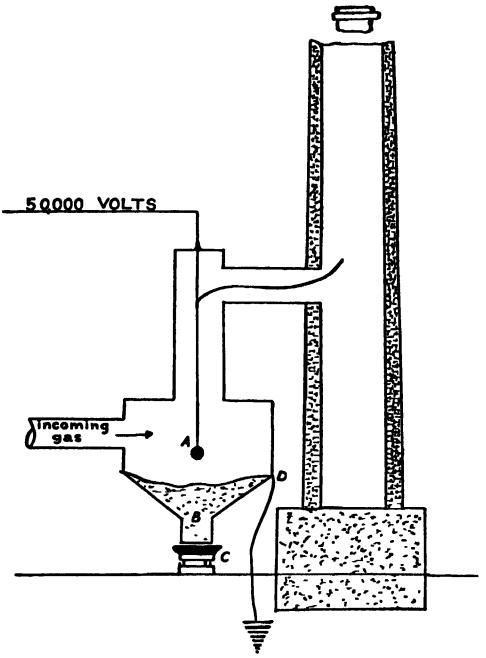


FIG. 152. The Cottrell process. The particles in the incoming gas are attracted to the electrode *A* and drop into the reservoir *B*. (Courtesy, Gray, Sandifur, and Hanna: "Fundamentals of Chemistry," Boston, Houghton Mifflin Co.)

the electrodes, the small particles are pulled from the flue and drop as sediment. Not only does this process remove the nuisance of smoke, but it makes possible the recovery of valuable materials such as metals and salts. The electronic device known as the Precipitron makes use of this principle. This apparatus is in wide use as a method for the purification of air in industrial plants.

SUSPENSIONS

The energy of motion exhibited by colloids, known as the Brownian movement, is sufficient to overcome the force of gravity, with the result that colloids do not settle out on standing. Larger particles do settle out. If the state of division is small, matter in suspension may not settle out

readily. In certain parts of the country, forest fires rage for days at a time. The fine smoke particles travel hundreds of miles and cause brilliant sunsets. The dust storms in central United States and in China deposit sediment many hundreds of miles from the source of the dust. However, these particles do finally settle out of the air.

Table 17

Solutions	*Colloids*	*Suspensions*
Atoms or small molecules	Small aggregates of atoms and molecules	Very large clusters of molecules
Invisible	Visible with ultramicroscope	Visible
Pass through filter paper	Pass through filter paper	Will not pass through filter paper
Do not settle out	Do not settle out	Settle out

References

Alexander: "Colloid Chemistry," New York, D. Van Nostrand Co.
Briscoe: "General Chemistry," Boston, Houghton Mifflin Co.
Foster. "Romance of Chemistry," New York, D. Appleton-Century Co.
Glasstone: "Recent Advances in General Chemistry," Philadelphia, The Blakiston Company.
Hedrick: "Everyman's Chemistry," New York, Harper and Brothers.
Holmes: "Introductory College Chemistry," New York, The Macmillan Co.
Martin: "Wonders of Modern Chemistry," New York, D. Van Nostrand Co.
Morrow: "Biochemical Methods," New York, John Wiley and Sons.
Weiser: "Colloid Chemistry," New York, John Wiley and Sons.

Questions and Problems

1. What is meant by a solution?
2. How does a solution differ from a colloidal suspension?
3. Why is whipped cream a colloid rather than a solution or a suspension of air in cream?
4. What evidence is there that solution is a chemical process?
5. What is: a solvent? a solute? a dispersion medium?
6. Can we dissolve a solid in a gas?
7. Can we dissolve a liquid in a gas?
8. What is meant by osmosis?
9. What are some examples of osmosis in nature?
10. Can we see a colloid? Explain.
11. The biologist finds that blood corpuscles burst when placed in distilled water. Can you explain?
12. Why are salts used as laxatives?
13. How do soapsuds differ from liquid soap?

Topics for Discussion

Gas Masks	Foamite Fire Extinguishers	Dust Storms
The Brownian Motion	Neo-silvol as an Antiseptic	Deliquescence

Experiments

1. Prepare a supersaturated solution of sodium acetate by dissolving 275 Gm. of it in 100 cc. of water. Let it cool slowly. When it is cool, drop a crystal into the flask. Watch the growth of crystals and notice the evolution of heat. (Owing to the expense of chemicals, have one student perform this for the class.)
2. Dissolve 20 Gm. of salt and 2 Gm. of gelatin or albumin (5 cc. of egg white will do) in 100 cc. of water. Place it in a thistle tube while you hold your finger against the small end of the tube. Tie a piece of parchment paper or animal membrane over the large end. Invert the tube and suspend it in a beaker of distilled water. See that the level of the solution is even with the water in the beaker. Observe and explain what happens in a few hours.

   Perform these tests 25 to 48 hours after the experiment has started. Salt molecules may be identified by a white precipitate when silver nitrate (do not add nitric acid this time) is added to a few cc. of water from the beaker. Were the salt molecules small enough to pass through the membrane? Gelatin or albumin is identified by adding nitric acid to a few cc. of beaker water, on warming, a yellow color results, which turns orange when ammonium hydroxide is added in excess. Were these molecules small enough to pass through?
3. Into 100 cc. of *boiling* water, pour 5 cc. of ferric chloride solution. Result?
4. To prepare a gel, dissolve 5 Gm. of gelatin or 3 Gm. of agar in 100 cc. of boiling water. Let it cool.
5. Make a colloidal flower garden. Dilute some concentrated sodium silicate (or use undiluted water glass) with an equal volume of water in a beaker. Drop small lumps or crystals of ferric chloride, copper sulfate, cobalt chloride, nickel nitrate, manganese sulfate, chrome alum, and other very soluble colored salts into the beaker. Let it stand for several hours, noting the results from time to time.
6. Add 3 Gm. of licorice powder to 50 cc. of 10 per cent sodium carbonate solution. Pour this rapidly into a tall cylinder containing 50 cc. of 10 per cent aluminum sulfate.

19. CLEANSING

He is like fuller's sope.

—MALACHI

Dirt consists of carbon and other particles which have been rubbed into the fiber of the cloth or have become fastened to the cloth by grease. Small bits of food may also cling to the fibers. Paint, dyestuffs, colored juices, and other materials may become attached to or absorbed by the fibers, thus causing stains. The removal of dirt is comparatively simple. Stain removal may become rather complex, depending upon whether stains adhere to the fibers, are actually absorbed by them, or react with them. The primary problem is to dissolve the dirt or stain if possible. Water dissolves some substances readily, but will not dissolve others, such as grease. Carbon will not dissolve in anything. Though warm or hot water will dissolve some substances which are insoluble in cold water, cold or hot water alone will not cleanse well.

METHODS OF CLEANSING

There are five general methods for cleansing:

1. Use of soap—dirt is emulsified and peptized.
2. Solution—dirt is dissolved in some liquid.
3. Absorption—dirt is absorbed by a solid, usually a powder.
4. Chemical change—dirt which is insoluble in ordinary solvents is changed into a soluble substance, or is bleached by a chemical reagent.
5. Abrasion—brushing and scouring are examples.

USE OF SOAP. Dust and carbon particles are frequently held in textiles by oil or grease. Soap removes the oil, setting free the dirt particles, which may then be removed by rubbing or agitation. The exact manner in which soap acts is obscure. In some cases, soap reacts with water to form a weak alkaline solution which removes dirt by emulsification. However, soap does not always form sufficient alkali for emulsification. Frequently, too, grease is not present.

Emulsification. Emulsification means the surrounding of droplets of fat or oil with a film of soap or some other substance. The film prevents the droplets from running together again. For instance, when oil and water are shaken together and allowed to stand, the oil droplets, which have

been formed during the shaking, coalesce into a layer on top of the water. When soap solution is added and the mixture is again shaken, the oil does not form a layer but remains dispersed throughout the water.

Surface Tension. Soap lowers the surface tension of water, thus permitting it to penetrate into tiny spaces that pure water will not wet. Surface tension is caused by the surface molecules sticking together. Mercury has a high surface tension; it forms into little globules when spilled on a desk. The surface tension of water is not as great as mercury, so water drops are flattened and may even spread out a little on the desk. Kerosene has a low surface tension and when dropped on wood or water spreads out as a thin film, even penetrating spaces which are inaccessible to water or mercury. This explains why kerosene is used to loosen rusted bolts.

Peptization. Soap also peptizes or splits the dirt particles into pieces having colloidal dimensions. Colloidal dirt particles absorb the soap molecules on their surfaces. The soap, being soluble in water, carries the dirt away with it.

Summary of Soap Cleansing. Cleansing by soap, therefore, is threefold in its action: it emulsifies the oil; it permits the water to penetrate; and it peptizes the dirt. In the absence of oil, the other two processes serve to remove the dirt.

SOAP

Soap is a salt of sodium or potassium hydroxide and a fatty acid and is one of the most important of the salts that have an alkaline reaction in water. If, for example, oleic acid and sodium hydroxide are mixed, a soap called *sodium oleate* is formed. Other fatty acids are stearic and palmitic. In actual practice, the fatty acids are not used because of their cost. Instead, the fats glyceryl palmitate, glyceryl stearate, and glyceryl oleate are used. The equation for the reaction is as follows:

Glyceryl palmitate plus sodium hydroxide yield soap plus glycerol.

$$C_3H_5(C_{15}H_{31}COO)_3 + 3NaOH \rightarrow 3Na(C_{15}H_{31}COO) + C_3H_5(OH)_3$$

If potassium hydroxide is used instead of sodium hydroxide, we have liquid soap. Glycerol is the chemical name of glycerine and it is a very valuable by-product of the soap industry. It is used in the manufacture of nitroglycerine and in many other chemical processes.

A History of Soap. Soap has been used for many centuries. Indeed, it is mentioned in the Old Testament: "For though thou wash thee with nitre and take thee much sope, yet thine iniquity is marked before me" (Jer. 2:22). Just what this soap was is difficult to determine. It is probable that it was made by mixing tallow of sheep and cattle with wood ashes, which produced a type of soap mixed with residual fat and ashes. It is not known that the Egyptians used soap, so the statement that "Cleo-

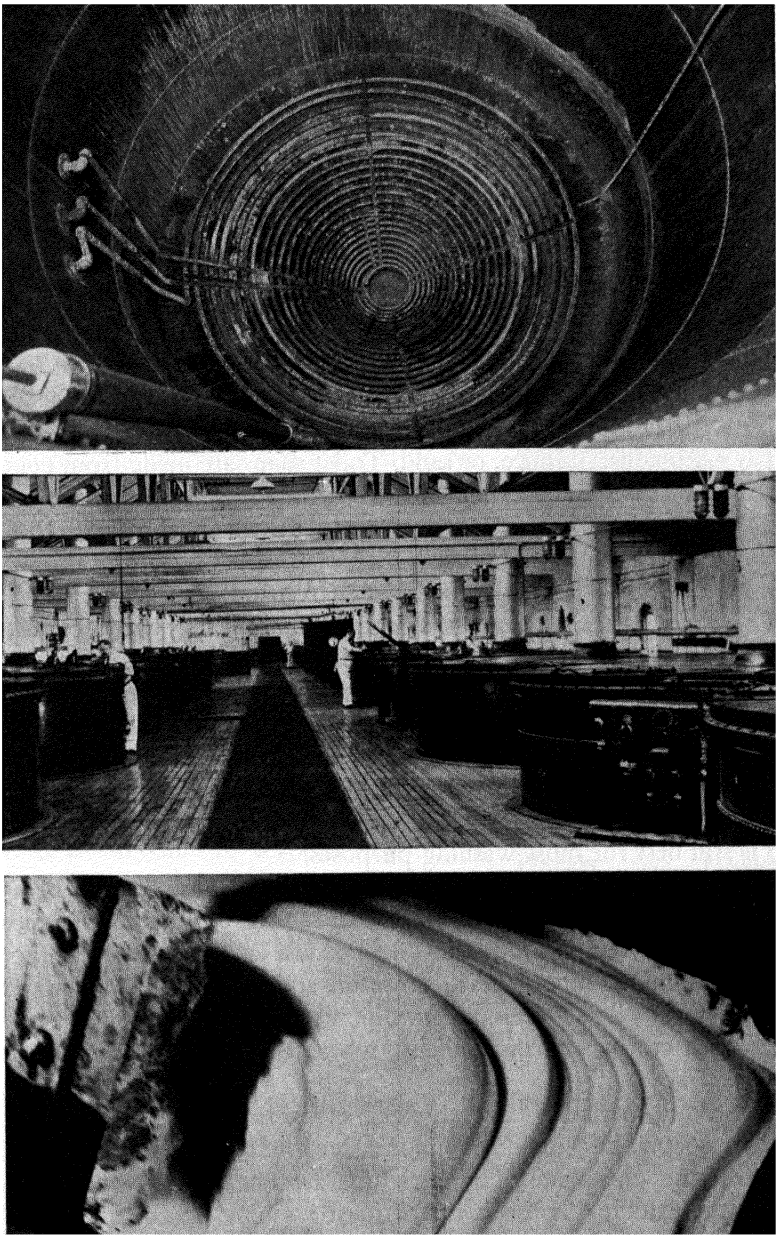


FIG. 153. The manufacture of soap. (*Top*) A soap kettle. (*Center*) The kettle room. (*Bottom*) A river of soap. (Courtesy, Procter and Gamble.)

patra's beauty was preserved by palm and olive oils" is open to question. It appears that the use of soap was unknown in the Middle Ages; hence the references to the people of that time as the "Great Unwashed."

In colonial times, women made soap from fat and wood ashes. After about 1820, soap began to be a commercial product and its quality has been improved greatly during the past century. By the development of the process of hydrogenation of liquid fats, oils such as fish oil and cottonseed oil have become important constituents of soap.

Varieties of Soap

Laundry soap is made from tallow, to which may be added rosin for greater lathering or naphtha for greater solvent action. If free alkali is present, it will cause the hands to become rough and tender and will weaken textiles. The use of such soaps is not economical but they may sell for a trifle less than neutral soap. Scouring soaps contain some abrasive, such as marbledust, pumice, or sand. Toilet soaps are made from cocoanut oil, palm oil, and olive oil. They should be neutral. Hardwater soaps contain borax or sodium carbonate, since both of these chemicals soften water. It is important to emphasize that no secret formula exists for any type of soap. Fig. 153 illustrates the process of soap manufacture.

There are other detergents which, although they are actually not soap, are equal to or even superior to real soap for some purposes. The best known of these detergents is a sulfate of lauryl alcohol which is sold under various trade names. Technically most of these detergents are a sodium salt of a fatty alcohol sulfate. One advantage of such materials is that they can be used in hard water. They do not form precipitates as does real soap. They are not as efficient as soap for badly soiled articles. Soap is still best for most washing purposes.

The soap molecule, as is evident from the formula, consists of a very long chain of atoms. It appears that one end of the chain is soluble in water while the other end is soluble in oils. Because of this property, the soap acts as an emulsifying agent to unite oil and water. Other examples of emulsifications are whole milk, in which the fat and water are held together with casein, and mayonnaise, where egg unites vinegar and salad oil (Fig. 154).

Numerous chemicals have an alkaline reaction and a cleansing action similar to soap. These include ammonia, lye, washing soda, sodium silicate, and trisodium phosphate. The last three are occasionally added to soap and are the principal constituents of most washing powders.

Solution of Dirt

Spots of car grease, butter, and other fats, which are not always cleaned readily with hot soapsuds, may be dissolved by using typical fat solvents.

In general, fats and oils may be removed by using ether, naphtha, gasoline, carbon tetrachloride, or chloroform. Ether evaporates so rapidly that dirt rings may remain on the textile. These rings may be avoided by gently rubbing a clean, ether-soaked rag with a circular motion from the outside of the spot toward its center. It must be emphasized that ether, gasoline, and benzine are inflammable and *must not be used near a flame.* Carbon tetrachloride and chloroform are not inflammable and are safe to use. Carbon tetrachloride is commonly sold under the name "Carbona."

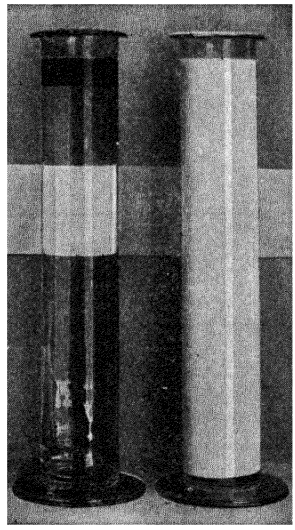


FIG. 154. Emulsions. In left-hand jar, oil and water have been shaken together. The oil will soon separate. In right-hand jar some soap has been added to the mixture of oil and water. As a result the emulsion becomes more permanent. (Courtesy, McPherson and Henderson: "Chemistry for Today," Boston, Ginn and Co.)

Most ink, fruit, coffee and other stains can be removed by washing them promptly before they have a chance to set. For instance, ordinary fountain pen ink can be removed while fresh by washing with plain water. After it dries, insoluble iron compounds are formed, which makes chemical removal necessary.

CHEMICAL REMOVAL

Many stains are insoluble in all of the common solvents. They must be bleached or changed into soluble compounds. Great care must be exercised in using any chemical reagent, as it may permanently injure the fabric. It is advisable to try the reagent on an inconspicuous part of the garment first to see that it does not react with the fabric or its color. It is also advisable to determine whether the textile is cotton, linen, wool, or silk. Acids attack cotton; alkalies may injuire cotton and will dissolve wool and silk.

ABRASION

Except for removing dust and mud, we seldom brush or scour textiles. Abrasion is used on wood and metals. Steel wool may be used on pans and wood, but it scratches. Whiting and jeweler's rouge are used on gold, silver, and highly polished surfaces. A soft paste may be made by mixing the whiting or rouge with either ammonia or alcohol.

DRY CLEANING

Dry cleaning processes make use of gasoline, benzine, carbon tetrachloride, naphtha or ethylene chloride. The last two are most common.

These dissolve oils and grease, thus setting free the dirt particles, which are then removed by mechanical agitation.

STAIN REMOVAL TABLE

The following chart indicates the materials used for removing some common stains. For detailed instruction as to the procedure to follow in each case and for the removal of additional stains, the references may be consulted. The Government Bulletin is particularly helpful.

Table 18

STAIN REMOVAL.

Blood	Cold or lukewarm water; then sodium hypochlorite, ammonia, or peroxide of hydrogen.
Chewing gum	Carbon tetrachloride and water alternately, or egg white followed by water.
Fruit, tea, coffee, grass	Water, then soap and ammonia, for cotton. For white wool, use water, then permanganate (see note), then peroxide. For colored wool, use water, then peroxide or alcoholic soap solution.
Ink, iron rust, mildew	Lemon juice and steam, alternately; lemon juice, salt and sun, or soap and water, or sour milk.
India Ink	Chloroform.
Iodine	Alcohol, or hypo, or potassium iodide solution.
Paint	Ether, or carbon tetrachloride, or turpentine.
Scorch . .	Peroxide (see Government Bulletin).
Tar . . .	Benzine or ether.
Wax . .	Alcohol, or press between blotters with hot iron.

Note. To make permanganate solution, dissolve one teaspoonful of potassium permanganate crystals in a pint of water. Apply a drop or two and allow it to remain for five minutes. Remove the resulting brown stain from wool with hydrogen peroxide to which has been added a few drops of some acid. From silk, cotton, or linen, remove the stain with saturated oxalic acid or lemon juice. Rinse well in every case.

REFERENCES

Beery: "Chemistry Applied to Home and Community," Philadelphia, J. B. Lippincott Co.

Hodgdon: "Elementary General Science," New York, Hinds, Hayden and Eldridge, pp. 270–272.

Rogers: "Manual of Industrial Chemistry," New York, D. Van Nostrand Co., Chap. 33.

Williams: "Introduction to Organic Chemistry," New York, D. Van Nostrand Co.

Stain Removal, Farmer's Bulletin No. 1474, U.S. Department of Agriculture.

Questions and Problems

1. How is soap made?
2. Explain the cleansing actions of soap.
3. State three general methods for stain removal.

Topics for Discussion

History of Soap Making	Soap Powder	Borax Mining
How Your Grandmother Made Soap	Detergents	Modern Soap Production

Experiments

1. Remove a grease spot by absorption.
2. Remove a grease spot with carbon tetrachloride.
3. Remove other typical stains, following the directions for each case as given in any of the first three references cited.
4. Demonstrate surface tension. Bend one end of a clean wire into a ring with a diameter of about 1 in. Tie a small loop of silk thread to the ring. Dip the ring into a soap solution to which has been added a little glycerine. Hold the resulting film up to the light and notice the motion of the liquid particles. Touch the inside of the loop with a hot wire. The loop assumes a circular shape, which shows that there is equal surface tension on all sides.
5. To identify free alkali in soap, dissolve it in absolute alcohol. Add alcoholic phenolphthalein. A red color indicates free alkali.

20. TEXTILES AND PLASTICS

Silk, muslin, and lace, crepe, velvet, and satin,
Brocade, and broadcloth, and other material,
Quite as expensive and much more ethereal;

—BUTLER

MODERN TEXTILES

A textile fiber is any fine filament which can be spun and woven into cloth. A textile is a term which includes a wide variety of materials such as cotton, wool, silk, nylon, linen, and cellulose acetate. There are, of course, many kinds of hair fibers or wools. There are many kinds of plant fibers, such as hemp, jute, and ramie. Just recently a new set of synthetic textiles have become commercially important. These contain no cellulose.

Textile fibers are nearly as old as man. Before the discovery of flax fiber, the first clothes probably consisted of leaves and twigs. Probably the flax fiber is the oldest of our useful textiles. Linen was used in Egypt as far back as 6000 B.C. The Bible contains frequent references to linen. Joseph was "arrayed in vestures of fine linen." It is of interest that the linen of ancient Egypt was as well made as our modern linen. It is known that the cultivation of silk was carried on at very early times. We have records of its use in China in 2700 B.C.

TEXTILE FIBERS

Textile fibers may be considered under two headings, natural textile fibers and man-made fibers. These can be further divided into single-celled seed hairs such as cotton, many-celled structures such as wool, groups of elongated cells such as flax, and the continuous filaments of the synthetic fibers.

Silks

The production of silk was a monopoly of China in ancient times. Not until the Middle Ages was some silk produced in Europe. Many stories have been written of the bribery, murder, and intrigue carried on by Persia and other nations who resented sending caravans of gold to China in exchange for silk, which sold for its weight in gold. Silk production was started in America in colonial times with poor success. At present, some progress is being made in California, where the season permits a good growth of the silkworm food, the mulberry leaf.

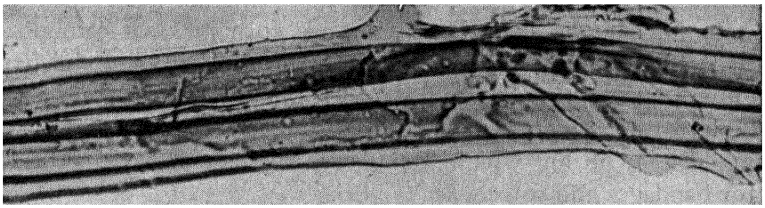


FIG. 155. Cocoon thread, mulberry silk. × 500. (Courtesy, Howard A. Walter, Philadelphia Textile School.)

Silk is a fiber produced by a certain species of caterpillar as it spins its cocoon. Two tiny fibers encased in a gummy sheath are exuded in a continuous filament several hundred feet in length. In processing, these cocoons are softened, the filaments unwound, and several filaments twisted together to form a thread.

Silk from the mulberry-fed worms is light in color and of fine quality. So called wild or Tussah silk is tan colored and coarse. The primary uses of Tussah silk are in the manufacture of plush, damask, rugs, carpets, and embroidery silks.

Degummed silk fibers are smooth, translucent tubes which reflect light so as to produce a high luster (Fig. 155). Silk is a strong textile fiber, a poor conductor of heat, and, in the raw state, absorbs water readily. Because of this hydroscopic property, it is desirable to wash silk in very soft water in order that the impurities may not be absorbed in the textile.

Silks are worn because of their beauty and light weight. They can be bleached very white. In order that silk may be firm and have better draping qualities it is rather customary to "weight" the fabric by adding salts of tin or aluminum which are readily absorbed by the fabric.

Although in past years silk was regarded as the most beautiful of all textile fibers, the introduction of nylon and other synthetic fibers has lessened the demand for silk at the present time. Silk stockings, once highly prized, are not in demand, since nylon ones have better qualities.

Linen

The linen fiber comes from the portion of the flax plant which lies between the outer bark and the woody center. It is a sort of inner bark.

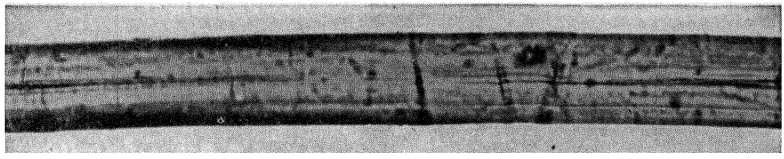


FIG. 156. Linen. × 500. (Courtesy, Howard A. Walter, Philadelphia Textile School.)

This bark consists of short, cylindrical, tubular threads placed end to end. Under the microscope, linen fibers resemble corn stalks or bamboo (Fig. 156). It is cellulose; hence, it consists of carbon, hydrogen, and oxygen. Linen fibers are stronger than cotton ones, but weaker than silk. Linen is permeable to air, which makes it comfortable for summer wear. Linen contains little or no lint which, along with the ease of wetting, makes it ideal for bandages and towels.

The flax plant is grown principally in Russia, Holland, and France, although the United States and Egypt have grown a good deal in recent years. It is of interest to note that flax will grow almost anywhere in the world as long as the soil is a sandy loam. In addition to the use of flax fibers in the manufacture of linen, the seeds are valuable as the source of linseed oil for the paint industry.

Closely allied to the flax fibers are the fibers of jute, used in bagging and upholstering; the hemp fiber, from which rope and cordage are produced; and ramie, which is used in the manufacture of many handwoven fabrics.

Cotton

A very important commercial textile fiber in the United States is cotton. A cotton fiber consists of a hollow tube of cellulose which is slightly flattened and twisted (Fig. 157). The fiber is almost pure cellulose (about 95 per cent). Although most cultivated cotton plants grow to a height of about 5 ft., there are trees which produce cotton fiber. Herodotus wrote: "there are trees which grow wild, the fruit of which is a wool." Marco Polo wrote that India produced the finest cotton that he had ever seen.

Although the cotton fiber is one of the weakest, the fibers can be woven very closely, which is one reason for its value as a textile. The value of a piece of cloth depends on the length of the individual fibers, which range from ¾ to 1½ in., the number of fibers twisted together, and the number of threads woven in each direction per square inch. Since cotton cloth offers little dead air space, it is not as comfortable for winter wear as wool. Fluffy, woolen-looking blankets are now being made of cotton but are inferior to wool both as to warmth and laundering qualities.

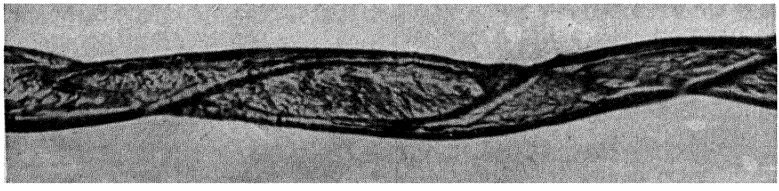


FIG. 157. Cotton. × 500. (Courtesy, Howard A. Walter, Philadelphia Textile School.)

A cotton fiber is a hair attached to the seed of the cotton plant. The cotton plant requires a long growing season and abundant rainfall so that it can be grown only in tropical or semitropical areas of the world. The invention of the cotton gin by Eli Whitney in 1794 stimulated the production of cotton by making the removal of the fibers from the seed an easy mechanical process. Later came the spinning jenny, which made cotton cloth cheap enough that people in all parts of the world could use it.

The finest cotton fibers are the strong variety known as Sea Island cotton. They vary in length from 1 to 2½ in. The usual varieties of cotton fibers have a average length of less than 1 in.

For years, the seeds were a nuisance, but at present cottonseed oil is extracted from them. Hydrogen gas under great pressure and at a high temperature is mixed with the oil in the presence of nickel dust. The result is the hydrogenated cooking fats. The nickel dust is used as a catalyst and is removed from the fat.

Wool

The hair-like covering of the sheep gives us one of the most valuable of all textile fibers. Under the term wool, we may also include the hair of Angora and Cashmere goats, the alpaca, and the llama.

Wool is a protein containing carbon, hydrogen, oxygen, nitrogen, and sulfur. (Silk is similar chemically except that it contains no sulfur.) The finest wool comes from the breed of sheep known as the Merino. The wool fiber is covered with a tiny scale-like sheath which produces a rough appearance and a dull luster (Fig. 158). It is the weakest of all common fibers. The scales make it difficult to weave closely so that the finished cloth is apt to be coarser than cotton and silk. Wool is a rather poor conductor of heat and many persons attribute the warmth of woolen garments to this fact. Actually, the main reason for the heat insulating property is that the type of weave encloses a large amount of air and the quiet air layer gives heat insulating properties. Moreover, a heavy wool worsted is separated from the skin by many tiny fibers while a clear finish wool for summer use lies close to the skin. The thicker air layer in the first case gives the sensation of warmth. Because it retains moisture longer than

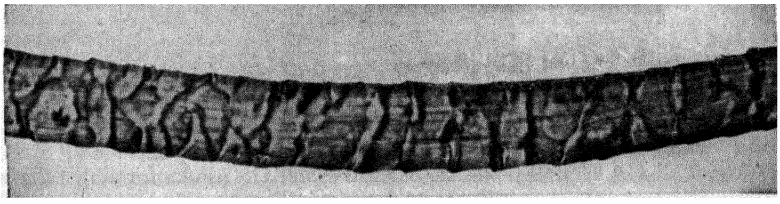


FIG. 158. Wool. × 500. (Courtesy, Howard A. Walter, Philadelphia Textile School.)

other textiles, it is suitable for bathing suits and other uses where rapid evaporation of moisture might chill the body.

Fur

This fabric is included in this chapter since the composition and use is similar to that of textile fibers. Fur resembles wool in that both are the hairy coverings of animals. In general, fur has the same characteristics as

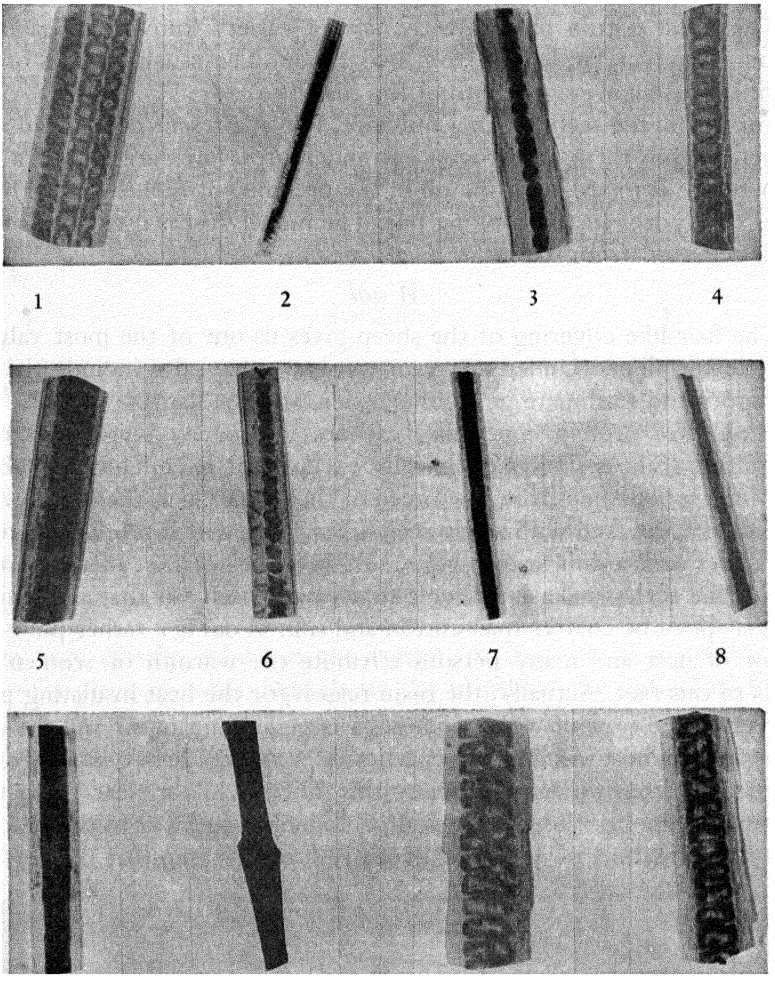


FIG. 159. The microscopic appearance of the hairs of certain animals. 1, chinchilla rabbit; 2, white rabbit; 3, guinea pig; 4, gray squirrel; 5, Persian cat; 6, Persian cat; 7, dog; 8, dog; 9, natural sable; 10, Russian sable; 11, Alaska fur seal; 12, aye-aye. (Courtesy, Smith and Glaister: "Recent Advances in Forensic Medicine," Philadelphia, The Blakiston Company.)

wool except that more dead air space is available, making fur the best nonconductor of heat and the warmest wearing apparel. All furs are about equally efficient in retaining body heat. Their relative costs are dependent on durability, beauty, and rarity. The hair of each animal is more or less characteristic of that animal. A microscopic examination of the hair will reveal its identity. Fur gives the same chemical tests as wool. It should be kept rather cool to retain its beauty (Fig. 159).

Synthetic Cellulose Fabrics

CELLULOSE. Many of our materials for home and industry result from man's utilization of cellulose, one of the most mysterious substances in nature. Cellulose is present in all vegetable matter, cotton fibers being nearly pure cellulose. Cellulose is composed of 44.4 per cent carbon, 6.2 per cent hydrogen, and 49.4 per cent oxygen. This indicates that the formula is perhaps $(C_6H_{10}O_5)$, the x indicating that the size of the molecule is unknown. The large cellulose molecules are bound together with a cementing substance to form the framework of all plant structures. We find cellulose in such varied substances as wood, cotton, linen, and celery. Man is unable to digest cellulose, but cattle and other herbivores can utilize it. Cellulose makes possible the substance paper, which has helped to develop modern civilization. Rayon, cellulose acetate, Duco, collodion, gun cotton, cellophane, and photographic film, to name only a few, are produced from cellulose.

Most cellulose is produced from spruce wood. Logs are chipped with knives in huge revolving drums. The small pieces of wood are heated with sodium hydroxide, with cellulose as the final product. For a description of other methods for the production of cellulose, the references should be consulted.

Rayon. The word rayon is the generic term for textile fibers produced chemically from cellulose or those fibers having a cellulose base. All varieties of rayon, including such trade names as Bemberg, Viscose, and Celanese, are produced by some chemical treatment of cellulose fibers. In the production of *viscose*, the cellulose is treated with carbon disulfide to produce cellulose xanthate. By treatment of this material with caustic soda solution, a viscous liquid is formed; hence the name *viscose*. The last step consists in forcing the liquid through a perforated cup into a coagulating fluid. The result is a cluster of rayon filaments (Fig. 160). Viscose is pure cellulose but it has a different type of crystallization. Ordinary viscose is much weaker when wet than when dry. The threads have a luster equal to silk and viscose fabric can replace silk in many cases. When viscose is extruded in sheets, it is called *cellophane.*

Bemberg is a rayon made by the cuprammonium process, in which copper sulfate and ammonium hydroxide solutions are used.

Celanese and Acele are cellulose acetate rayons, rather than pure cellulose ones. In their manufacture, cellulose is treated with glacial acetic acid and acetic anhydride in the presence of sulfuric acid. As the result of a series of washings under controlled conditions, there is produced a viscous cellulose acetate. By adding acetone and pumping the solution through tiny holes into warm air, acetate rayon is produced. This process has the difficulty that time, temperature, and other factors influence fiber production. This rayon is perhaps the most important of all the cellulose fabrics. It is used in draperies, upholstery, and as dress material.

Another important use of cellulose acetate is in the manufacture of safety motion picture film. Inasmuch as the ordinary film is a cellulose nitrate which burns easily and must be carefully guarded, the cellulose

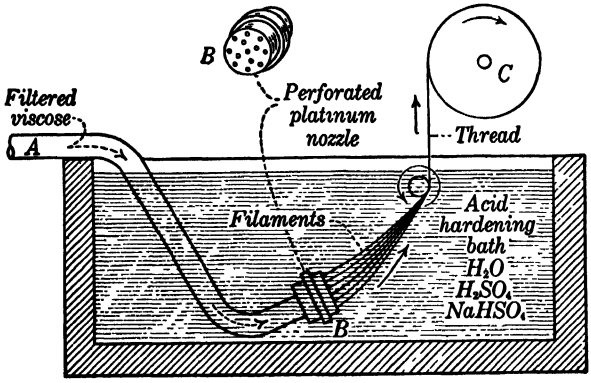


FIG. 160. Making rayon threads. Pure cellulose enters through *A* and is forced through tiny holes in the nozzle *B* into the acid hardening bath. The thread is wound on the reel C. (Courtesy, McPherson and Henderson: "Chemistry for Today," Boston, Ginn and Co.)

acetate, being slow burning, can be used in locations where the nitrate might be dangerous.

Synthetic Textiles Containing No Cellulose

A large array of synthetic fibers has been produced in the chemical laboratory in the last two decades. Some familiar examples are nylon, casein fibers, and soybean fibers.

NYLON. The first all-chemical synthetic fiber was produced by the DuPont Corporation in 1938. This textile is popularly said to be derived from "coal, air, and water." Actually, there is a basis of truth in this statement, since one of the constituents is adipic acid, a coal tar derivative, and the other component, hexamethylene diamine, needs ammonia for its production. (The word nylon has no especial meaning. It is simply a coined word.)

Nylon fibers, when viewed by a microscope, are uniform, smooth, and have a light luster. They resemble glass fibers in appearance and are stronger than any other synthetic or natural fiber. One great advantage of nylon fibers over any other textile fiber is that they absorb very little water. Consequently, the wet strength is nearly as great as the strength when dry. Nylon fabric is not attacked by many chemicals. It is disintegrated by nitric acid and phenol. Since nylon is much more resistant to wear than silk, it is replacing all other fabrics for hosiery.

CASEIN FIBERS. The use of milk casein in the textile industry indicates the wide range of materials which the chemist makes available. By a rather complicated chemical process, casein is changed into a viscous mass which can be made into textile fibers. It is used in many types of garments.

FIBER IDENTIFICATION TESTS

It is frequently desirable to distinguish between various types of fibers so as to detect adulteration or misbranding. There are three types of identification in common use. One or all may be necessary for complete identification. They are: (a) physical tests, including strength and luster; (b) microscopic examination; (c) chemical tests.

The chemical tests can be divided into three types: burning test, color test, and solubility test. In a text of this character, only a few simple tests can be given. The reader is referred to the references for further details.

The experiments at the end of the chapter form a preliminary set which can be performed in any laboratory.

PLASTICS

Plastics are those solid materials which, during manufacture, are in such a condition that they can be moulded into shape by heat, or pressure, or both. During the Second World War, shortages in many fields led to the development of many new materials which are classed as plastics. Plastics are not cheap and the ideal plastic has probably not been yet made. They cannot compete with metals in hardness, ductility, and tensile strength. Nevertheless, they play a very important role in modern industrial life. Because of the immense number of such materials, we shall describe only a few of the most important and refer the reader to the references. It will be helpful to list the eight most important plastics and to discuss each briefly.

1. phenol formaldehydes
2. cellulose acetates
3. urea formaldehydes
4. methyl methacrylates
5. nylon
6. melamines
7. polystyrenes
8. vinyl copolymers

PHENOL PLASTICS

The oldest plastic group, and one which is still of great importance is the phenol formaldehyde class (phenolic plastics). The best-known member of the group is Bakelite.

In 1909, the chemist Baekeland announced the discovery of a new plastic material which he made by heating phenol (carbolic acid) and formaldehyde in the presence of a catalyst (hydrochloric acid). When heated under pressure for several hours, a hard, insoluble, infusible, and very strong product results. It is light in weight and is made into pipes, beads, umbrella handles, and radio panels, as well as a host of other articles. Its limitation is that it cannot be made into many colors. It is still one of the most important plastics.

A similar type of plastic is the *urea formaldehyde* group (Plaskon). Since this material can be produced in color, many counter tops and electrical fixtures are made of the plastic. Many of these materials are translucent, being used for lamp shades.

Cellulose acetate, in addition to being one of the most valuable textile fabrics, can be produced also as a plastic. It is one of the most versatile of all prewar plastics. Some uses are door handles, costume jewelry, automobile trim, and photographic film.

METHYL METHACRYLATES (ACRYLIC RESINS)

These plastics have remarkable optical properties. The index of refraction (1.49) is about that of optical crown glass so that they are formed into spectacle lenses, dentures, and airplane windows. They are not as brittle as glass. Some trade names are Lucite and Plexiglas.

NYLON

Few persons think of nylon as a plastic, and it was not used as such until the last few years. It is a thermoplastic, meaning that it softens under heat. As a plastic it has great strength, is almost fireproof, is resistant to most chemicals, and can be machined easily. The applications of nylon as a plastic are legion. We will mention only a few: window screens, tire cords, tubing, wire insulation, paint brushes, and dishes. It is estimated that the world will use many million pounds of nylon in the immediate future, both as a fabric and as a plastic.

MELAMINE PLASTICS

These are some of the new plastics which are excellent insulators and are very hard. They can be used for table tops and in electrical circuit breakers. Another interesting use is in the production of tableware such as dishes. The method of production is the treatment of calcium carbide

with nitrogen to produce the chemical, *melamine*. This is caused to react with formaldehyde. Two trade names are Melmac and Resimene.

POLYSTYRENE PLASTICS (STYRENE RESINS)

These plastics have excellent water resistance and superior electrical properties, especially in the high frequency field. They are used as insulators in coaxial cables. They are able to replace fused quartz for many purposes. Some types are highly transparent and can be used in optical devices.

VINYL RESINS

These plastic materials have excellent adhesive properties, which makes them an excellent binder for automobile safety glass. They are used as dentures, flashlight lenses, music records (Vinylite), poker chips, slide rules, Scotch Tape, and Plastic Wood. The housewife is familiar with this plastic under the trade name Koroseal.

References

Beery: "Chemistry Applied to Home and Community," Philadelphia, J. B. Lippincott Co.

Dubois "Plastics," Chicago, American Technical Society.

Lowy, Harrow, and Apfelbaum: "Organic Chemistry," New York, John Wiley and Sons.

Mathews: "Textile Fibers," New York, John Wiley and Sons.

Powers. "Synthetic Resins and Rubbers," New York, John Wiley and Sons.

Richardson and Wilson: "Fundamentals of Plastics," New York, The McGraw-Hill Book Co.

Rogers: "Manual of Industrial Chemistry," New York, D. Van Nostrand Co.

Simonds: "Industrial Plastics," New York, Pitman Publishing Co.

Simons: "The New Plastics," New York, D. Van Nostrand Co.

Weil and Anhorn. "Plastic Horizons," Lancaster, Cattell Press.

Questions and Problems

1. What is a plastic?
2. How is nylon produced?
3. Name four plastics.
4. How could you determine if a wool garment contains some cotton?
5. What is: cellophane? Lucite? Koroseal?
6. Name three synthetic fibers. How do they differ in property?
7. Why is a woolen garment usually warmer than a cotton one of the same type?
8. Why is linen a desirable fiber?
9. Give two reasons why nylon is rapidly replacing silk.
10. Why is wool worn in cold weather?

Topics for Discussion

Silkworm Culture	A Study of Nylon	Modern Plastics
Silk Weighting	Rayon Manufacture	Products Derived from Cellulose

Experiments

1. Examine pieces of unknown textiles, using the tests given in the chart. Make a written report, pasting to it a piece of your unknown material with one corner burned. All cloth should be boiled in water to remove sizing and should be dried before using.

FIBER TEST CHART

Reagent	*Silk (Cultivated)*	*Silk (Tussah)*	*Cotton*	*Linen*	*Wool*	*Viscose Rayon*	*Nylon*	*Acetate Rayon*
Acetone								x
HCl conc.	x						x	x
HNO_3 conc.	Yellow	Yellow			Yellow		x	x
Phenol 90%							x	x
5% NaOH	x	x slowly			x			Saponifies
H_2SO_4 conc.	x	x	x	x		x		x
Millon's Reagent	Red	Red			Red			

x indicates fiber is soluble.

Note. To prepare Millon's reagent, dissolve 15 Gm. of mercury in 30 cc. concentrated nitric acid. When completely dissolved, add 70 cc. of water. This material is poisonous and corrosive. Use great care.

BURNING AND MICROSCOPE TESTS

	Cotton	*Linen*	*Wool*	*Silk*	*Viscose Rayon*	*Nylon*	*Acetate Rayon*
Does it burn readily?	Yes	Yes	Crinkles	Crinkles	Yes	No	Yes
Odor?	Burning Paper	Paper	Hair	Hair	Paper	Boiling String Beans	Acetic Acid
Diagram of Fiber	Twisted	Bamboo-like	Scales	Smooth Tube	Smooth Tube	Lustrous Like Glass	Smooth Tube

21. ENERGY APPLIED TO MACHINES

One machine can do the work of fifty ordinary men. No machine can do the work of one extraordinary man.

—ELBERT HUBBARD

We have already (see p. 192) made use of the term *energy* in connection with the various radiations by atoms. Energy is always associated with material objects, yet it seems to be unlike them. Absence of energy from objects makes them lifeless, cold, and dead. In the present chapter, we shall describe some forms of energy and their applications to machines. In other chapters, various manifestations of energy are discussed.

Energy exists in many forms, all of which can be considered as belonging to two fundamental types, potential energy (energy of state or position) and kinetic energy (energy of motion). We wind a clock spring and the clock acquires potential energy, which is released in the form of kinetic energy as the clock keeps time. In operating an automobile, we use gasoline produced by the energy of the sun in the past ages. The liquid contains potential energy. When it is passed into the carburetor and exploded in the running motor, kinetic energy is produced. A storage battery has potential energy which is changed into kinetic energy of electricity when the battery is in use. Energy is stored in the water in dams. It exists in a chemical form in such materials as sulfuric acid. Our energy sources are chiefly coal, oil, gas, wind, and water.

If a baseball is thrown into the air, the ball starts upward with kinetic energy, because of the work done on it by the thrower. The ball rises with decreasing kinetic energy and gains potential energy as it moves until, at the top of its path, all kinetic energy has become potential energy. The ball falls and the potential energy decreases until at the ground the energy is again in the kinetic form.

When food containing potential energy is taken into the body, a chemical change results, which enables the body to perform tasks. One of the tasks is that of the heart doing work in pumping blood to all parts of the body. Another task is breathing.

We summarize these effects by saying that the bodies have a form of energy, meaning that *they have the capacity of doing work on either themselves or other bodies.*

It is evident that the constitution of energy has not been explained. We

can describe only its effects. It will be further noted that in each of the cases cited, work has been done by some animate or inanimate agency. *Energy can be considered as the cause of work or as the result of work done.*

One ft. lb. of work is done when 1 lb. of weight is lifted vertically to a height of 1 ft.

In the metric system, one of the units of work is the erg. This is the work done when 1 dyne of force acts through a distance of 1 cm. A more common unit is the joule—10,000,000 ergs.

An example of this is the baseball. The thrower does work on the ball, producing energy. When the ball returns to the thrower, it does work on the hand when it is caught.

The potential energy of a baseball is measured by the product of the weight and height. A ⅓ lb. baseball at a height of 30 ft. is said to possess 10 ft. lb. of potential energy. The kinetic energy of a moving automobile can be calculated by the relation $Ke = \frac{1}{2}MV^2$ where M is the mass of the car and V is the speed. For example, a 3,000 lb. car moving at 60 mi. per hr. (88 ft. per sec.) has a kinetic energy of 11,616,000 ft. poundals or 363,000 ft. lb. (32.2 ft. poundals equal 1 ft. lb.). Because the energy depends upon the square of the speed, a car moving at the rate of 60 mi. per hr. has four times the energy of the same machine moving at 30 mi. per hr. This accounts for the great damage done in the event of collision at high speeds. The damage done depends not on the momentum, as is often stated, but on the kinetic energy.

Conservation of Energy

One of the great principles of science is that of Conservation of Energy. This principle states that the total amount of energy in the universe is constant. (This does not mean that the amount of energy remains constant on the earth.) We may change energy from one form to another, e.g., chemical to electrical, but according to this principle we can never create it or destroy it. On the earth, we are constantly giving out energy in the form of light and heat to other parts of the universe, so that the earth actually loses a part of its store. Most of our energy came to the earth from the sun in past ages. We are using our supply very rapidly. In every operation of machinery, some energy is lost as a result of frictional forces. This is wasted in the form of useless heat.

It may be that we gain from the sun as much as we lose, but it is difficult to prove this statement. Most scientists believe that the earth is actually losing more energy than it gains, although the amount in the universe is constant. Some sources of energy on the earth are our supplies of coal and other fuels, our water moving in rivers, and the sun's rays (Fig. 161).

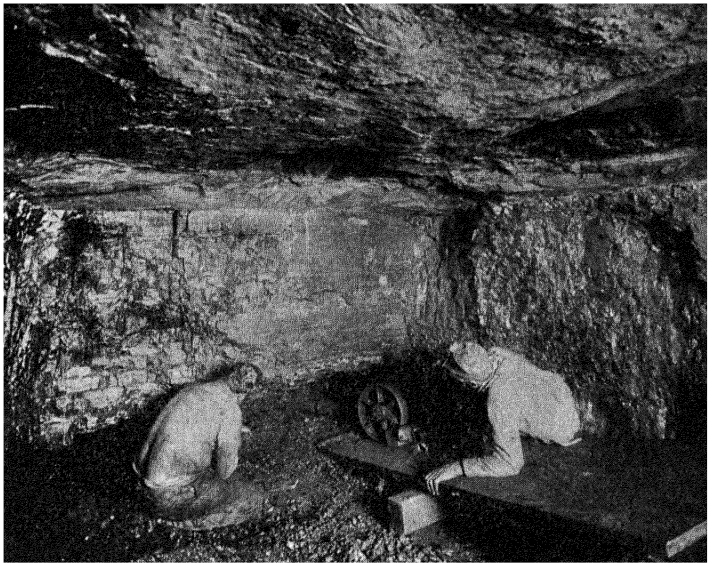


FIG. 161. Stored sunshine. (Courtesy, Wendt and Smith· "Matter and Energy," Philadelphia, The Blakiston Company.)

It may be that, under certain conditions such as the high temperature of the sun, the principle of conservation of energy may need modification. It was stated in Chapter 1 that the temperature of the sun is maintained possibly by the creation of energy from matter.

Table 19

ENERGY VALUES

Potential energy of an alarm clock spring . .	5 ft. lb.
Potential energy of a pound of coal . .	1,600,000 ft. lb.
Potential energy of a pound of steam .	160,000 ft. lb.
Kinetic energy of a baseball moving at a speed of 45 ft. per sec.	23 ft. lb.

ENERGY TRANSFORMATIONS

Some very interesting experiments can be performed to illustrate the transformations of energy from one form to another. The Knipp singing tubes illustrate heat energy being changed into sound energy. The thermocouple (see p. 305) is an example of the change of heat energy into the electrical form. Many chemical reactions, such as thermit, illustrate the relations between chemical energy, heat, and light. The magneto (Fig. 162) produces electrical energy which lights a lamp. This is an example

of the change of mechanical energy into electrical energy. A swinging pendulum illustrates energy changing from the potential to the kinetic form. The radio loudspeaker is an example of electrical energy being changed into sound energy.

Velocity and Acceleration

This is an age of speed. We travel in an automobile at 60 miles per hour, in trains at 100 miles an hour. Our airplanes sometimes attain the speed of more than 700 miles an hour, which means that we cross the continent in

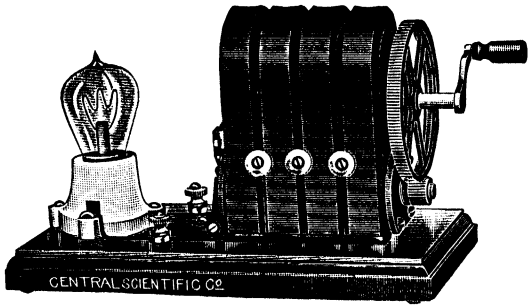


Fig. 162. The magneto. (Courtesy, Central Scientific Company.)

a few hours. In an x-ray tube, electrons sometimes have a speed of over 150,000 miles per second.

During the World War of 1914–18, shells from the guns called "Big Berthas" reached the amazing speed of 1 mile per second. For several weeks, the Germans shelled Paris from a distance of 75 miles. In order to accomplish this feat, the shells were fired into the atmosphere at an angle of 50° and with such speed that they rose to the then unbelievable height of about 30 miles, the greatest height that any object had ascended into the stratosphere up to that time. The rockets fired by the Germans in 1944 traveled at a speed greater than that of sound waves and rose to a height of about 60 miles.

Speed is the rate at which we move, while *velocity* is speed in a definite direction. If we are driving along a straight road at 30 mi. per hr. and we turn a corner with the speedometer still reading 30, we have changed the velocity but not the speed. We all know that changing the direction sometimes causes skidding. The change of velocity when the car is turning the corner brings into action the inertia of the car, which tends to prevent the turn.

We wish our automobile to have plenty of "pickup" from a stop and to get away in traffic. By these expressions we mean that, when we push on the accelerator, we wish a quick increase in velocity. This increase in

velocity is called *acceleration. Acceleration is velocity divided by time.* We are constantly accelerating or decelerating our cars. We injure ourselves when we fall from a ladder because our rate of fall increases rapidly and we strike the ground with great force. The force of gravity accelerates the motion of all falling objects. Galileo, by his famous "Leaning Tower of Pisa" experiment, proved that all falling bodies have the same acceleration if we neglect air resistance. This means that, in a vacuum, a feather and a brick fall with the same rapidity.

Sir Isaac Newton expressed these ideas in the famous Laws of Motion. The first law states that a *body at rest tends to remain at rest and a body in motion remains in uniform motion in a straight line unless acted upon by an external force.*

The second law states that *change of motion of a body is proportional to the applied force and the change of motion takes place in the direction of the force.*

The third law states that *action and reaction are always equal, and opposite in direction.* This last law means that whenever one body exerts a force on a second body, the second body exerts an equal opposing force on the first body. If a man pushes on a wall with a force of 50 lb., the wall reacts with a force of 50 lb. on the man. These famous laws of motion and the law of gravitation were formulated by Newton as a result of his own studies as well as those of Kepler and Galileo. They stand as great mileposts along the road of scientific progress.

Force

When one opens a door, lifts a book, claps his hands, utters a word, or steers an automobile, he is exerting force. Anything which performs what muscle can accomplish exerts a force. A force may be regarded as a push or a pull. A force tends to produce a change in the motion of a body.

One unit of force is the pound. It is the force required to lift 1 lb. of mass. One lb. of force is equivalent to 32.16 poundals. The dyne is the force required to give 1 Gm. of mass the acceleration of 1 cm. per sec. per sec.

GRAVITATION

One of the outstanding forces in nature is called gravitation. There is exerted everywhere in the universe a force which acts upon every material object. This force has the effect of giving weight to all objects on the earth. A man who weighs 160 lb. on the earth is pulled to the earth with a force of 160 lb. If he is in an airplane 5 mi. above the earth, he weighs slightly less than 160 lb. We assume that on the moon the same man would weigh $\frac{1}{6}$ as much as on the earth. The value of this force is expressed by the law: *The force of gravitation between two bodies depends directly upon the product of the masses and inversely upon the*

square of the distance between their centers. We may write it as an equation:

$$\text{Force} = G \times \frac{M_1 \times M_2}{D^2}$$

In this equation, the force is expressed in dynes; G is a universal constant; M_1 is the mass of one body and M_2 is the mass of the other in grams; D is the distance between their centers in centimeters.

Calculations with this formula lead to some curious results in the stellar universe. A companion star of Sirius in the constellation Canis Major seems to be so dense that a piece of the star the size of a brick would weigh 140,000 lb. The weight of the imaginary man in the moon compared to his weight on the earth can be calculated as follows: the radius of the moon is ¼ the radius of the earth; the mass of the moon is $\frac{1}{90}$ of the mass of the earth (these are approximate numbers). We can now write a proportion:

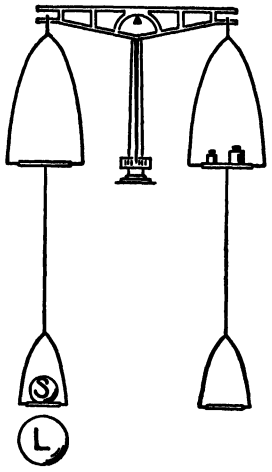
$$\frac{160}{\text{Weight on moon}} = \frac{90 \times 1}{1 \times 16}$$

Thus, his weight on the moon would be about 28 lb.

The mass of the earth has been determined by several experimenters. One of the methods was that used by the scientist Jolly. Using a beam balance, Jolly measured the attracting force between a large mass of lead and a mass of mercury (Fig. 163). By this means, he determined the gravitational constant G. Since he knew the weights of the metals (the attractive force of the earth), he could, by using Newton's Law of Gravitation, easily determine the mass of the earth. The result was 6.7×10^{21} tons!

The pound is defined as the pull of the earth on a block of platinum kept at London. Since this pull varies as we move about over the earth's surface, it is necessary to state at what point we measure the weight. However, since the difference is small, for ordinary purposes we shall consider the weight of the body to be the same everywhere on the earth.

Another interesting "force" is the so-called "centrifugal force." We have the centrifugal pump, the vacuum cleaner, the centrifugal clothes dryer, the loop-the-loop, and the merry-go-round. When the automobile rounds the curve, we lean inward; a skater leans when turning a curve. Skidding of the wheels of an automobile is due to "centrifugal force." Each of these effects illustrates the tendency of a body to continue in a straight line (the law of inertia). In the dryer, the water leaves the clothes whenever the centripetal force (force toward the center) is insufficient to keep the drops moving in a circle. A skidding car is simply tending to travel in a straight line. By banking the curve, we can overcome this



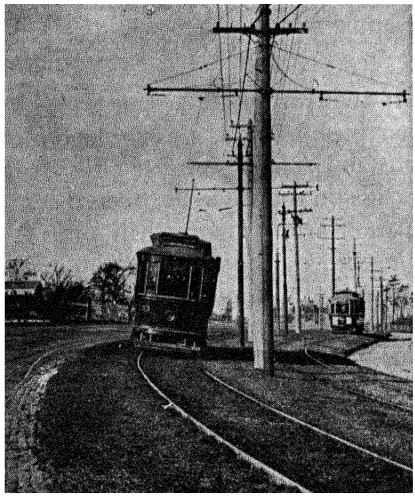


FIG. 163. (*Left*) Jolly's method of determining the gravitation constant G. L is a mass of lead and S a dish of mercury. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)
FIG. 164. (*Right*) A banked curve. (Courtesy, Central Scientific Co.)

tendency (Fig. 164). At the Indianapolis automobile speedway, some of the curves have a bank of 18°.

Theory of Gravitation

The law of gravitation was first stated by Newton. Since that time, many scientists have tried to offer some explanation of the mysterious force which controls all bodies in the universe. We believe that the stars themselves are held in place by the attractions of neighboring stars. Up until the time of Einstein, there had been no satisfactory explanation of this curious force, which increases as the masses of the bodies increase. It probably has some intimate connection with the structure of the universe.

Einstein, as a consequence of his Theory of Relativity, proposed the following revolutionary explanation. Gravitation and accelerated motion are equivalent; they cannot be distinguished from each other. In order to make this statement intelligible, we shall use the following example. Let us imagine ourselves in a closed elevator being hoisted upward with an acceleration of 32 ft. per sec. per sec. If an apple is released in the elevator, we will rise to meet it, even if there is no pull of gravity. Since we cannot see out of the elevator and we are not aware of our motion, we will say that the apple is falling with the acceleration of the gravity, 32 ft. per sec. per sec. In other words, we cannot distinguish the apple falling with the

acceleration of gravity from an upward acceleration of the elevator and the apple at rest.

CONCURRENT FORCES

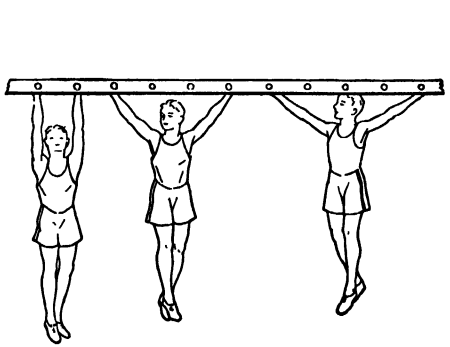
If two forces are acting on a body, the direction of the two effects, either push or pull, must be considered. If a boy grasps a bar with both hands and "chins" himself (Fig. 165), the pull that each arm must exert depends on the angle between the arms. If the arms are parallel and vertical, each arm supports half of the boy's weight. If the arms make an angle with each other, the pull in each arm is greater than before, since the arms are to some extent pulling on each other. If the arms are at right angles to each other, the pull in each arm, for a boy weighing 100 lb., is about 71 lb. ($50\sqrt{2}$).

Similarly, if two men are each pulling with a force of 75 lb. on a box, and if they exert their forces in the same direction, their total pull is 150 lb. If, however, they pull at right angles to each other, each man must pull more than 75 lb. to produce the same effective force.

If two forces act in exactly the same direction, we add these forces directly to determine the total force. If the two forces are not in the same direction, the forces must be added by the vector method.

A vector is any quantity which has magnitude as well as direction. Thus, velocity, acceleration, and force are said to be vectors. Speed and mass are not vectors.

In the solution of this vector problem, each 75 lb. force is represented by a line drawn from the point of application of the force, in this case the box, in the direction of the line of action of the force. The forces are laid off to some arbitrarily chosen scale and a parallelogram is constructed on the two lines. The diagonal of the parallelogram drawn from the point of application represents both the direction and size of the single force which



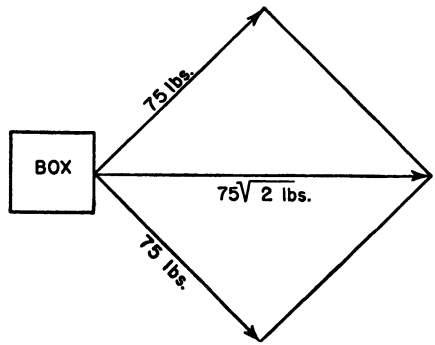


FIG. 165. Sketch illustrating the forces exerted by the arms at different angles to the vertical. (Courtesy, Millikan, Gale, and Edwards: "A First Course in Physics for Colleges," Boston, Ginn and Co.)

FIG. 166. Composition of vectors.

would have the same effect as the two original forces. Figure 166 shows the vector solution of the two forces. The value is $75\sqrt{2}$.

Another application of such forces is the airplane. Because of the rapid rotation of the propeller, there is a stream of air pushing against the wings. Part of this air force produces the "lift" of the plane. The forward force exerted by the propeller combined with this lift force counterbalances the weight of the plane (Fig. 167). The kite is a similar example.

If an airplane wing with the lower surface horizontal is moving through the air, the pressure on the upper surface is slightly less than that on the lower surface, due to the fact that the air speed is greater near the top than near the bottom. The shape of the wing causes this effect. For example, if the pressure underneath the wing is 14.7 lb. per sq. in. and the pressure above is 14.6 lb. per sq. in., there is a difference of 0.1 lb. per sq. in. This pressure multiplied by the surface area of the wing produces the lifting force. The same effect is used in the curving of baseballs and the operation of a gas burner.

The child on a swing furnishes another interesting example of the action of concurrent forces. The weight of the child W is balanced by the combination of the force T exerted by the swing rope and the push P of the person holding the swing aside (Fig. 168).

Every housewife has noticed that a loaded clothesline, if stretched too

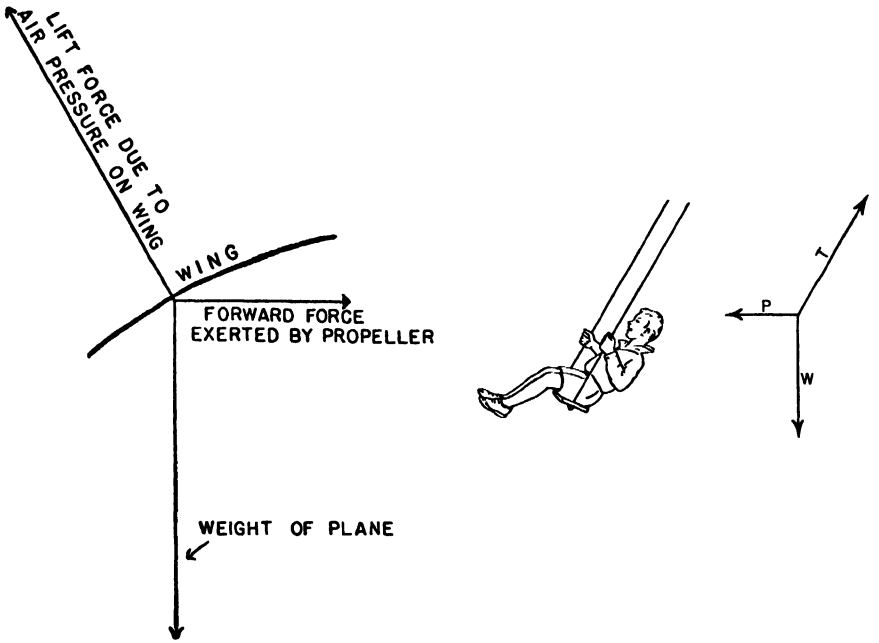


Fig. 167. (*Left*) Forces on an airplane. (Courtesy, Heil: "The Physical World," Philadelphia, The Blakiston Company.)

Fig. 168. (*Right*) Child on swing. W, weight of the child; P, the push; T, tension in the swing rope.

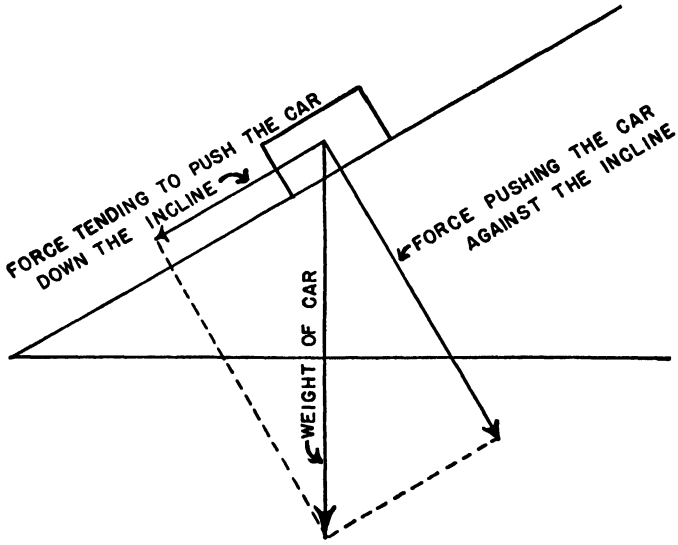


FIG. 169. A car on the inclined plane. (Courtesy, Heil: "The Physical World," Philadelphia, The Blakiston Company.)

tightly, may break. Likewise, the tightwire walker must be certain that his wire is not stretched too tightly, since in such a wire a 150 lb. man may produce a force of a ton or more on the wire.

When a car moves up an incline such as the ramp of a garage, the engine need support only part of the weight, since the ramp supports part. This will be clear from the vector diagram (Fig. 169). The weight of the car acts vertically downward. This weight can be considered as made up of two parts, one force perpendicular and one parallel to the ramp. The engine, neglecting friction, need support only the parallel force in order to pull the car up the slope. For example, if a 3000 lb. car is on a 30° slope, the engine must support 1500 lb. The force perpendicular to the slope is about 2600 lb. (In this example friction is neglected.) The law of the inclined plane (see p. 297) gives the following relation for this example:

$$\frac{3000}{1500} = \frac{\text{Length of ramp}}{\text{Height of ramp}}$$

WORK

From earliest time, men have been forced to work in order to exist. However, as civilization progressed, man learned how to utilize the energy available around him to do his work for him. He placed sails on his ships to make use of the energy of moving air. Paddle wheels turned by the energy of falling water operated his mills to grind food. *Work equals the*

force multiplied by the distance through which the force acts provided the force and the distance are in the same direction. Should a 100 lb. boy run upstairs to a height of 12 ft., 1200 ft. lb. would be the product of the weight and the vertical height which he covers. It will be noticed that the same type of example was given for potential energy. As a result of the work done, the boy has acquired potential energy. However, if the boy holds a stone in his hand without moving it, he exerts force only. Even if he carries the stone across the room, he does no work on the stone because he is pushing vertically and at the same time walking horizontally. The reason for the fatigue when holding the weight is that we are exerting muscular effort (a force). But when the force moves the stone vertically, work is done. We pay for work done when we hire a workman to build a house; we pay for energy consumed in doing work when we pay our electric light bill; we buy gasoline so that its explosive vapor may do work for us in moving a car.

If a 3000 lb. car travels along a level road for a distance of 500 ft. against a frictional resistance of 500 lb., the work done by the engine is 500×500 or 250,000 ft. lb. We note that the weight of the car does not enter directly into the problem. If the 3000 lb. car is on a 30° slope and the engine exerts a force of 1500 lb. over a distance of 50 ft., the work done, assuming no frictional force, is 1500×50 or 75,000 ft. lb. In each case, the useful force and the distance must be in the same direction.

POWER

In olden times, it was customary to pay a workman for the amount of work accomplished regardless of the time required to perform it. A man received a certain wage for performing a definite amount of work. However, as machines became more common, it became a common practice to pay a workman by the hour for services rendered. As a result, the word *power* came into common use. Power is the rate of working. If 55 lb. are lifted 10 ft. high each second, the power of the working agency is said to be 1 horse power. One horse power is equivalent to 550 ft. lb. per sec. If a 200 lb. man runs up stairs at a rate of $2\frac{3}{4}$ ft. per sec., he is working at the rate of 1 hp. The average man cannot work at this rate except for very short periods of time.

In the Eighteenth Century, James Watt spent much time in improving the steam engine. In order to study the power of such engines, he studied the work rate of the average horse. He found that an average horse could walk at the rate of $2\frac{1}{2}$ mi. per hr. while pulling a load of 150 lb., or at a rate of 550 ft. lb. per sec. Many of our smaller electric motors are only a fraction of 1 hp. Modern automobile motors average 60 hp. Airplane engines are now built having a rating of 2,000 hp. Great ocean liners have a turbine engine rating of as much as 100,000 hp.

Although the horse power is used in the United States for many types of machines, such as steam engines and motors, the watt and kilowatt are the units of power used in electricity. Seven hundred forty-six watts equal one horse power. We often find that a motor rated in horse power is operating a generator rated in kilowatts (1,000 w. = 1 kw.).

It is important to emphasize that, in the exact scientific sense, power is not a synonym for force. Only in popular language is a powerful man one who can exert great force.

MACHINES

Very early, man discovered that there were certain devices which could be used to aid him in doing his work, principally by making his muscular effort easier. He found that he could roll great stones, fell trees, and overcome other obstacles by their aid. These devices are called machines. All of our useful machines are devices by which one form of energy is changed into a type we wish to use. For example, we use electricity to operate motors and produce light and heat.

LEVERS. Probably the first machine developed was the lever. We find the lever depicted in Egyptian sculpture. The cave man may have discovered that by using the stout limb of a tree, he could pry large boulders out of his path. His fulcrum was probably a small stone or a tree trunk (Fig. 170). The child uses the see-saw (teeter board) and finds that a heavy boy can balance a light one by adjusting their positions on the support. Sometimes the children use a third child to secure a balance. The carpenter finds that it is easier to pound a nail if the hammer has a long handle. It is easier to close a door by pushing on a knob than pushing in the middle of the panel. Other familiar examples of the lever are the canoe paddle, the shovel, the rowboat oar, and the broom. It must be emphasized that the *machine does not save work.* It makes it possible to do the work more easily. The less the force, the greater the distance through which the force must act, since work equals *force times distance.*

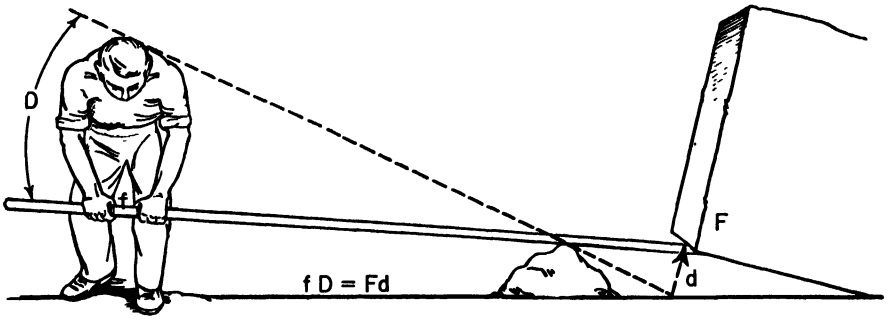


FIG. 170. The simple first class lever. The effort (*f*) moving through the distance (*D*) raises the load (*F*) through the small distance (*d*).

On the see-saw, the lighter boy sometimes sits on the longer end of the board, moving up and down through a greater distance than the heavy boy. An essential part of the lever is the fulcrum, the edge on which the see-saw turns. Archimedes, the famous scientist of Syracuse, said, "Give me whereon I can stand and I will move the world." He meant that if he had a fulcrum outside the earth, a long lever, and a resting place for himself, he could pry the earth out of its position in space.

A very simple law may be used in making calculations with the lever. In the case of a bar balanced on a fulcrum and having weights of 5 and 10

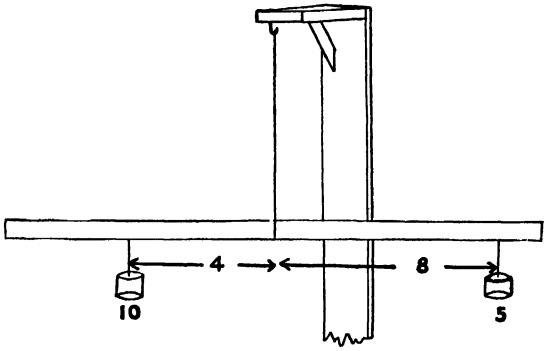


FIG. 171.

lb. on opposite sides at distances of 8 and 4 ft. from the fulcrum (Fig. 171), we may write $8 \times 5 = 10 \times 4$, or force times lever arm equals resistance times lever arm. If f is 5 and F is 10, D is 8 and d is 4, then $fD = Fd$.

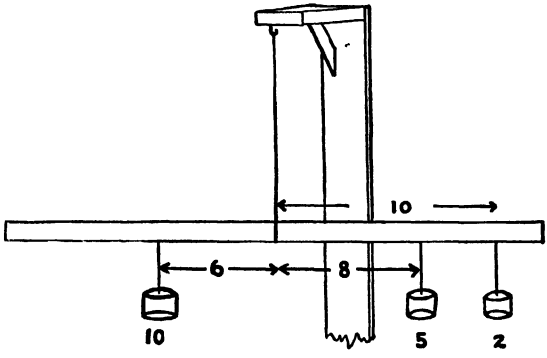


FIG. 172.

In case there are three forces, as in Fig. 172, $2 \times 10 + 5 \times 8 = 10 \times 6$. (If the bar is not balanced before the weights are added, the weight of the bar must be considered in the calculations.)

Levers are divided into three classes. The first is exemplified by a pair of shears, the second by a wheelbarrow, and the third by a canoe paddle

or the forearm (Fig. 173). In each case, the distances are measured to the fulcrum.

In case the bar has not been balanced in making a calculation, the total weight of the bar is considered as concentrated at the center of gravity of the bar. Thus, the distance from the center of gravity of the bar to the fulcrum becomes the lever arm for the weight of the bar.

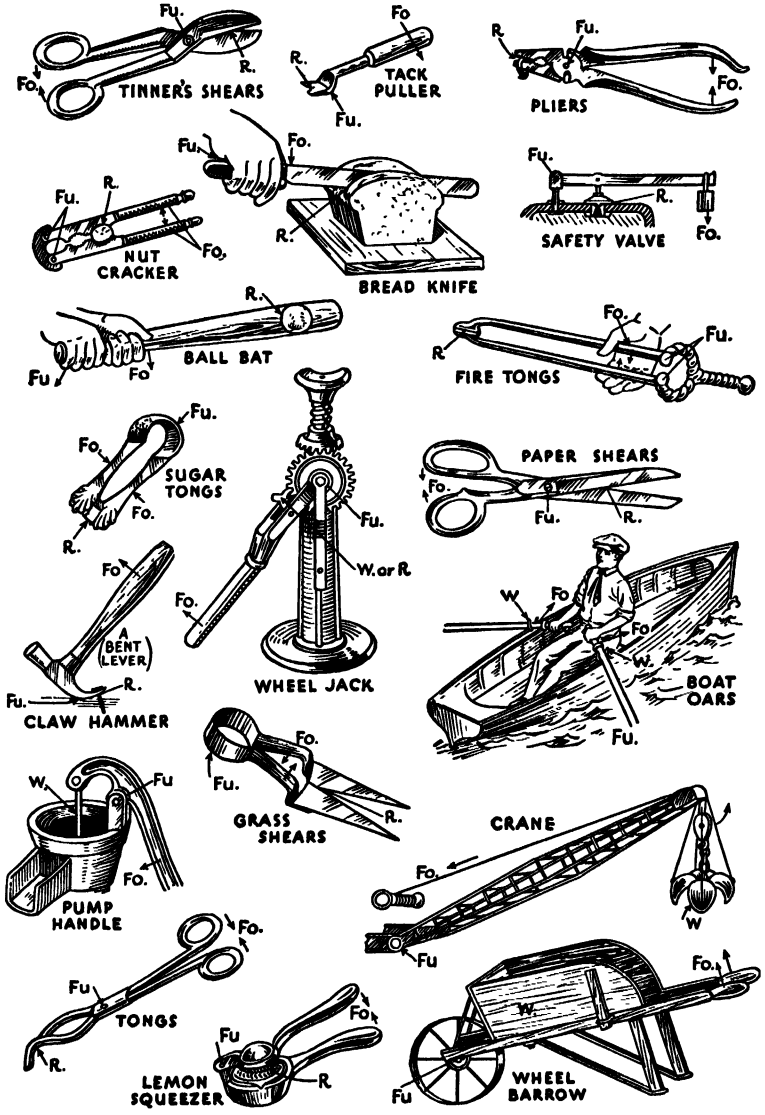


FIG. 173. Various lever applications. In the drawings *Fu.* is the fulcrum, *Fo.* is the force exerted and *R.* or *W.* is the resistance overcome. (Courtesy, Pieper and Beauchamp: "Everyday Problems in Science," Chicago, Scott, Foresman and Co.)

Mechanical Advantage. The mechanical advantage is defined as R/F or the resistance overcome divided by the force applied. By mechanical advantage, we mean the saving in force. If, by means of the lever, we can lift 2 lb. by pushing only 1 lb., the lever has a mechanical advantage of 2.

INCLINED PLANE. Another type of machine is the inclined plane, which we have illustrated by the ramp in a garage. A workman wishing to lift a 300 lb. barrel from the ground to a warehouse floor 3 ft. high uses a plank placed with one end on the ground and the other on the floor of the building. He may now roll the barrel up the plank by pushing less than 300 lb. For a plank 15 ft. long, he will need to push only 60 lb. The longer the plank, the less the force he must exert. However, he must push through a longer distance, so he saves himself no work. The ratio of the weight of the barrel to the force applied by the workman is called the mechanical advantage. The law of the inclined plane states that *the weight multiplied by the vertical height equals the force multiplied by the length of the plane* (Fig. 174) or $WH = FL$. (It must be emphasized, however, that this relation is true only if there is no friction. Since friction is always present, the force exerted in the example will be more than 60 lb.)

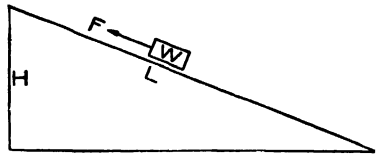


FIG. 174. The inclined plane.

In general, the law of machines states that, *neglecting friction, the resistance overcome multiplied by the distance through which the resistance acts equals the effort multiplied by the distance through which the effort is exerted.*

Efficiency. Because of the roughness of the plank, the workman actually does more work (force times distance) on the barrel than he gets out of the operation. The wasted work is used to overcome the resistance due to friction. The *efficiency is the ratio of the useful work done by the machine to the work put into the machine.* It is a measure of the useful work. No machine is frictionless and, in consequence, the efficiency is always less than 100 per cent. If, for example, the workman uses a force of 100 lb. to roll the 300 lb. barrel up the plank of length 15 ft. so that the barrel rises 3 ft., the efficiency equals $\frac{300 \times 3}{100 \times 15}$ or 60 per cent.

A hod carrier carrying bricks up a ladder does his work inefficiently, since he must lift his weight as well as the bricks. A more efficient way would be to use a pulley system operated by the man on the ground. Some machines, such as the electrical transformer and the steam turbine, have a high efficiency of about 95 per cent, while others, such as the wheelbarrow, may have only 12 per cent efficiency.

If we could build a perfect machine, we could produce perpetual

motion so that a machine once started would move itself forever. But, since friction is always present, perpetual motion is impossible in a machine. The earth and the other planets of the solar system have almost perpetual motion, because there is practically no frictional resistance to the motion. From the earliest times, men have tried to devise machines which, once started, would run of themselves. In the past, many patents were issued on such pieces of apparatus, but at present no patent will be granted on such a machine. It will be of interest to the reader to consult the cyclopedia for examples of perpetual motion machines.

FRICTION

Friction in solid materials is due to the roughness of the two surfaces which rub together. Perhaps we think of friction as undesirable. It is true that friction means low efficiency. Because of this, we oil the rubbing parts of motors and other machines, since the friction between layers of oil is usually less than that between metals.

But without friction we could not walk. We slip on smooth ice because there is too little friction between our shoes and the ice. Because of friction, nails stay in wood; cloth can be woven; we can start a car and stop it when we wish.

Most automobile drivers have very erroneous ideas of friction as applied to the stopping distance of cars. Most persons believe that balloon tires will skid less easily than narrow, high-pressure tires, that wide brake bands are better than narrow ones, that light cars can stop more easily than heavy ones. Actually, the friction between two surfaces is independent of the area of the contact surfaces so that balloon tires skid just as easily as high pressure ones, and light cars and heavy cars under the same conditions will stop in the same distance, since the weight of the car is not a factor.

In order that a moving car may be stopped, the frictional force of the tires on the road does work as the car moves through the stopping distance. The kinetic energy of the car equals the work done by friction.

$$\frac{Wv^2}{2g} = cWd$$

In this relation, W is the weight of the car; v is the velocity in ft. per sec.; c is the coefficient of friction; d is the minimum stopping distance in ft.; and g is the acceleration of gravity in ft. per sec. per sec. By solving for v, we have the relation $v = \sqrt{2gcd}$. Thus, the only factor which affects the minimum stopping distance is the coefficient of friction between tires and road. The weight of the car has no effect.

The automobile companies have compiled data giving the shortest stopping distance for various automobile speeds under ideal conditions.

No car traveling 30 mi. per hr. can be stopped in less than 75 ft., while a car moving at the rate of 60 mi. per hr. requires 220 ft. to stop. These distances include the distances travelled while the driver thinks of stopping (reaction time). It must be remembered that these distances are for the ideal conditions of good brakes, new tires, and dry roadway. Actually, the distances are usually greater than those given. No auto can "stop on a dime" when moving 30 mi. per hr.

Gases and liquids also exert friction. Modern high speed trains and automobiles are streamlined to reduce the resistance due to the friction of the air through which the machine is moving. Because of the resistance of the air, raindrops fall rather slowly and parachutes are used to check the fall of aviators. Airplanes travel in the stratosphere partly because of the decreased air resistance.

Other Types of Machines. Other simple machines in common use are the screw, the wheel and axle, and the pulley. All machines are composed of a few simple ones.

As one watches a printing press or a knitting machine in operation, it is difficult to believe that such complicated devices are composed of a great number of the simple machines. The great computing machines weighing many tons and performing intricate mathematical calculations are a mass of simple machines accurately coordinated.

The automobile is a familiar example of the combination of simple machines. As we press the starter, the foot is a lever with the heel as the fulcrum. The starting motor turns the engine by a wheel and axle. The engine has a crankshaft which is a lever. The steering wheel is a wheel and axle. The forearm is a third class lever with the fulcrum at the elbow. As we drive the car up a ramp in a garage, we utilize the inclined plane. We change a tire by using a jackscrew.

References

Foley: "College Physics," Philadelphia, The Blakiston Company.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
Lemon. "From Galileo to the Nuclear Age," Chicago, University of Chicago Press.
Saunders: "A Survey of Physics," New York, Henry Holt and Co.

Questions and Problems

1. A boy goes fishing, carrying a pole and a 1 lb. can of beans. He catches a fish and wishes to weigh it. If he has a foot rule, how can he find the weight?
2. A forearm is 1 ft. long from the elbow to the palm of the hand. If a 2 lb. weight is in the hand, what is the pull in the muscles of the forearm, assuming the muscle action to take place 4 in. from the elbow? Answer: 6 lb.
3. What is meant by conservation of energy?
4. State the law of machines.
5. What is: mechanical advantage? efficiency?
6. Distinguish between force and work,

7. A workman pushes a 1,000 lb. weight up a plank 10 ft. long. One end of the plank is 2 ft. higher than the other. He exerts a force of 300 lb. Calculate the mechanical advantage and the efficiency. Answers: 3⅓, 66⅔ per cent.
8. A boy weighing 100 lb. runs up a flight of stairs 20 ft. high in 5 sec. Calculate the work done and the horse power exerted. Answers: 2,000 ft. lb.; 0.7 hp.
9. Define: horse power; kilowatt.
10. Give an illustration of each class of lever.
11. Name the simple machines.
12. What is power?
13. Would a body fall faster on the moon than on the earth?
14. What is meant by the term foot pound?
15. A 100 lb. weight is raised 20 ft. in a vertical direction. What is the increase in potential energy? Answer. 2,000 ft. lb.
16. If there is no perpetual motion, why has the earth moved around the sun for so long?
17. What is the law of gravitation?
18. A plank 10 ft. long, supported at its center, is used as a see-saw. A 100 lb. boy sits on one end. Where must a 150 lb. boy sit? Answer. 1.7 ft. from end.
19. A boy weighing 100 lb. sits in a swing and is pulled back so that the ropes make an angle of 45°. What is the load on the ropes? Answer. 141.4 lb.
20. A 25 lb. sack of sugar is lifted from the floor to a table 30 ft. high in 1 sec. How much work is done? What is the power? Answers: 750 ft. lb., 1.3 hp.
21. A 10 ton truck is moved 1 mi. along a level road by a pull of 1000 lb. What amount of work is done? Answer. 5,280,000 ft. lb.
22. What types of machines give a high mechanical advantage?

Visual Aids

"Machines," Eastman Classroom Film
"Energy and Its Transformations," University of Chicago Film

Topics for Discussion

Perpetual Motion
Efficiency of Machines
Centrifugal Force
Conservation of Energy
Automobile Jacks
Friction
Lubrication

Experiments

1. Carefully balance a meter stick in a clamp, noting the position of the knife edge. Place a 100 Gm. weight at the 60 cm. mark and adjust a 50 Gm. weight until the bar is balanced. Record the distance from the fulcrum to the 50 and 100 Gm. weights. Check the lever law. (Caution: If hangers are used, be sure to include their weights.)
2. Place 50 Gm. at the 80 cm. mark and adjust the 100 Gm. weight to secure a balance. Check the lever law.
3. Slide the meter stick in its support and clamp it at the 70 cm. mark. Using only the 100 Gm. weight, adjust its position until the bar is balanced. Calculate the weight of the meter stick. (Consider the meter stick weight to be concentrated at the 50 cm. mark. Then the meter stick lever arm is 20 cm.)
4. Using a stop watch, run up a flight of stairs and calculate your work and power. Measure the height of one step and count the steps.
5. If apparatus is available, study some energy transformations. Any physics text will give several forms which can easily be studied.

22. HEAT, A FORM OF ENERGY

Heat consists in a minute vibratory motion of the particles of bodies.
—ISAAC NEWTON

Previous to the nineteenth century, it was generally believed that a body was hot because some sort of a liquid or gas had entered it. This substance, called "*caloric*," was believed to have no weight. It was thought that it could be poured into a block of iron, making the block hot. In 1798, Count Rumford, an American scientist (born Benjamin Thompson), was engaged in military work in Bavaria. He noticed, while boring cannon, that, as the boring proceeded, the cannon became hot. Being of a scientific turn of mind, he proceeded to test a theory of his, that the heat came from the work which was being done and not from *caloric*. He tried a dull tool which did not turn out any metal, but the cannon still became hot. Since nothing had entered the metal, he concluded that the operation of rubbing two surfaces together produced heat. Somewhat later, Sir Humphrey Davy found that he could melt ice by rubbing two cakes of it together. These experiments finally led men to believe that *heat was a form of energy produced by doing work*. The question was finally settled when Prescott Joule (Fig. 175) churned water with a paddle, measuring the amount of *work (foot pounds)* done and the amount of *heat (British thermal units)* produced. It seems strange to us that the wrong idea of heat persisted until such recent times. Unfortunately, wrong ideas are often difficult to eradicate from the minds of people.

Most persons are confused by the words *heat* and *temperature*. Temperature is a relative term; boiling water is at a higher temperature than is lukewarm water. On the other hand, a tub of lukewarm water, because of its great mass, may contain more heat energy than a tin cup of boiling water. A thermometer measures temperature but does not directly indicate the amount of heat energy in a substance. *We pay for heat and not for temperature*. The coldest temperature recorded on the earth outside a scientific laboratory is about —90° F. reported from Siberia. Men have produced solid helium at a temperature of about —450° F. This is within a few degrees of absolute zero (—273° C. or —459° F.). The highest temperature on record, 134° F., was recorded in Death Valley.

From a study of certain problems in heat, scientists have come to the conclusion that there is a *lowest* temperature at which point no heat

energy exists. We believe that at this *absolute zero* the molecules of substances have no heat energy. They are not in motion. Were we, by means of a flame, to apply heat to a piece of copper at absolute zero, the molecules would take in energy and begin to move to and fro. If the piece of metal were very small, the molecules would absorb the heat rapidly and the temperature would rise quickly. This means that, as a rule, adding heat to a substance also increases the temperature. Exceptions to this are found in the change of state (see p. 307). If we were to use a piece of aluminum of the same mass as the copper, the rise of temperature would be slower. Since we have used the same flame in the two cases, it is evident that the rise in temperature depends on the composition of the substance under test. If we supply the same amount of heat to the aluminum and copper, we find that the temperature of the copper has increased more than twice that of the aluminum.

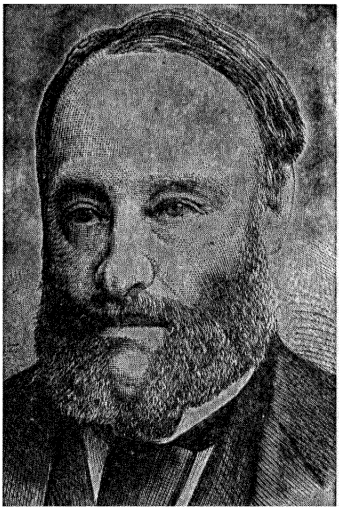


FIG. 175. James Prescott Joule (1818–1889). This scientist determined the mechanical equivalent of heat; proved experimentally the identity of the various forms of energy. (Courtesy, Tower, Smith, Turton, and Cope: "Physics," Philadelphia, The Blakiston Company.)

SPECIFIC HEAT

Similarly, if two identical beakers, one containing 100 Gm. of water and the other 100 Gm. of oil, are heated for the same length of time over the same flame, so that the same amount of heat is applied to each beaker, the oil will be at a much higher temperature than the water. If the water temperature has been increased by 10° C., the oil temperature will have increased by about 21° C. The term *specific heat* designates the effect of heat on the temperature of bodies. Water has the highest specific heat and is used as a standard, all other substances being compared to it. Because of its high specific heat, boiling water gives very painful burns, since it gives out a great deal of heat to the skin. Specific heat may be defined as the ratio of the amount of heat required to raise 1 Gm. of a substance 1° C. to the heat required to raise 1 Gm. of water 1° C.

Thus, it is evident that the amount of heat in a body depends upon the *mass*, the *specific heat*, and the *temperature*. Heat is measured in *calories* or *British thermal units*.

A calorie is the amount of heat required to raise the temperature of 1 Gm. of water 1° C. A British thermal unit is the heat required to raise the temperature of 1 lb. of water 1° F.

Table 20

SPECIFIC HEATS

Aluminum	0 219
Lead	0 03
Olive oil	0 47
Water	1 00
Copper	0 093
Mercury	0 033
Ice	0.502
Steam	0 47

TEMPERATURE

Temperature is the intensity of heat. It determines the flow of heat. Everyone has some sense of temperature. This means that we can usually estimate which is the warmer of two objects. If a body is warmer than the hand, it feels warm. If an object is at a lower temperature than the hand, it feels cool. Unfortunately, this sense is not accurate. If a person comes from cold outdoors into a room, he may exclaim that the room is warm, but after he remains for a time, he may begin to complain that the room is cold. Another illustration is a marble or tile floor in a warm room. The marble will feel cold even though it is at the same temperature as the woodwork. It can be seen that touch cannot be depended upon for temperature measurements.

An interesting demonstration is to place thermometers on pieces of copper, granite, and wood. Although the thermometers read the same, the copper and granite will feel much colder to the hand than the wood, because they are better conductors of heat.

In measuring temperature, it is necessary that we use the temperature of some object as a fixed point (starting point). There must be some temperature that everyone will agree upon as a starting point. We might use normal body temperature (98.6° F.) for such a point. However, body temperature varies slightly with different individuals and thus is not suitable.

It is rather amusing that the most obvious substance, water, was not considered until suggestions of such temperatures as melting butter, temperature of a deer's body, the temperature of a cellar in Paris, and the boiling point of alcohol had been discarded. It is now agreed to use the temperature of melting ice and the temperature of water boiling at a barometric height of 76 cm. (standard pressure) as fixed points.

THERMOMETERS. Any device which measures temperature is called a thermometer. Until the time of Galileo, thermometers were unknown. It was desired to make an instrument to measure the temperature of fever

Table 21

STANDARD TEMPERATURES

Substance	*C.*	*F.*	*Absolute*
Helium (boiling point)	−269	−454	4
Mercury (freezing point)	−38 9	−38	234
Water (freezing point)	0	32	273
Tin (melting point)	232	450	505
Silver (melting point)	960	1,760	1233
Tungsten (melting point)	3000	5,400	3273
Sun (surface temperature)	6000	10,800	6273

patients. Galileo's thermometer consisted of a glass bulb with a long stem (Fig. 176). The bulb and part of the stem were filled with air and the remainder of the stem contained water. When the temperature rose because of the body heat, the air in the bulb expanded, pushing the water column downward. This was a crude thermometer. The next steps were the scaling of the stem and the use of mercury. Of the many scales that have been invented, only two have survived, the Fahrenheit and the centigrade (Fig. 177).

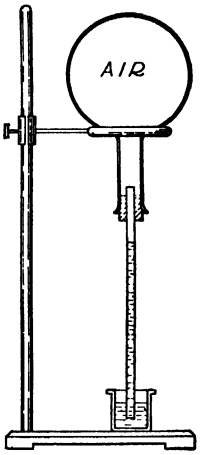


FIG. 176. Galileo's thermometer. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

There is a third thermometer, the Réaumur, which has a limited use in Europe.

A mercury thermometer is made by filling the bulb and the stem with mercury. The glass is then heated and sealed off. The bulb is now placed in melting ice and the position of the mercury column marked. For a Fahrenheit thermometer, this point is called 32; for a centigrade, it is called 0. The thermometer is now placed in steam over boiling water, and the atmospheric pressure noted by means of a barometer. If the pressure is 76 cm., the thermometer reading is 212° F. and 100° C. The thermometer is then divided into equal divisions, 100 divisions on the centigrade and 180 divisions on the Fahrenheit. If we wish to find the value of one temperature in terms of the other, we use the relation $\frac{F. - 32}{180} = \frac{C.}{100}$. For example, to find the value of 20° C. in terms of F., we substitute 20 for the C., in which case F. is 68.

For ordinary temperatures, mercury is the best liquid, since it does not stick to glass. A clinical thermometer is a mercury thermometer that has

a constriction in the stem, so that the mercury does not drop back after the bulb is removed from the patient's mouth. This enables the physician to read the thermometer at his leisure.

Oven thermometers are made of pyrex glass and contain nitrogen above the mercury. One may use such a thermometer up to 700° C. For temperatures below the freezing point of mercury, alcohol is used.

THERMOCOUPLE. For high temperatures, we use a device known as a thermocouple. In this device, two wires of different metals, such as copper and iron, have their ends fastened together as shown in Fig. 178. A current measuring instrument is placed in the circuit. If one junction is heated and the other kept cold, an electric current will flow in the circuit. The amount of the current depends on the difference in temperature between the two junctions. A thermocouple can be made cheaply and the observer need not be near the furnace to read the temperature. Since the galvanometer can be placed in an office some distance away, such couples are used in steel furnaces and pottery kilns. A very small couple (0.02 in. in diameter) enclosed in a vacuum is the most sensitive thermometer known. Such an apparatus can be used to measure the temperature of planets such as Mars.

In measuring the temperature of the sun and of glass and steel furnaces, a pyrometer is used. It is well known that the color of a hot body is a measure of its temperature. Cherry red indicates a temperature of about 500° C. and blue, a temperature of several thousand degrees. In the optical pyrometer, a lamp filament is placed in front of the furnace or hot object and the brightness of the filament adjusted. (There are certain corrections to be made to secure a reading.)

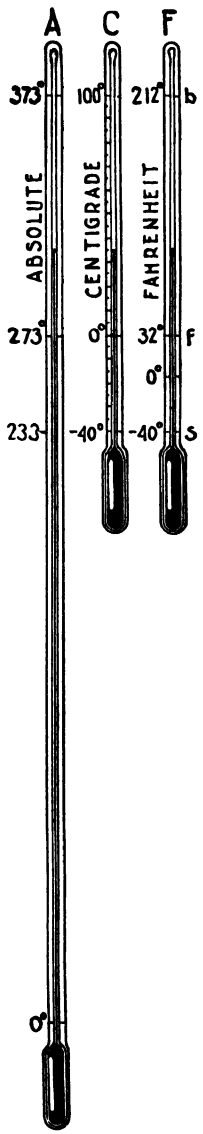


FIG. 177. Thermometer scales. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

EXPANSION

Everyone is familiar with the spaces left for expansion between railroad rails, with the mercury cups in a clock pendulum, and with the thermostat for temperature control. When heat is applied to materials, they usually change shape; in most cases, they increase in length. We have all noticed a sidewalk buckling on a hot summer day, because of insufficient expansion joints. A concrete road has gaps left between blocks to provide for expansion.

All large bridges have a very elaborate system of expansion joints which permit the metal to change length without warping the bridge. If an iron rod is 1 ft. long at 0° C. and we heat it 1° C., the new length will be 1.00001 ft. For each degree rise, the length will increase by the same amount. This fraction is called the coefficient of linear expansion for iron. Other metals increase by different amounts. The increase in length of a unit length of an object as we heat it by 1° C. is called the coefficient of linear expansion. The increase in length = the original length × the coefficient × temperature change.

The rim of the balance wheel of a good watch is so made that it changes shape without causing the watch to gain or lose time. We find that a cheap watch loses time in hot weather.

When boiling water is poured into a thick glass jar, the inside will expand more rapidly than the outside, and the jar may crack. For this reason, chemical glassware is always thin. Some of the newer glasses like pyrex do not expand much when heated and can be used over a direct flame. If a quartz rod is available, one may demonstrate its low expansion by heating an end of the rod to redness and plunging it into ice water. The rod will not break.

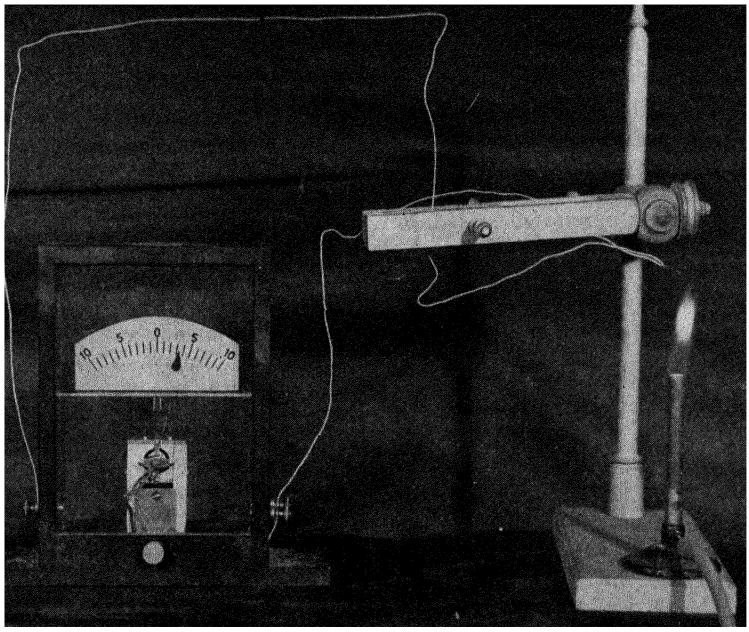


FIG. 178. The thermocouple. Two wires of copper and iron have their ends fastened together to form a junction. When this junction is placed in a flame a current operates the galvanometer.

EXPANSION OF WATER. The expansion of water on cooling is a very interesting and unusual process. If we have a closed jar filled with water at 20° C. and begin to cool it, the volume will shrink until it reaches 4° C. At this point, the volume becomes a minimum (1 cc. weighs 1 Gm.) but, if the cooling continues, the volume may increase so rapidly that the pressure breaks the jar. We are all familiar with the bursting of water pipes in cold weather. Nature makes use of this increase in volume with freezing to preserve fish in lakes and rivers. Because ice is less dense than water, the ice forms at the top of the water instead of at the bottom (a cu. ft. of water weighs about 62.5 lb. and a cu. ft. of ice about 56 lb.). In deep lakes, the water at the bottom has a temperature of about 4° C. throughout the year.

CHANGE OF STATE

There are at least three possible states of matter: solid, liquid, and gas. Water is a substance which we know as ice, liquid water, and steam (water vapor). Most substances are known only in two states at ordinary temperature, for example, solid and liquid butter, liquid and gaseous gasoline.

HEAT OF FUSION. The process of changing from one state to the other is very interesting. We shall illustrate by means of water. If we drop a piece of ice into a pan of water and apply heat, we find that the temperature remains at 0° C. until all the ice has melted. *We have applied heat but no change of temperature has resulted.* The heat applied to melt the ice is called the heat of fusion. *The number of calories required to melt one gram of substance without change of temperature is called the heat of fusion of that substance.*

Experiment shows that 80 calories of heat are required to melt a gram of ice without any change of temperature. Apparently, the heat has been used to tear the molecules apart. The energy is not lost, but is stored as potential energy (see p. 283). When water freezes at 0° C., the same amount of heat is given off.

An interesting application of this principle is the use of water to prevent vegetables from freezing in the cellar. Most vegetables freeze at about −2° C. If several tubs of water were placed in the cellar and the temperature should drop to 0° C., the water would become ice, thereby liberating 80 calories for each gram frozen. The liberated heat would warm the cellar and might protect the vegetables.

Perhaps the most important use of the heat of fusion of ice is the ice box or refrigerator. In the ice box, the cake of ice, in melting, absorbs the heat from the contents of the box, so that they become colder. It is essential that the ice should melt rapidly. Covering the ice with paper or cloth defeats the purpose of the box. Since cold air is more dense than

warm air, the ice is placed in the top compartment to produce a circulation which will cool the food.

HEAT OF VAPORIZATION. In the case of the change of state from a liquid to a gas, we have a principle similar to the heat of fusion. If 1 Gm. of water is changed to water vapor at 100° C., 540 calories of heat are required to change the state. This is the *heat of vaporization* of water.

In Chapter 11, it has been stated that molecules of gas are in rapid motion, having kinetic energy due to the temperature. In a liquid, some of the molecules have rather high speeds, while others move more slowly. The high speed molecules may have enough kinetic energy to push through the surface of the liquid and escape. Since the temperature of the liquid is determined by the speed of the molecules, the liquid thus becomes cooler. Everyone has noticed that when alcohol, gasoline, or ether are poured on the hand, the liquid quickly disappears, leaving the hand cold. Fever patients are bathed in alcohol to remove excess heat from the skin and thus give relief to the sufferer. The explanation is that the heat of the body has increased the kinetic energy of the molecules of the alcohol, resulting in rapid evaporation, which removes heat from the body.

Everyone has noticed that wet clothes on the body feel cold. In this case, the body heat is being used in causing the evaporation of the water. Woolen bathing suits are more comfortable than cotton because of the slower evaporation from the wool.

A fan cools our skin by causing a circulation of air which removes perspiration. (If the humidity is high, evaporation does not take place rapidly.) Evaporation takes place rapidly from the leaves of trees, and the sap rises in the trunk to replace the loss.

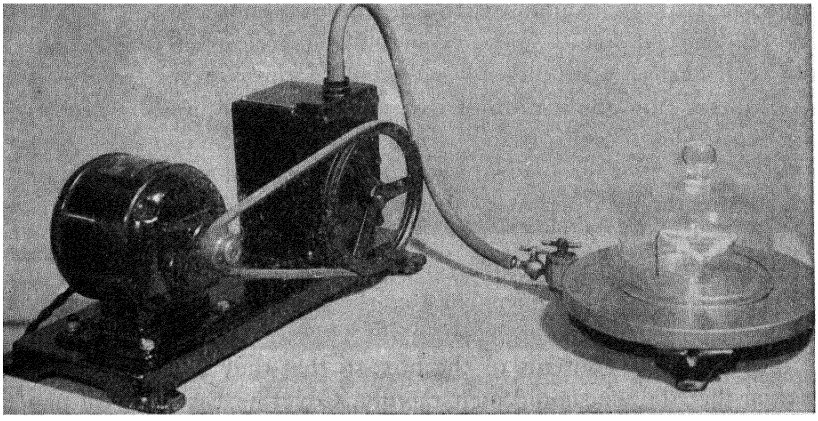


FIG. 179. Underneath the bell jar is placed a small amount of water and a dish of concentrated sulfuric acid. When the air is exhausted by the pump the water evaporates rapidly and cools. At 32° F. it boils as it freezes.

One of Aesop's fables relates that on a cold winter day a wood satyr came upon a half-frozen traveller who had lost his way. Taking pity on the man, the satyr took him to his hut and went to prepare some broth. Returning with the steaming liquid, he noticed that the half-frozen man was blowing on his hands to warm them. When the traveller was given the broth, he blew on the liquid to cool it. The satyr would not tolerate a man who could blow *hot* and *cold* with the same breath. The scientific explanation is left as an exercise for the student.

BOILING. A boiling liquid is one which is bubbling as it evaporates. When a pan of water is placed on the stove, the temperature of the water rises until the boiling point is reached. As soon as the water begins to bubble vigorously, the temperature remains constant until all of the water has changed into water vapor. Because of this fact, one cannot hasten the cooking of vegetables by boiling the water vigorously. As soon as the water begins to boil, the heat supply should be decreased until it is just sufficient to maintain the boiling temperature. However, the cooking of foods can be hastened by adding salt to the water, thus raising the boiling point.

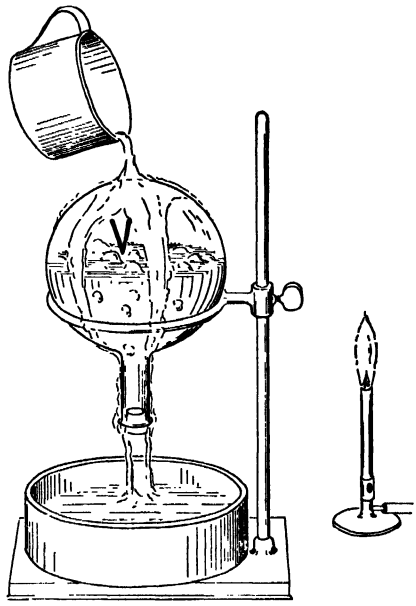


FIG. 180. Boiling under reduced pressure in a flask of volume (V). (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Water can boil at temperatures from 0° C. up to above 100° C., since its boiling point depends upon the atmospheric pressure above the liquid. For instance, water will boil at 0° C. (32° F.) when the pressure is 4 mm. and will boil at 100° C. (212° F.) when the pressure is 760 mm. (Appendix IV). In order not to burn the syrup, sugar refiners boil the solution at about 50° C. in vacuum pans. On high mountains, water boils at such low temperature that food will not cook in open vessels, making the use of pressure cookers necessary. At an elevation of over 14,000 feet (Pike's Peak), the mean boiling temperature is about 86° C. (187° F.).

A very instructive experiment can be performed to illustrate the boiling of water at 0° C. A good vacuum pump is used to exhaust the air from a bell jar in which is placed a small amount of water and a dish of sulfuric acid. The concentrated acid absorbs the water vapor so that ice forms on the boiling water (Fig. 179).

As a demonstration of boiling under reduced pressure, partially fill a *round-bottom* flask with water and boil it. After the water has boiled vigorously, remove the flask from the flame and cork it tightly. Invert the flask and pour water over it. The water will resume boiling, because the cold water condenses the water vapor and reduces the pressure inside the flask (Fig. 180).

Refrigeration

Dry Ice. One of the interesting applications of evaporation is the production of solid carbon dioxide (dry ice). Tanks of carbon dioxide, such as are used at soda fountains, contain a mixture of liquid and vapor. If such a tank is placed on its side (the valve slightly lower than the bottom) and the valve is opened, the liquid rushes out and as it escapes some of it evaporates, absorbing heat from the residue. This residue becomes a solid with a temperature of —80° C. "Dry ice" is used in the preservation of

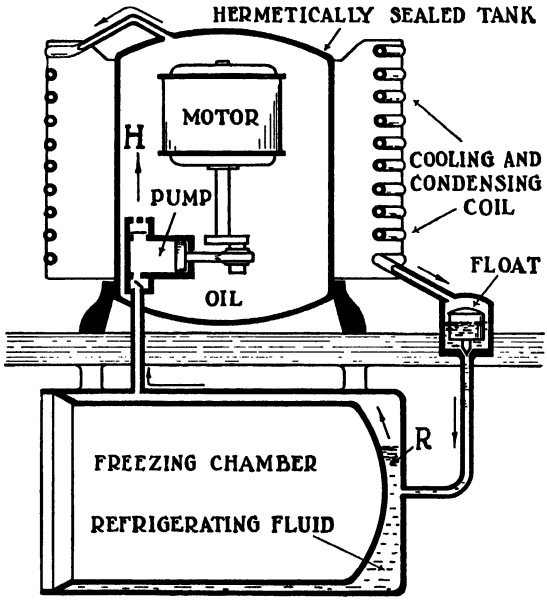


Fig. 181. A simplified diagram of an electric refrigerator. (Courtesy, General Electric Co.)

foods and in the shipment of ice cream. Rapid freezing at a low temperature of —80° C. does not injure meats and vegetables as does ordinary freezing. Hence food frozen by "dry ice" keeps indefinitely with no loss of flavor. Such a process freezes foods so quickly that it prevents the formation of large crystals of ice, which would destroy cell walls. Frozen foods are familiar articles in the stores.

The *mechanical refrigerator* makes use of the heat absorbed as a liquid evaporates. The liquid must be one which boils at a temperature below the melting point of ice and which can be changed easily from the vapor to a liquid state. Some satisfactory liquids are sulfur dioxide (B.P., —10° C.), methyl chloride (B.P., —24° C.), ammonia (B.P., —38° C.), and Freon (B.P., —30° C.).

The liquid is placed in a partial vacuum in a system (Fig. 181) consisting of the expansion chamber *R* in the food box, a compression cham-

ber *H* above the food box, and the connecting pipes. Heat coming from the food causes evaporation in *R*. The motor in the compartment *H* compresses this vapor and it is passed through the condensing coils, where it again becomes a liquid. The liquid returns to the expansion chamber through the float. Such a refrigerator is satisfactory as long as no gas escapes to the air and as long as the motor functions properly. A good mechanism is rather expensive so that a cheap refrigerator is likely to be a liability. Perhaps it should be emphasized that the only essential difference between an ice refrigerator and a mechanical one is that the latter provides a means for conserving the refrigerant so that it is used over again without a loss.

Unlike the mechanical refrigerator, the *gas refrigerator* has no moving parts. Its action depends upon the fact that ammonia is much more soluble in cold water than in hot. At 32° F., 1 qt. of water will dissolve 1300 qt. of ammonia; at 68° F., about 700 qt.; and less at higher temperatures. A strong *solution* of ammonia is heated by a small gas flame. As the temperature rises, some of the ammonia evaporates and is condensed to *liquid ammonia* in the rectifier. The heat from the food chamber causes this liquid to evaporate. The gas is dissolved in cold water again so that the process is continuous. In the newest type, the only requisite is a small gas flame, which can be produced by either a liquid or a gaseous fuel.

Fuels

There are three types of fuel: solid, liquid, and gas. The value of fuel depends principally upon the heating units it contains. The heat value is expressed in B.T.U. per lb. or in the case of gases, in B.T.U. per cu. ft. Solid and liquid fuels also contain sulfur and other impurities which sometimes make them undesirable. A good solid fuel should have a high fuel value, low ash content, and be free from volatile matter including sulfur. In Table 22, the analyses of several typical fuels are given:

Table 22

Fuel Analysis

	Volatile (*Per Cent*)	*Carbon* (*Per Cent*)	*Ash* (*Per Cent*)	*Sulfur* (*Per Cent*)	*B.T.U.* (*Per Pound*)
Peat (Florida)	56 83	24.30	15 68	0.49	8,930
Lignite (Dakota)	59 19	26.75	11.43	3 54	6,970
Bituminous (Coalport)	19 68	71 21	7 79	0 992	14,600
Anthracite (Lehigh)	5 00	86 00	9 00	0.50	13,570
Coke (Koppers)	0 70	91.86	7.50	0.69	13,000
Oak Wood	..	..	..	..	10,320
Gasoline	..	..	..	..	30,000
Alcohol	..	..	..	..	20,000
Gas (coal)	..	..	..	..	200*
Gas (natural)	..	..	..	..	1,150*

* Per cubic foot.

Heat Transfer

Heat is a form of energy which moves from place to place. We receive heat from the sun, from the hot air furnace, and from stoves. Heat energy is transferred in three different ways, although any heating device may utilize more than one method.

Convection. The type of heat transfer called convection is rather easy to understand. If one heats a kettle of water on the stove and places a little red dye in the bottom of the kettle, it will be noticed that very soon the entire volume of water will be colored. The hot water at the bottom becomes less dense and rises to the top. In this way, a circulation is started that affects the whole mass of the water. In hot water heating systems, the water is heated in the boiler in the basement, rises through pipes to the radiators on the upper floors, loses heat, and returns to the basement as cool water.

Air also conveys heat by this method. Our storms, as we have seen (p. 162), are due to heated air rising to the upper atmosphere and cool, dense air rushing in to take its place. Ocean currents such as the Gulf Stream and wind belts such as the Trade Winds (p. 163) are examples of convection currents.

In the hot air furnace (Fig. 182), dense, cold air passes through the jacket over the heated dome of the furnace, expands, and rises through pipes to registers. From there it rises to the ceiling of the room. The cold air on the floor, being heavier, sinks to the basement, starting a circulation. Although hot air heating is an excellent type, too often improper installations make it very inefficient. Registers should never be placed under windows, since the cold air entering will blanket the rising air. Sometimes such registers will act as cold air ducts instead of hot air inlets. Every hot air installation should be constructed according to correct scientific principles. Although rising air is a good carrier of heat, when prevented from moving it acts as an excellent insulator. Wool and fur are warm because they have little spaces in which air is trapped. Every camper knows that a sleeping bag is better than many blankets. The air trapped in the bag acts as an insulator. If paper, asbestos, or felt is placed between the walls of the house, the trapped air prevents the escape of heat. (It is incorrect to say entrance of cold unless we mean the entrance of a current of cold air.)

Conduction. If one places a solid silver teaspoon in hot liquid, it will be noticed that in a very short time the handle will become hot. Likewise, the metal handles of hot cooking utensils are usually warm, although the handles are not over the flame. A boy who places his tongue on a piece of metal which is very cold finds that his tongue freezes to the metal. Solids differ in their conductivity for heat. Silver is the best

conductor, while wood and wool are poor conductors. Aluminum, also a good conductor, makes excellent cooking utensils because it distributes the heat rapidly with less possibility of burning the food.

Heat is transmitted through solids (liquids and gases are poor conductors of heat) in some manner not well understood. If one end of a bar is heated, it is thought that the free electrons in the bar move faster and, because of their collisions with atoms, cause the heat to move through the substance. If we place one end of a copper rod and one end of an iron rod in a flame, we shall discover that in a very short time the opposite end of the copper rod will be hot. The iron rod will become hot more slowly.

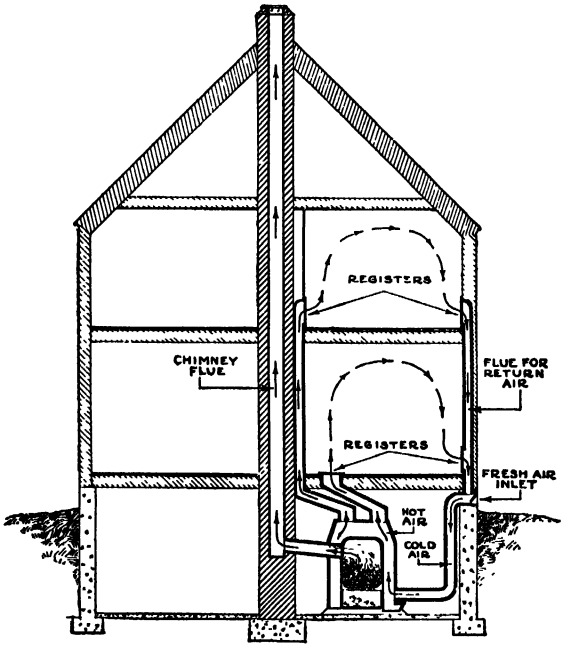


FIG. 182. The hot air furnace. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

Metals which are excellent conductors of heat are also excellent conductors of electricity.

An interesting demonstration can be performed by the use of several metal rods. If rods of aluminum, copper, brass, and iron are so arranged that one end of each can be heated with a common flame, and if a bit of paraffin is placed on each at the same distance from the flame, one can study the conductivity by noting the order in which the globules of paraffin are melted.

RADIATION. The third method of heat transfer, radiation, is the most universal but at the same time the most mysterious. All our lives we have

received heat as a result of energy being transmitted through the 93,000,000 miles that separate us from the sun. But when it is remembered that the temperature of the interspace is probably that of absolute zero, and that most of the space is a more perfect vacuum than any that can be produced on the earth, it will be seen that neither conduction nor convection can in any manner account for the heat transference. The energy travels with the speed of light and is possibly transmitted in the form of electromagnetic waves sent out into space by some disturbance of the atoms in the sun. This energy is transferred to objects on the earth. This theory is fully discussed in Chapter 13.

If the radiation falls on a highly polished piece of metal, some of the waves are reflected just as light is reflected from a mirror. If, on the other hand, the radiation falls on black cloth, nearly all will be absorbed and the cloth will become hot. Because of the reflecting power, we wear white clothes in summer. The radiometer (Fig. 183), a familiar sight in opticians' windows, rotates because of the radiant energy it receives. The vanes receive unequal heating, the black side being heated faster than the polished surface. Consequently, the air molecules rebound from the black



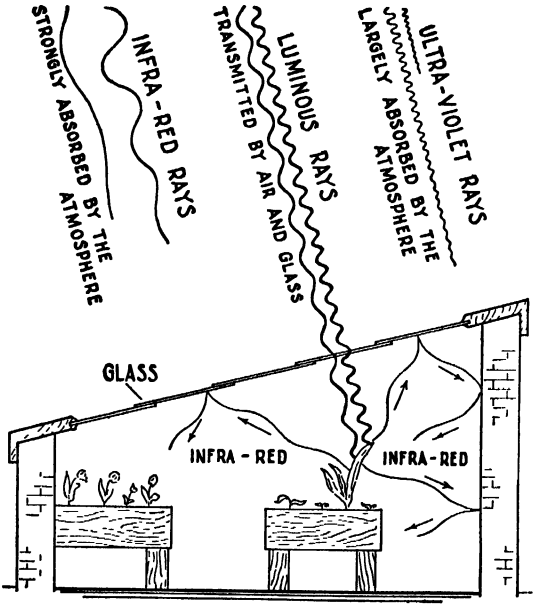


FIG. 183. (*Left*) The radiometer. (Courtesy, Central Scientific Company.)
FIG. 184. (*Right*) Illustrating the action of a greenhouse. The light waves are transmitted by the glass and upon striking the earth are changed into heat waves which cannot escape. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

surface and this surface in turn moves away from the source of heat. Good radiators are also good absorbers of radiation.

A greenhouse is a good example of the effect of the waves of energy. Sunlight, which is composed of waves of various lengths, strikes the glass. Some wave lengths penetrate and some are absorbed. The waves which pass through the glass strike the soil inside and are changed to heat waves (infrared rays). These long waves cannot escape through the glass and are trapped, thus warming the ground. Glass will transmit high temperature radiation (light) but will not transmit low temperature radiation

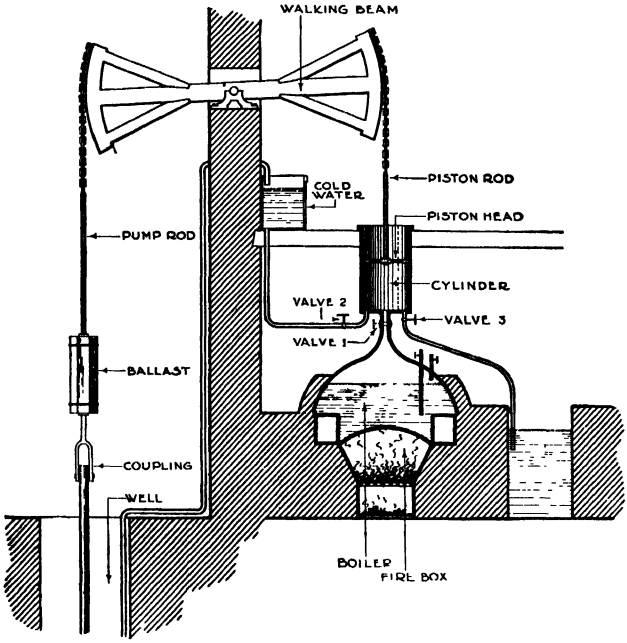


FIG. 185. The Newcomen engine. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

(heat). The greenhouse is a heat trap. Many people are mystified by the fact that a greenhouse or a sun parlor is often warm on a sunny day in winter even though the temperature is low out of doors (Fig. 184).

HEAT ENERGY APPLIED TO MACHINES

Man has applied the principles of heat to the steam engine and to the gasoline motor. Many a boy has used a small jet of steam to drive a paddle wheel. Today, this principle has direct application in the *steam turbine*, which is one of the most efficient of all engines. High pressure steam jets

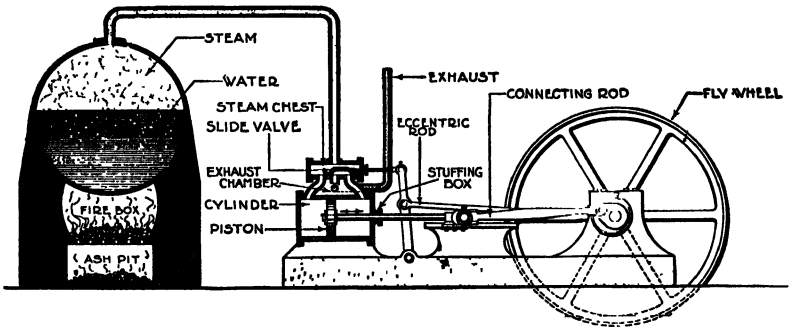


FIG. 186. Model of a modern steam engine. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

strike the turbine blades in such a way that nearly all the energy of the steam is utilized. Such turbines are used on many large ships.

The *steam engine* of the type used in locomotives was developed by several inventors, among them Newcomen and James Watt. Watt's principal improvements to the steam engine were devices to make the operation automatic and to increase the efficiency (Fig. 185). In the modern engine, the firebox produces steam under a pressure of several hundred pounds per square inch. This high pressure steam enters the cylinder, moving the piston as it expands. When the piston has reached the end of its stroke, the slide valve moves so that the steam enters at the other end of the cylinder, forcing the piston back to the original position. This

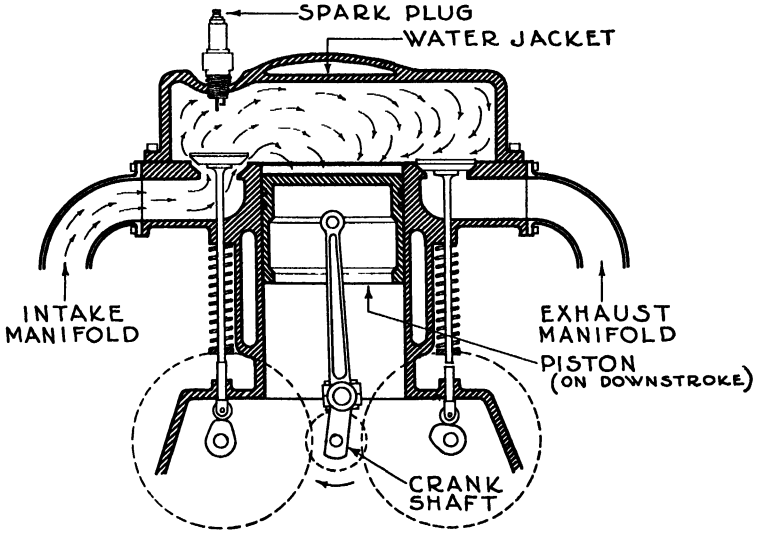


FIG. 187. Suction stroke (down). (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

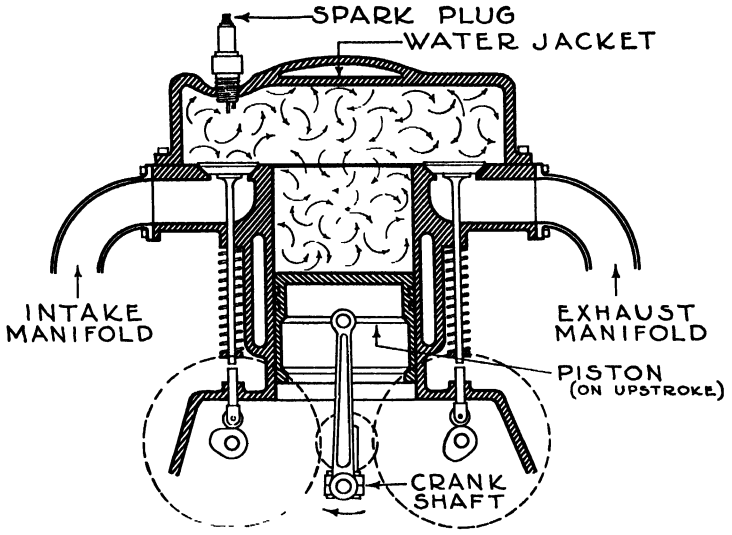


FIG. 188. Compression stroke (up). (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

operation is continuous as the piston motion drives the engine (Fig. 186). Some attempts have been made to replace steam by mercury vapor, which makes a more efficient engine. Thus far the mercury engine is in the experimental stage.

In contrast to the steam engine, in which we have a fire box and a

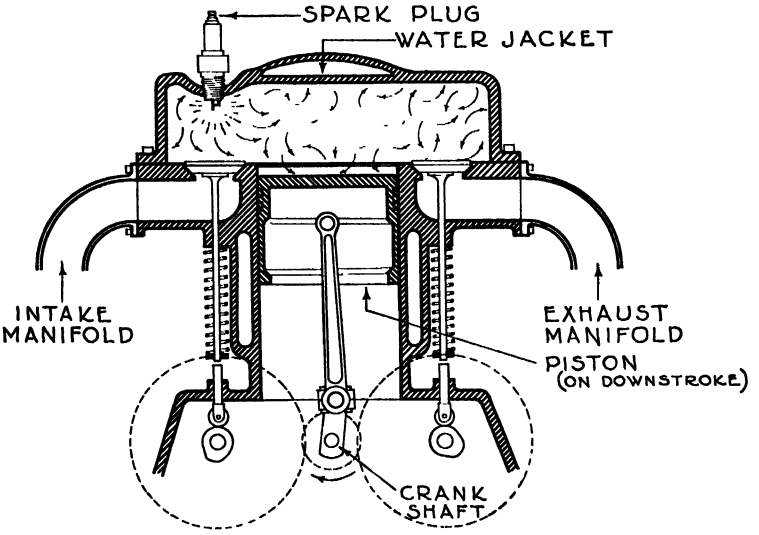


FIG. 189. Power stroke (down). (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

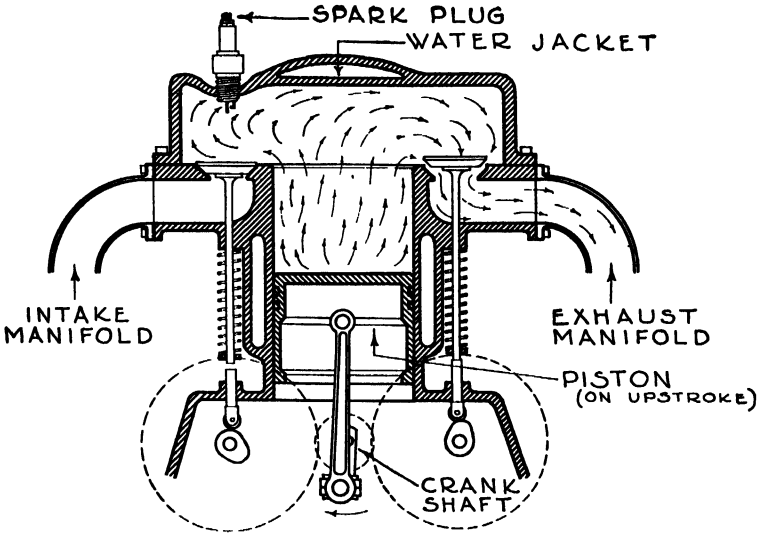


FIG. 190. Exhaust stroke (up). (Courtesy Bowden· "Foundations of Science," Philadelphia, The Blakiston Company.)

cylinder, the *internal combustion engine* burns the fuel inside the cylinder. In the gas engine, combustible gases mixed with air are pulled into the cylinder from the carburetor by the downward stroke of the piston (suction stroke) (Fig. 187). The rising cylinder in the compression stroke (Fig. 188) compresses the mixture of gases to a small volume. At this stage, both valves are closed. The spark plug now fires the compressed gases, forcing the piston down on the power stroke (Fig. 189). The power stroke does work on the crankshaft of the engine. The rising piston now forces the burned gases out through the exhaust valve (exhaust stroke) (Fig. 190). The next cycle is another suction stroke. The four strokes constitute four-cycle operation. In the automobile motor having several cylinders, the firing proceeds in such a way that each piston in turn acts on the crankshaft in such a time interval that smooth motion is produced. In recent years, the tendency of automobile designers has been to produce high compression motors. Unless a material is mixed with the gasoline to retard the combustion, the mixture may explode before the piston is ready to descend. This causes a "knock" which is harmful to the motor. One of the materials used as an "antiknock" is tetraethyl lead (see p. 129).

Just recently, another type of internal combustion motor has become important in commercial life. This motor, the *Diesel* engine, is now in use on steamships and in many large power plants. Many trucks are now powered with Diesel engines and many modern locomotives are of the Diesel electric type.

The Diesel engine is a compression type in which the compression ratio is about 16 to 1. It has a two-stroke cycle.

Compression ratio refers to the change of volume experienced by the gas during the compression stroke. If, for example, an initial volume of 1,000 cc. is reduced to 1/16 of this amount, the compression ratio is said to be 16:1. Modern four-cycle engines used in automobiles have an average ratio of 6:1.

The Diesel engine has no carburetor in which the gas and air are mixed. There are no spark plugs. Instead, the fuel is blown into the cylinder through a small opening called the injector so that the fuel and air are mixed inside the cylinder. Because the cylinder is already filled with very hot air under high pressure, the oil burns without the necessity of a spark. It is estimated that the compressed air is at a temperature of about 1,000° F. This temperature is hot enough to fire the oil without the use of any flame. The engine is very efficient, about 36 per cent, as compared to 25 per cent for the aviation engine and 20 per cent for automobile engines.

It has been found possible to use almost any liquid fuel in the Diesel engine but it operates best with a good quality fuel of the type of kerosene. Because of the high compression needed and the weight of the motor, passenger cars do not use these engines to any extent. However, we may expect to see such engines in passenger cars in the future.

References

Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.
Foley: "College Physics," Philadelphia, The Blakiston Company.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
Howe: "Introduction to Physics," New York, The McGraw-Hill Book Co.
Lemon: "From Galileo to the Nuclear Age," Chicago, University of Chicago Press.
Mott-Smith: "The Story of Energy," New York, D. Appleton-Century Co.
Saunders: "A Survey of Physics," New York, Henry Holt and Co.

Questions and Problems

1. If the humidity is 100 per cent, is a fan helpful?
2. In hot, dry countries porous bags are filled with water and placed in the air to cool. Why?
3. Marble always feels cool even in summer. Why?
4. Why is ice placed in the top of an ice box instead of at the bottom?
5. Why do patches of dirty snow melt more rapidly than clean ones?
6. Why do we discard dark clothing in summer?
7. Explain why gasoline feels cold when spilled on the hand.
8. Why is a greenhouse or sun parlor warm on a sunny day in winter?
9. If the temperature is 40° F. what is it centigrade? Answer: 4.4° C.
10. If a thermometer is at 27° C. what will be the Fahrenheit reading? Answer: 80.6° F.
11. Give a list of instruments which will measure temperatures from −100° C. to 3000° C.

12. Why was Galileo's thermometer unsatisfactory?
13. How many degrees Absolute does 30° C. equal? Answer: 303° A.
14. Normal body temperature is 98.6° F. What is the centigrade reading? Answer: 37° C.
15. How many calories will be given out by a steam heating system if the steam enters at 100° C. and leaves as water at 60° C.? Answer: 580 cal./Gm.
16. Why is a steam burn more serious than a boiling water one?
17. Why is a pressure cooker often used?
18. What is meant by absolute zero?
19. Why not use water for a thermometer material?
20. Describe the cycles of a four-cycle gasoline engine.
21. A hospital patient had a temperature of 38° C. Did he have a fever? Answer: Yes, 100.4° F.
22. What is the scientific meaning of the saying "a watched pot never boils"?
23. Clothes sometimes freeze dry. Explain.
24. Why does warm air rise?
25. Why is Pyrex safer than ordinary glass for hot liquids?
26. Ten Gm. of ice at 0° C. are changed into water at 10° C. How many calories of heat are required? Answer: 900.
27. Could we cool the kitchen by allowing the door of the household refrigerator to remain open?
28. A 30 ft. steel rail has a temperature variation between winter and summer of 50° C. What is the length variation? Answer. 0.018 ft.

Visual Aids

"How the Icing Unit Works," General Electric Co. Film
"Refrigeration," Eastman Classroom Film

Topics for Discussion

Heating Systems	Thermostats	Electric and Gas Refrigerators
Biography of Rumford	Automatic Fire Sprinklers	Expansion Joints
Clock Pendulums	Recording Thermometers	

Experiments

1. Make a study of thermostats. Investigate the construction of one in the schoolroom; in the incubator; in the electric refrigerator.
2. Study conduction of heat. Place the ends of four rods, copper, iron, brass and aluminum, in a flame and record the time intervals until the other ends of the rods become hot enough to melt wax.
3. Study a simple fire sprinkler. Cork a glass flask which is partly filled with water with a one hole rubber stopper. Plug one end of a short glass tube with Wood's metal and insert the tube in the stopper. Invert the flask and gently warm the metal in the tube with a candle flame. Water will flow out and extinguish the candle.
4. Place a beaker of water over a flame and by means of a medicine dropper place a little red dye at the bottom of the beaker. As the water becomes warmer, the dye will circulate through the entire beaker. This is convection.
5. Make a table of some of the liquids used as refrigerants. Secure information concerning odor, boiling point, chemical properties, and physiologic properties of sulfur dioxide, methyl chloride, methyl formate, Freon, carbon dioxide, and ammonia. Decide which is the best liquid for domestic use.

6. Visit a power plant for the study of steam engines, gas engines, and Diesel engines. Make a sketch of a four cycle engine, including one drawing for each cycle. If possible secure an old four-cylinder, or still better, a one-cylinder gasoline engine, and examine the valve construction. This makes a very valuable experiment for general science classes.
7. Determine the specific heat of an oil by heating 100 Gm. of the oil and 100 Gm. of water in identical beakers, using the same flame and the same time for each.
8. Make a survey of insulating materials such as asbestos, cork, paper, wool. Study the thermal insulation in homes, refrigerators, and furnaces.

23. ENERGY AND ITS RELATION TO SOUND

. . . Of all noises I think music the least disagreeable.
—SAMUEL JOHNSON

We live in a world of sound. Our ears are constantly making us aware of the sounds of wind, birds, insects, and a multitude of mechanical devices. When we clap our hands, slam a door, or pluck a violin string, energy travels in the air in the form of sound waves.

A boy whistling or dragging a stick along a fence is producing a series of sound vibrations. If one strikes a bell or rod and immediately touches it with the finger tips, a vibration can be detected. Sounds are produced by the vibrations of elastic objects. These sound waves are transmitted by solids such as steel, by liquids, and by gases. Sound waves do not travel in a vacuum as do light waves. (A wave motion is the passage of a vibration through a medium.) They require material media for their propagation. (If a bell is rung in a vacuum (Fig. 191), no sound can be heard.) Moreover, sound waves do not travel as do water waves, but as longitudinal waves. In order to understand this, imagine a row of men standing one behind the other, each man having his hands firmly braced on the shoulders of the man in front of him. If a bystander gives the rear man a push forward at the shoulders, each man in the row will be pushed so that he leans forward, although none of the men actually move out of their positions. A longitudinal wave has passed through the group.

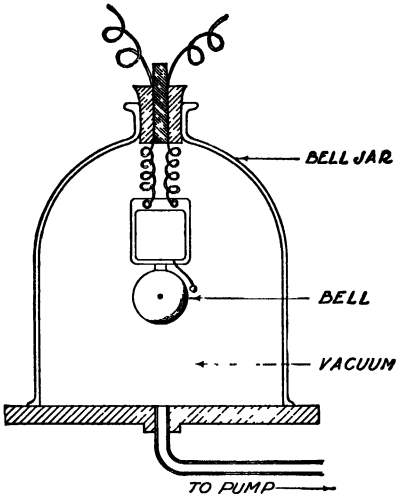


FIG. 191. A bell in a vacuum. (Courtesy, Bowden. "Foundations of Science," Philadelphia, The Blakiston Company.)

Another example is a field of ripened wheat. A breeze blows the heads over and a wave travels in the field. The stalks vibrate to and fro as the longitudinal wave passes through the field. In like manner, the air particles move back and forth as the sound waves pass through the atmosphere.

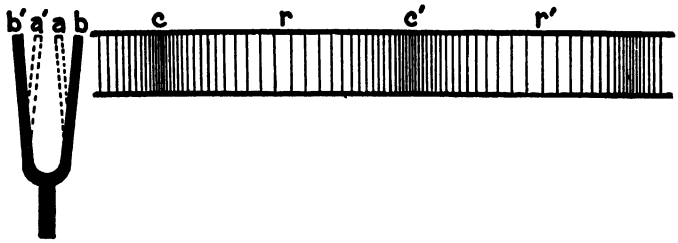


FIG. 192. Compression waves in a pipe produced by a vibrating tuning fork. *c* and *c'* represents compressions. *r* and *r'* are rarefactions. The motion of the prong from *a* to *b* and return produces a compression and a rarefaction. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Such waves are called compressional waves because the air is first compressed and then released from the pressure. In Fig. 192, the fork prong at position *b* sends a compressional wave into the pipe which is shown at *c*. The fork at *a* forms the rarefaction *r*. The distance from *c* to *c'* is the wave length of the sound wave. A stretched piano wire set into vibration by the hammer of a piano sends out compressional waves into the air. These waves, upon striking the ear, produce the sensation known as sound. Two good examples of compressional waves are thunder and the explosion of a firecracker. The sudden expansion of the air compresses the adjacent layers, which in turn expand. These compressions and rarefactions travel through the air.

If the number of vibrations[1] per second of the elastic body, for example, the tuning fork, is as great as 30, the ear recognizes the wave motion as a sound. Any number of vibrations less than 30 per sec. is usually not con-

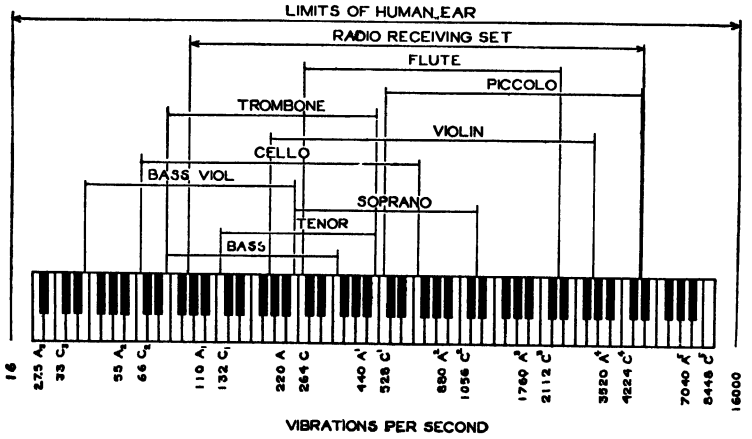


FIG. 193. Pitch range of various musical instruments.

[1] A vibration is the complete forward and backward motion of the elastic body.

sidered an audible sound although some organ makers use a pipe sounding 16 vibrations per sec. The ear recognizes as musical tones vibrations as high as 4,000 per sec., and it can detect sounds up to 20,000 vibrations per sec. (Fig. 193). These high notes sound like squeaks and are not considered musical. *The number of vibrations per second is the pitch of the tone.*

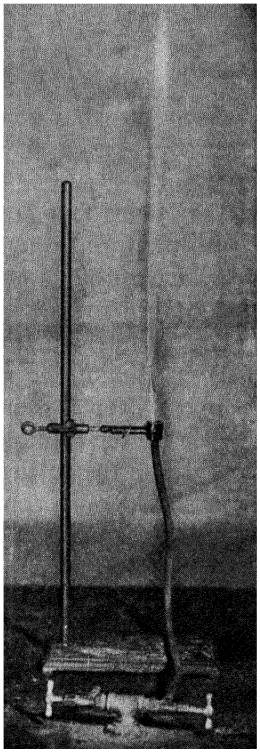


FIG. 194. The whistling flame. If a high-pitched note is sounded in the vicinity of the flame, the flame will "duck."

As a rule, young persons have a keener sense of pitch than elderly people. There are mechanical devices which can register high-pitched notes that are inaudible to the human ear. One of these devices is the whistling flame.

To produce a whistling flame, a glass tube is drawn down to a tip with a bore of about 1 mm. (Fig. 194). Gas is passed through the tube and the pressure is adjusted so that the gas flame is on the point of flaring. Usually such a flame will be about 1 ft. high. As a high-pitched whistle is sounded or a bunch of keys is rattled, the flame will "duck" as the compressional waves pass over the outlet.

ULTRASONIC WAVES

During the past few years, compressional waves with a pitch of the order of one million have been produced by causing a piece of quartz to vibrate in a liquid. This is called the piezo-electric effect and the vibrating plate can be operated so as to produce waves of a very high pitch. The piece of quartz, cut in a special way, is placed between two metal plates. A high potential is connected to the plates, setting up an alternating voltage (see p. 379) which causes the quartz to expand in one direction and contract in the other. The vibrations set up supersonic waves in the liquid above the quartz. Some interesting properties of the waves are their ability to destroy bacteria which may be in the liquid. The high frequency sounds are now used to sterilize milk, age whiskey, improve the quality of photographic films, precipitate smoke in chimneys, and assist in mixing mayonnaise. This work is still in an experimental stage.

SOUND WAVES

Sound waves travel much more rapidly in solids and liquids than in gases. The speed in air at ordinary temperatures is about 1120 ft. per sec.

(Sound travels 1087 ft. per sec. at 0° C. with an increase of 2 ft. per sec. for each degree rise in temperature.) Sound waves may be reflected and focussed by curved surfaces. There are several whispering galleries in the world which focus the sound. Some of these are the Hall of Statues in the Capitol at Washington, the Mormon Tabernacle in Salt Lake City, and St. Paul's in London. A word spoken in a whisper at one point can be clearly heard at a distant point.

Table 23

SPEEDS OF SOUND IN VARIOUS MEDIA

Water....	4,728 ft. per sec.
Aluminum	16,470 " " "
Copper	11,670 " " "
Granite	13,000 " " "

THE EAR

We do not know just how we hear. There are several theories of hearing, each of which is rather unsatisfactory. The ear (Fig. 195) consists of a passage (meatus) about 1 in. deep which ends at the drum (tympanic membrane). Inside the membrane is a cavity (the drum cavity). In this cavity are three tiny bones—hammer, anvil, and stirrup. The handle of the hammer is attached to the membrane and the base of the stirrup touches

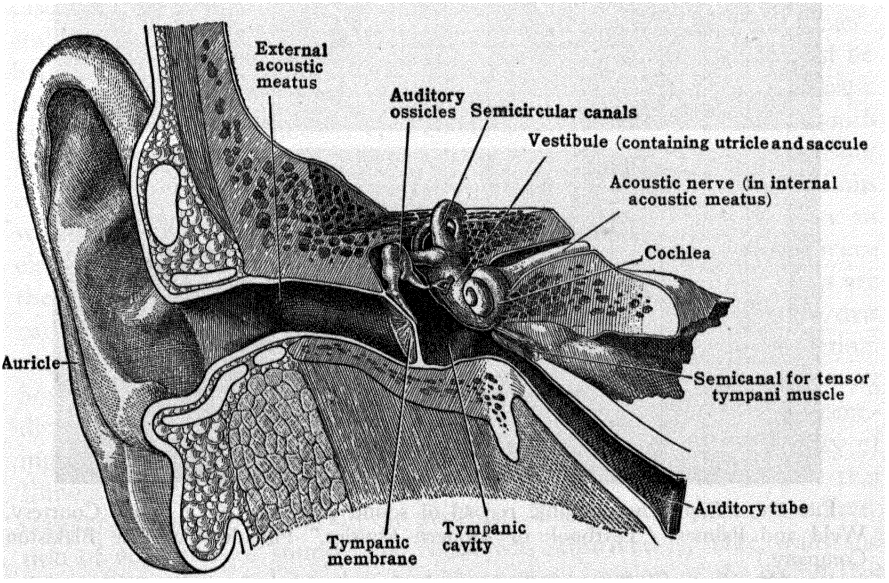


FIG. 195. The ear. (Courtesy, "Morris' Human Anatomy," Philadelphia, The Blakiston Company.)

an inner membrane (oval window). In the inner ear is the cochlea, a spiral tube shaped like a snail shell. The cochlea contains two liquids, the perilymph and the endolymph. Associated with the cochlea is the organ of Corti and the basilar membrane. The outer drum and the bones cause the oval window to vibrate, which in turn causes vibrations of the inner ear liquids. These moving liquids excite sensory hair cells in the basilar membrane and in some unexplained manner change the mechanical impulses into nerve impulses.

The ear is so sensitive that it can detect a sound wave whose power is less than a billionth of a watt, a quantity so small that we cannot appreciate it. It can also withstand the loudness of a boiler shop. On the musical side, the ear can distinguish a change in pitch of two or three vibrations per second. Scientists have set up a scale of loudness for which they use the unit named *decibel.*

Most sounds do not consist of one frequency alone but are a composite of several modes of vibration. *The composite sound determines the quality*

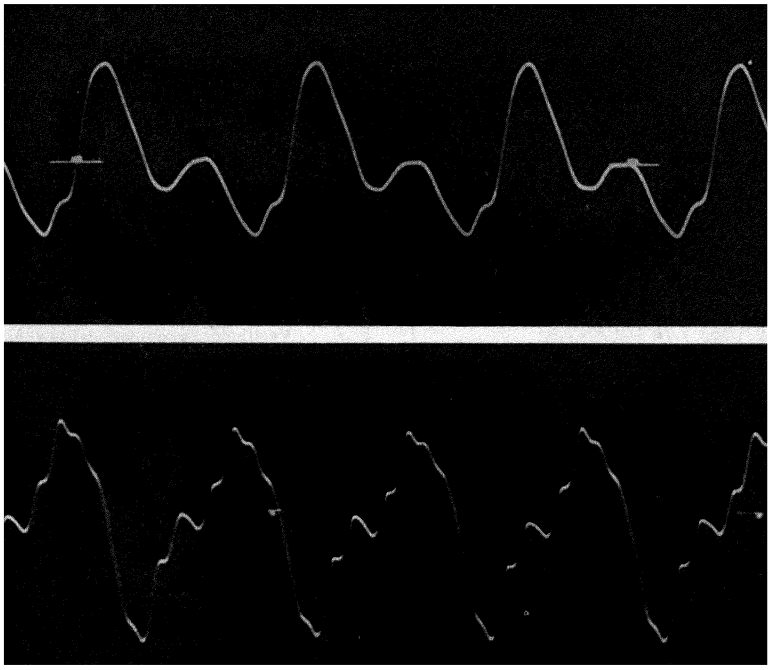


FIG. 196. (*Top*) Photographic record of sound produced by a flute. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

FIG. 197. (*Bottom*) Photographic record of musical sound produced by a violin. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

Table 24

DECIBEL VALUES ABOVE A ZERO REFERENCE LEVEL

Quietly rustling leaves at 5 ft	30 decibels
A typewriter in operation at 5 ft	50 decibels
An ordinary human voice at 3 ft	60 decibels
Street traffic at 50 ft	70 decibels
Riveter at 2 ft	100 decibels
Painful noise	120 decibels

of a tone. If a piano string is sounding 440 vibrations per sec. (fundamental), it will sound several multiple frequencies simultaneously; e.g., 880, 1,760. These are called *harmonics* or *overtones.* Each musical instrument has its own peculiar set of overtones which give it its indivdual quality. Figs. 196 and 197 show photographic records of the waves from a flute and a violin. It is evident that the shapes of the waves are different in the two cases. The shapes of the waves from the two instruments show that the quality of the tones differ, even though the same selection is being played on both.

ACOUSTICS OF AUDITORIUMS

One of the most important developments in the study of sound is the subject of architectural acoustics. The word acoustics means hearing. In a room with good acoustics, the auditor with average hearing should easily hear and enjoy words and music, provided they are originally clear and distinct. Bad acoustics in an auditorium may be due to echoes, reverberations, or dead spots. When a sound is produced in a room, it must be absorbed by the walls, floors, and objects in the room, or it must escape through doors and windows. Otherwise, it will be reflected. If the room has hard walls, the sound will be reflected from wall to wall, thus causing echoes and reverberations. Until 1900, the improvement of auditoriums was a "hit or miss" experiment. Dr. W. C. Sabine at Harvard, after an elaborate series of experiments, set up certain laws which should govern the construction of rooms if they are to have good acoustics. Echoes are caused by the sound being reflected from a wall in such a manner that the hearer may hear the word twice, once directly and once by reflection. Sometimes the echo of a word mingles with the following word coming directly from the speaker. The result is a jumble of sound that makes listening very difficult. Fig. 198 represents an auditorium of the University of Illinois. In this room, the echoes and reverberations were so bad that speakers refused to appear on the platform. The drawing shows the direction of reflection of sound. The room was improved by false walls and concealed curtains which absorbed the greater portion of the sound that would otherwise have been reflected.

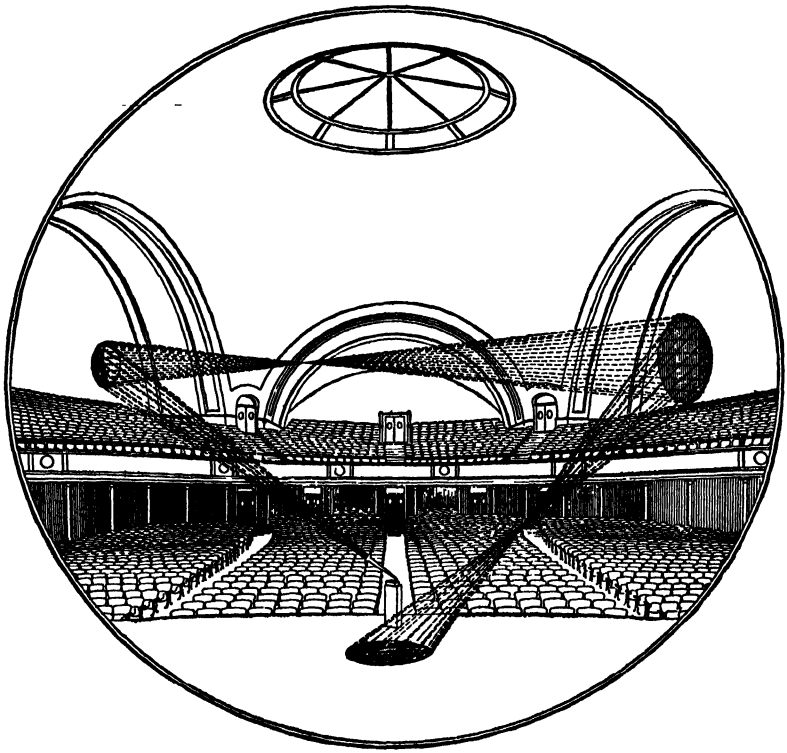


FIG. 198. Drawing showing how an echo is formed on the stage by two reflections. Such an auditorium has bad stage acoustics. (Reproduced by permission from "Acoustics of Buildings," by Watson, published by John Wiley and Sons, Inc.)

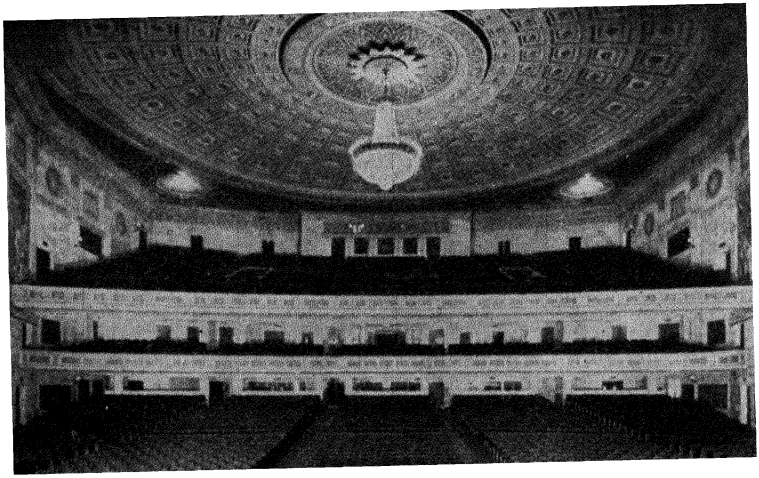


FIG. 199. The Eastman Theater, Rochester, N. Y. The acoustics of this auditorium are excellent. (Reproduced by permission from "Acoustics of Buildings," by Watson, published by John Wiley and Sons, Inc.)

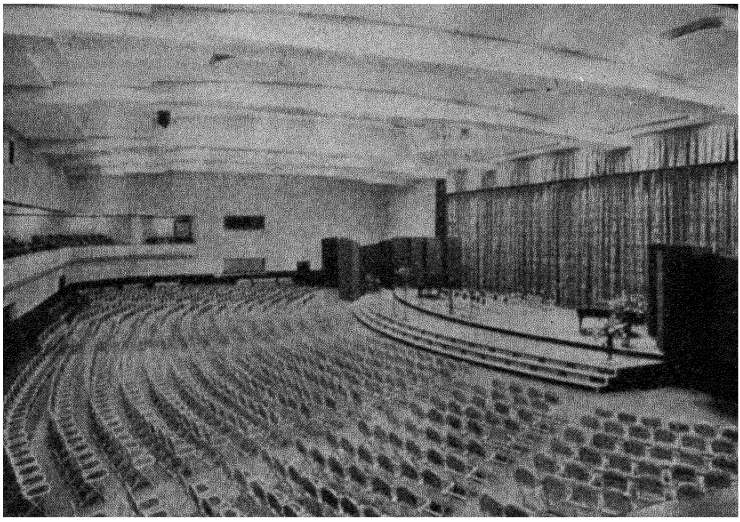


FIG. 200. Radio City Music Hall. This great auditorium has excellent acoustical properties due to the special treatment of the walls and ceiling. (Courtesy, Johns-Manville.)

Sometimes, owing to reflections, there are dead spots in a room. At such places the auditors hear very little. *Reverberation* means that the sound travels from wall to wall around the room, making the room noisy and causing the speech to be muffled. In such rooms, the sound may be audible for a few seconds after the source of sound is stopped. This interval is called the *reverberation time*. The listener has the sensation of a roar of sound. A familiar example of excessive reverberation is the sound of footsteps of a person walking about in an empty house. The room seems to be full of people walking about. On the other hand, if there is no reverberation, one has the sensation of deadness of the sound. It is estimated that in an average room a reverberation ought to last at least $\frac{1}{10}$ of a second for best sound effects.

There are several methods for remedying bad acoustics. As a rule, a circular room is unsatisfactory. Rectangular rooms with walls and ceilings of the proper material are best (Fig. 199). Bad conditions may be remedied by hanging draperies, using rugs on the floors, installing false ceilings, and constructing the walls of absorbing materials. There are many materials, such as wall board and special plasters, which are designed for the purpose of absorbing sound. The acoustical correction of an auditorium is a task for an expert (Figs. 200, 201, 202).

PRACTICAL APPLICATIONS OF ECHOES

Although echoes are very disturbing in auditoriums, they have been found useful in many commercial operations. One of the modern uses of

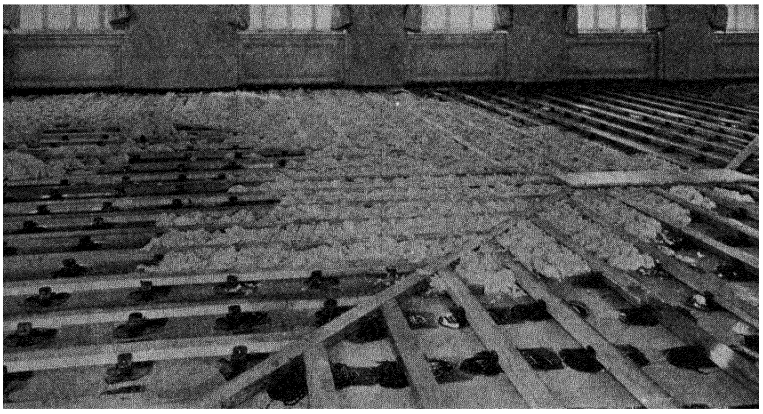


FIG. 201. The photograph shows the method of sound-proofing the floor of a dance hall. (Courtesy, Johns-Manville.)

echoes is the study of ocean depths (see p. 97). A wave of sound is sent down into the water and the time required for the sound to return is noted. Since we know that the speed of sound in water is 1440 m. per sec., the great deeps can be studied by a moving vessel.

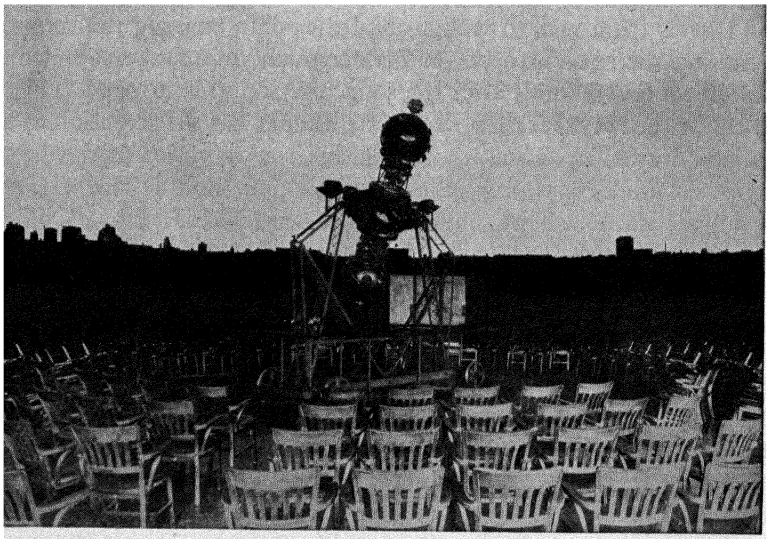


FIG. 202. The Fels Planetarium of the Franklin Institute. The acoustical treatment of the hemispherical dome made this an excellent room for hearing. (Courtesy, Johns-Manville.)

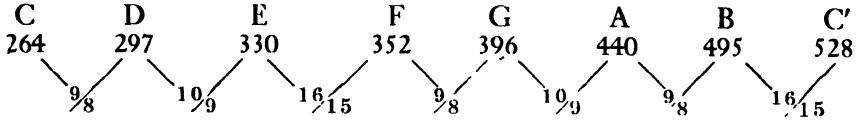
Noise and Music

We divide sound into noise and music. As a rule, we mean by noise a succession of irregular, unsteady sounds which, being discordant, are unpleasant to the ear. Some examples are a wagon rattling over a rough pavement, the squeals of animals in pain, or the crashing of colliding materials. A boy dragging a stick over the picket fence is producing a vibration each time he strikes the picket. If he strikes 30 pickets per second in regular order, he produces a musical note but if he strikes one and then another in no regular interval of time he is said to be producing only noise. If all of a set of wooden sticks tuned to a musical scale are dropped at once the effect is a noise, but if certain sticks are dropped in a regular order, we have a series of musical tones.

There are certain combinations of tones which are very pleasing to the human ear. Occidental music is based on the diatonic scale. It is probable that in ancient times certain singing tones were found to be more pleasant than others. In this way the scale arose from the folk songs of the people.

MAJOR SCALE

There are certain combinations of frequencies which are pleasing to the ear. It has been found that notes bearing relations to each other of 9 to 8, 16 to 15, and 10 to 9 form a scale that is musical. For instance, the major scale in the key of C is as follows:



All major diatonic scales, no matter what the key, have the same frequency relations. The second note must be $\frac{9}{8}$ of the first and the third $\frac{10}{9}$ of the second, as indicated above. There are, moreover, certain combinations of these frequencies which are pleasant to the ear. For instance, middle C (264) and C′ (528) may be played together, thus forming the octave. The various combinations of pitch which are pleasant constitute the musical selections. Some peoples, such as the Chinese, use in music a pentatonic combination of tones which sound strange to the western ear.

Beats

In order to explain why the diatonic scale is pleasing, it is necessary to discuss beats. If, for example, two people are walking side by side, one

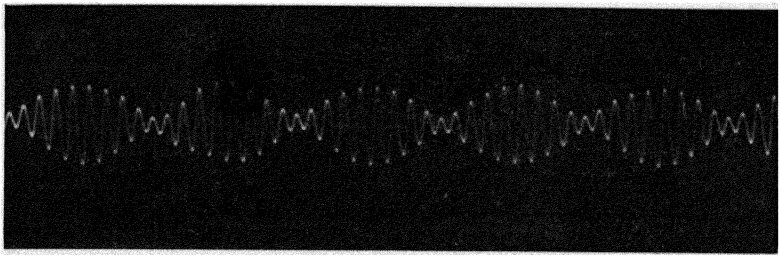


FIG. 203. An oscilloscope record of beats provided by two tuning forks which have a slightly different pitch. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

taking 30 steps per minute and the other 29 steps in the same time, we find that once each minute both will step at the same time. This effect will be an increased sound, a *beat.*

If two banjo strings are supposed to be tuned to the same pitch, for example, 400 vibrations per sec., and if we hear two beats during the second when both strings are vibrating, we know that there is a difference in pitch of 2 vibrations per sec. between the two strings. Many piano tuners adjust the pitch by counting beats between adjacent strings which are being tuned. These slow beats are unpleasant to the ear and are avoided in music. Fig. 203 shows graphically the action of two tuning forks in producing beats.

CONSONANCE. Referring to our discussion of the musical scale, it will be noted that in a diatonic scale the notes differ by as few as 22 vibrations per sec. (E and F), and by as many as 55 (A and B). In general, we may state that the intervals average 30 vibrations per sec. It is probable that two notes such as C (264) and E (330) are pleasing because they have a difference of 66 vibrations per sec. In general, a large number of beats per second is not unpleasant. This may be a partial explanation of our musical discrimination of pleasing tone.

The consonant ratios are: octave, 1:2; fifth, 2:3; fourth, 3:4; major third, 4:5; minor third, 5:6; major sixth, 3:5; and minor sixth, 5:8.

MINOR SCALE

In the minor scale, the notes bear the following relation to each other: $\frac{9}{8}$, $\frac{16}{15}$, $\frac{10}{9}$, $\frac{9}{8}$, $\frac{16}{15}$, $\frac{9}{8}$, $\frac{10}{9}$. It will be noted that only the ratios of $\frac{10}{9}$ and $\frac{16}{15}$ have been interchanged. This scale is less pleasing than the major and is used in musical selections where sadness and gloom are represented.

TEMPERED SCALE

In the tempered scale, the interval between two tones is always the same, a half tone. If 440 is multiplied by the number 1.06, we have

A#. By multiplying A# by 1.06, we get the note B. The process is repeated for the entire octave.

Actually, it is not feasible to use the exact pitch of the diatonic scale in designing the strings of a piano. It would be necessary to have about 60 keys in each octave, or a total of about 400 keys for the piano keyboard. To avoid this difficulty, the tempered scale is used. By sacrificing exact frequency, it is possible to make a scale that is not unpleasant, but which can be manipulated by the piano performer.

Table 25

COMPARISON OF DIATONIC AND TEMPERED SCALES

	C	*D*	*E*	*F*	*G*	*A*	*B*	*C'*
Diatonic	264	297	330	352	396	440	495	528
Tempered	261 6	293 7	329 6	349 2	392	440	493 9	523 3

MUSICAL INSTRUMENTS

One of the simplest of musical instruments is the tuning fork. This is a steel bar bent into the form of a U. Such a fork, when set into vibration, sends out a regular succession of waves of one frequency, having no harmonics. For this reason, tuning forks are used as standards of pitch. They are not desirable musical instruments because they have no beauty of tone. Musical instruments are divided into three classes: the strings, the percussions, and the wind instruments.

The strings are instruments which produce sound vibrations by means of stretched strings of gut or wire, set into vibrations by a hammer (piano), bow (violin), or the hand (banjo). Some examples of wind instruments are the pipe organ, flute, clarinet, cornet, trombone, and human voice. The percussion instruments include the drum, xylophone, bell, and marimba. (The marimba is one of the newest of percussion instruments. It is of African origin.)

The instruments containing strings have, in addition to the strings, a sounding board or resonator. As the string is set into vibration, it transmits energy to the sounding board, setting it into vibration. Most of the sound comes from the resonator and not from the strings. We are all familiar with the stories of the violins produced by Stradivarius. The beauty of the tones produced by his violins depends upon the care with which the body of the violin was constructed. A Stradivarius is probably the most costly instrument in use at the present time.

In the case of the pipes, such as the clarinet and the organ pipe, the

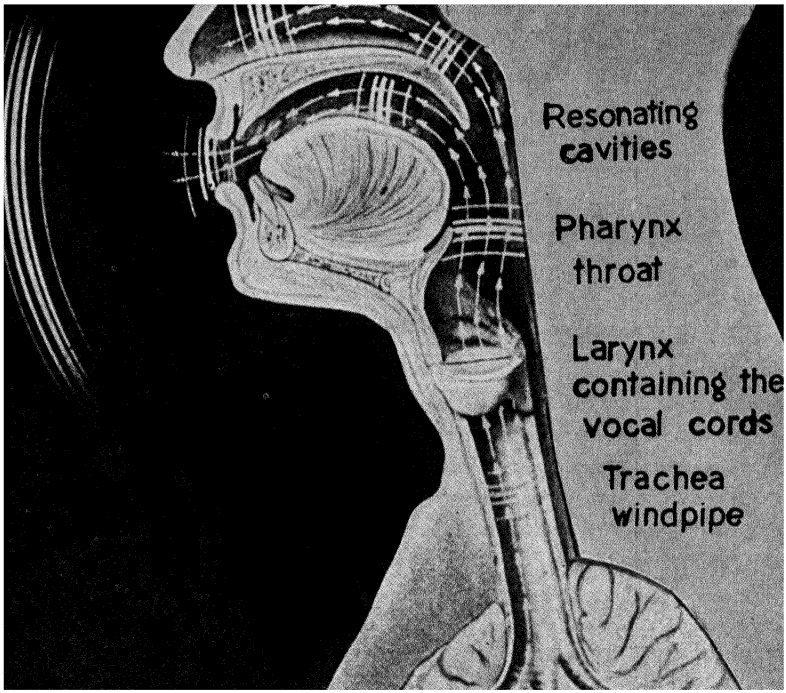


FIG. 204. The mechanism of speech. The air from the lungs passes through the larynx and sets the vocal cords into motion. The cavities of the nose and throat act as resonators, enhancing the sound. (From the educational picture "Sound Waves and Their Sources," by H. I. Schlesinger and H. B. Lemon, produced by Erpi Picture Consultants and the University of Chicago Press.)

lips or a reed set up vibrations in the pipe. The human voice is an instrument having two vocal cords which are set into vibration as the air passes through the openings. The lungs force air upward through the trachea and larynx into the mouth and nose. The cords, which are triangular, act like reeds of an organ (Fig. 204). The rate of vibration of the cords is controlled by the muscles of the larynx. The nose, mouth, and throat act as the resonators for the cords, so that, by varying the shape of the mouth, we can change the pitch and quality of the tone. The trained singer has learned to utilize all the cavities of the head in order to produce pleasing tones.

REFERENCES

Bragg: "The World of Sound," New York, E. P. Dutton and Co.
Culver: "Musical Acoustics," Philadelphia, The Blakiston Company.
Jauncey: "Modern Physics," New York, D. Van Nostrand Co. (Supersonic waves.)
Jeans: "Science and Music," New York, The Macmillan Co.
Jones: "Sound," New York, D. Van Nostrand Co. (Excellent for music students.)

Lemon: "From Galileo to the Nuclear Age," Chicago, University of Chicago Press.
McKinney and Anderson "Discovering Music," New York, American Book Co.
Miller: "Science of Musical Sounds," New York, The Macmillan Co.
Mills. "A Fugue in Cycles and Bells," New York, D. Van Nostrand Co.
Richardson: "Sound," New York, Longmans, Green and Co.
Watson: "Acoustics of Buildings," New York, John Wiley and Sons.

Questions and Problems

1. What is: pitch? quality?
2. What is meant by music?
3. Why can sound not be transmitted in a vacuum?
4. Describe the three general types of musical instruments.
5. What is meant by the term acoustics?
6. Give two modern applications of sound.
7. Distinguish between noise and music.
8. How can we improve a room having a bad echo? Should we permit reverberation?
9. How do we hear?
10. By what means are we able to utter sounds?
11. What is: diatonic scale? the equally tempered scale?
12. Write the major scale of D (297).

Topics for Discussion

Chinese Music	Carillons	The Marimba
The Theremin	The Player Piano	Ultrasonic Waves
Acoustics of Auditoriums	The Hammond Organ	The Phonograph

Experiments

1. Construct a whistling flame and study its action.
2. Sound a flute or a xylophone bar in an auditorium. Investigate the echoes and search for dead spots. Time the reverberations.
3. Using a Galton whistle, study the pitch perception limits of the various members of the class.
4. Have someone demonstrate the methods for changing the pitch of musical instruments.
5. If an oscillograph or an oscilloscope is available, connect a microphone to the instrument and have members of the class sing notes into the microphone. Study the wave form of the different voices. Use also a tuning fork and an organ pipe. The instrument will illustrate both pitch and quality. (There are now on the market inexpensive oscillographs which should be a part of the equipment of every general science course.)

24. ENERGY MANIFESTED AS LIGHT

The great world of light, that lies
Behind all human destinies.

—HENRY W. LONGFELLOW

One of the great mysteries of science is the phenomenon of light. We see objects about us, and we distinguish the colors of objects by means of the light which enters the eyes, but as yet, a complete explanation of the phenomena of seeing and of light transmission has not been given. In Chapter 13, it is stated that there are two theories which attempt to explain the method by which light is transmitted from one object to another. One theory assumes waves in space and the other treats of quanta (photons). We shall assume in the present chapter that light transmission is a wave motion. It seems probable that the emission of light from a hot body such as an electric lamp is due to the motion of the electrons in the atoms of the filament.

Ordinary white light may result from the combined effect of a great many different electronic motions, or it may be produced by the complicated motion of one electron in the atom. Light of a single wave length (monochromatic) is probably due to one simple vibration of the electron. We have seen that the eye responds to a small band of electromagnetic waves extending from about 0.00008 cm. (red) to about 0.00004 cm. (violet). This is known as the visible spectrum.

Light travels in straight lines. Anyone who sights a gun is making use of this principle. Objects cast sharp shadows. The moon is so small compared to the sun that, if the light curved around the edge of the moon, an eclipse of the sun would be impossible. Although light does bend slightly when passing through a narrow slit, as we may notice when viewing a bright light through nearly closed fingers (see p. 194), for our present purpose we shall assume that light travels in straight lines.

The bending of a light wave into a shadow when it passes the edge of an object is called diffraction. The diffraction grating is based on this principle.

In Chapter 13, it is stated that Newton believed light to be composed of corpuscles travelling in straight lines. Young showed that interference, a wave phenomenon, could be produced by the combination of two light rays that had come from a single source.

One commercial use of interference is for testing for irregularities of glass surfaces. In Fig. 205, the irregular fringes indicate that the lens is

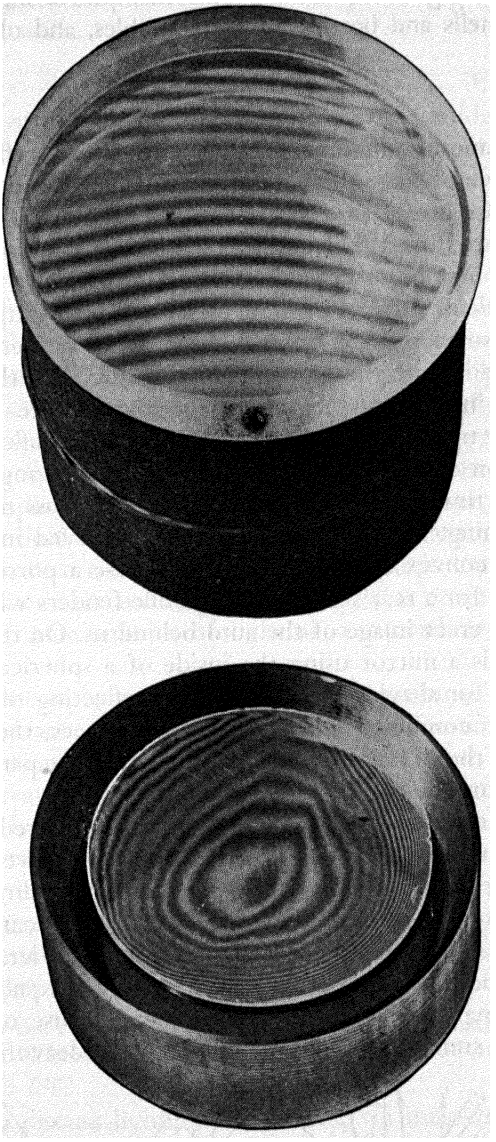


FIG. 205. The interference of light waves between two glass plates is used to test the surface. An irregular surface will produce fringes as shown in the lower figure. If the surfaces are quite smooth the fringes will appear as in the upper figure. (Courtesy, Bausch and Lomb Optical Co.)

not satisfactory. In the upper figure, the symmetrical bands show that the surface is correctly ground. Some familiar examples of interference are the colors of sea shells and beetles, of soap bubbles, and of the oil film on water.

Reflection

Perhaps our most common experience with light is reflection. We look into a mirror; we observe the blue of the sky; we notice that the clouds are white; we are aware that some types of paper give a glare and that some materials are dull. We decorate the walls of a room with light paint so that the light may be reflected instead of absorbed.

A mirror reflects a beam of light in such a manner that the reflected light leaves the surface at the same angle with the perpendicular that the incident light made with the perpendicular. In Fig. 206, the arrows pointing downward indicate the light striking the surface *MN*, while the arrows pointing upward show the direction of the reflected light. This type of reflection does not enable us to see the reflecting surface. All of us have at some time walked toward a large plate glass mirror, believing it to be an opening. Many of our mirrors are curved instead of flat. A crystal ball is a convex spherical mirror. We use a portion of a convex spherical surface for a rear sight on automobile fenders where we wish to produce a small, erect image of the auto behind us. On the other hand, a concave mirror is a mirror using the inside of a spherical surface. Such mirrors are used for shaving mirrors and for reflecting telescopes. When these mirrors are combined with cylindrical surfaces, they give the distorted images of the "House of Magic" in amusement parks. Automobile headlight reflectors are parabolic mirrors.

However, in most cases, the reflected light is scattered by rough surfaces such as painted walls or rough wood. In Fig. 206 we notice that the arrows indicating the reflected beams point in different directions. We see articles in the room and out of doors because light is scattered by them. The blue of the sky is sunlight scattered by dust and air. The colors of the clouds are due to scattered sunlight. We may get snow blindness in winter and we may be sunburned in summer because of the scattered ultraviolet rays in sunlight. Lighting engineers are endeavoring to eliminate

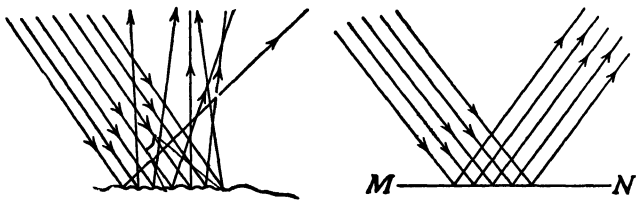


Fig. 206. Diffuse and direct reflection. (Courtesy, Tower, Smith, Turton, and Cope: "Physics," Philadelphia, The Blakiston Company.)

direct lighting in homes because of the glare, which is harmful to the eyes, and to substitute indirect illumination produced by light scattered by light-colored walls.

Illumination

The history of illumination began with a crude holder in which a fat burned. Then came the candle, which gave a yellow smoky flame of low intensity. This was followed by the kerosene lamp, which reached its highest efficiency in the latter part of the nineteenth century. However, most of the comfort of modern lighting is due to the invention of the electric light by the British physicist Swan in 1876. Edison improved this lamp and placed the operation on a commercial scale by installing a system of electric lighting in New York City. The Edison-Swan lamp, which consisted of a carbon filament in an evacuated glass bulb, was rather unsatisfactory for several reasons. One difficulty was that the carbon filament evaporated and spread a black film over the glass. Other faults were that the color of the light contained too great a proportion of red rays, and the lamp was expensive to operate. As a result of a search for a filament material which could be operated at a higher temperature, W. D. Coolidge was able to produce filaments of tungsten. Lamps containing tungsten wires give a whiter light and require less than ¼ as much electrical energy to produce the same amount of light as was produced by the carbon filament.

A further discovery proved that the evaporation of the filament and the subsequent blackening of the bulb could be prevented by filling the bulb with a small amount of an inert gas such as argon. The atoms of this gas retard the evaporation so that the filament can be operated at a higher temperature. The modern bulb is frosted by spraying the inside of the glass with hydrofluoric acid.

There is a great waste of energy in the production of light. Only about 5 per cent of the electrical energy is transformed into light in the filament lamp, the remainder being transformed into heat. The efficiency of a lamp is rated in candle power per watt, or lumens per watt.

The lumen is the term used in measuring a quantity (flux) of light. A candle flame emits about 12 lumens. For reading comfort, one should have at least 5 lumens per square foot of page.

In order to discuss lighting efficiencies, we must remember that the eye is most sensitive in the region of the yellow-green and least sensitive in the blue-violet and red. A very efficient lamp may not be a pleasant one to use. If we could operate a filament at the temperature of the sun's surface, 6,000° C., we would have a light source similar to sunlight. Since this is not possible at present, other methods must be used. Lamps such as the neon lamp, the sodium lamp, and the mercury arc are very efficient, but the type of light is not satisfactory for use in the home. Nevertheless, the

neon sign is invaluable for business use and the sodium lamp may soon revolutionize highway lighting.

The most recent type of light, the fluorescent source, has proved to be a very valuable type. In this type, the inside of the glass is coated with fluorescent minerals which emit light under the action of the ultraviolet radiation which is present in the bulb but which does not escape from the glass. The fluorescent lamp has a tungsten filament at either end. The lamp contains mercury vapor and argon. When the light is turned on, the filaments emit electrons which ionize the mercury vapor. Somewhat later the filaments are extinguished and the ultraviolet is produced by a gas dis-

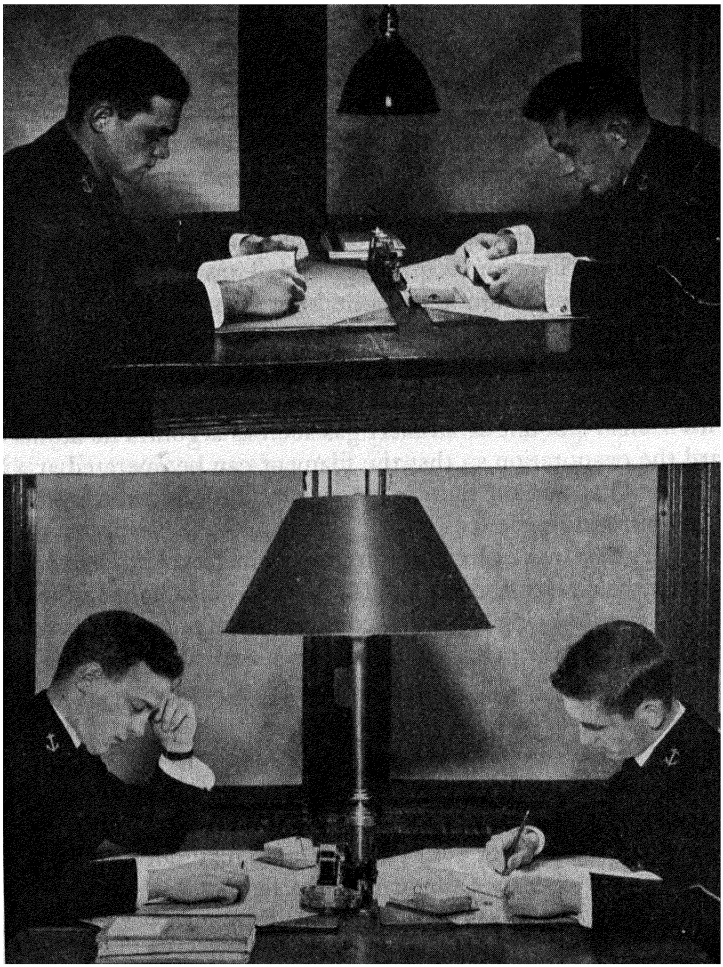


FIG. 207. Illumination old and new. (Courtesy, General Electric Co.)

Table 26

LIGHT EFFICIENCIES (APPROXIMATE VALUES)

Kind of Lamp	*Lumens per Watt*	*Candle Power per Watt*
Carbon filament	3.6	0.3
Tungsten filament	10	0.8
Tungsten (gas filled)	25	2 0
Mercury arc in quartz	50	4.0
Carbon arc . .	25	2.0
Sodium vapor . .	60	5.0
Fluorescent mercury	75	6.0

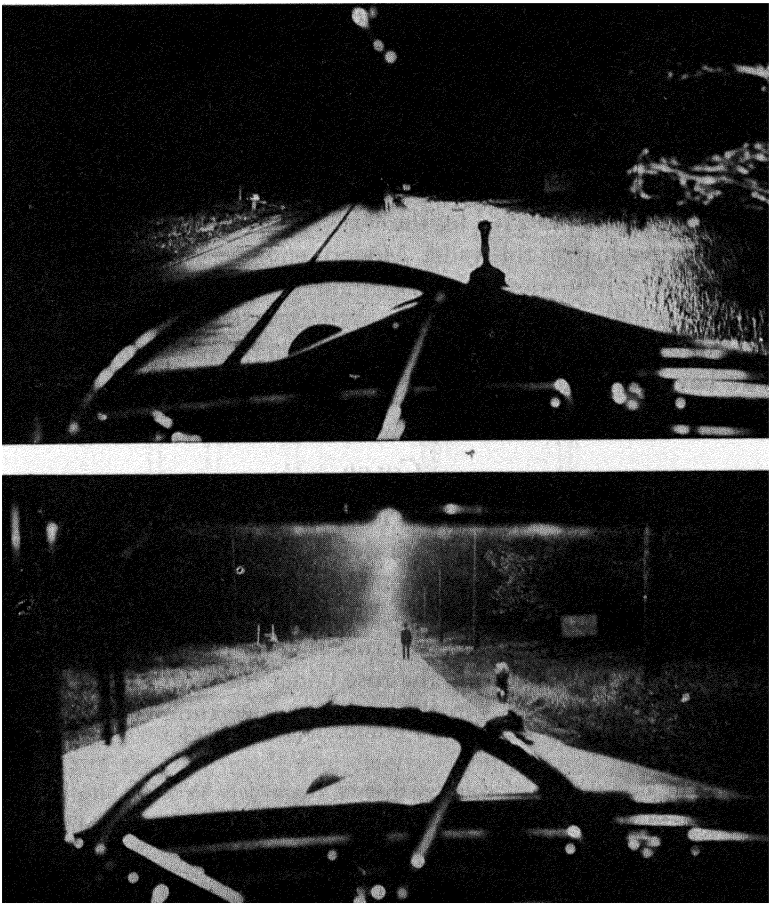


FIG. 208. The new sodium highway light contrasted with old methods for road lighting. (Courtesy, General Electric Co.)

charge in the mercury vapor. We thus have a combination of light from the mercury vapor and the fluorescent light emitted by the minerals on the glass wall. In such a lamp, nearly 50 per cent of the energy is transformed into light.

If we wish to observe an object closely, we place it very near a light source. By this means, we increase the illumination on the material. *Illumination* is measured by a unit called the *foot candle*. If a candle of a certain specified size is held 1 ft. from a book, the page is illuminated by 1 ft. candle. If a 36 candle-power lamp is placed 3 ft. from the book, the illumination is 4 ft. candles. From this follows the relation:

$$\text{Illumination} = \frac{\text{Candle power}}{\text{Distance squared}}$$

$$I = \frac{cp}{d^2}$$

The eye is very adaptable and can adjust itself to a great range of illumination. However, experience has shown that many rooms are not satisfactorily illuminated. Classrooms should have about 20 ft. candles, which is equivalent to a 500 candle-power lamp at a distance of 5 ft. Since the best light is that reflected by the walls, indirect lighting sources would need to be greater than this value. Modern engineers envision the room of the future without windows and with indirect lighting which will produce a uniform soft light casting no shadows. In Figs. 207, 208, modern illumination is contrasted with older forms of lighting. Many modern buildings already have indirect lighting. For best vision, the eye requires sufficient light, absence of glare, steady light, and illumination of the proper color.

Color

Man has always admired color. He enjoys the colors of roses, of the green foliage of trees, and of brilliant dyes. Most colors are due to reflected sunlight. As the sunlight falls on a pure red rose, all the parts of the spectrum are absorbed by the flower except the red, which is reflected to the eye. We do not know just why the rose reflects red, but we can test the statement just made by viewing the rose under the light of a mercury arc. Since there are no red rays in the mercury spectrum, the rose will not be red.

Perhaps the best theory of color is that of resonance. When white light strikes the rose, most of the light becomes heat. The red part of the spectrum excites in the molecules of the rose electronic motions which are in resonance with the frequency of the red rays. As a result, red is emitted from the rose. Chlorophyll, the coloring matter in green plants, seems to absorb the red and radiate the green part of the spectrum. In some way, this absorbed energy causes plant growth by utilizing carbon dioxide from the atmosphere.

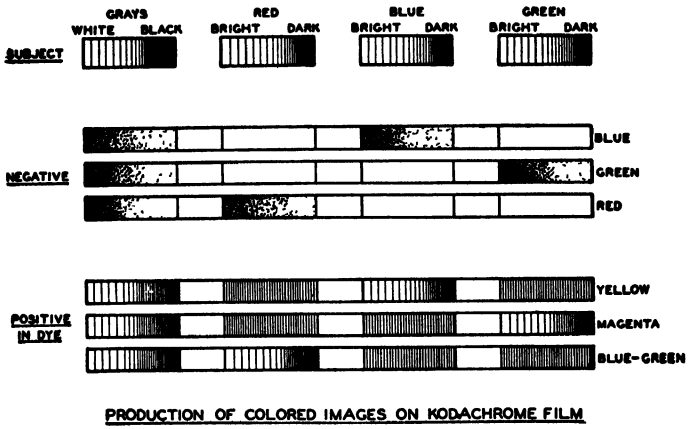


FIG. 209. (Courtesy, Eastman Kodak Co.)

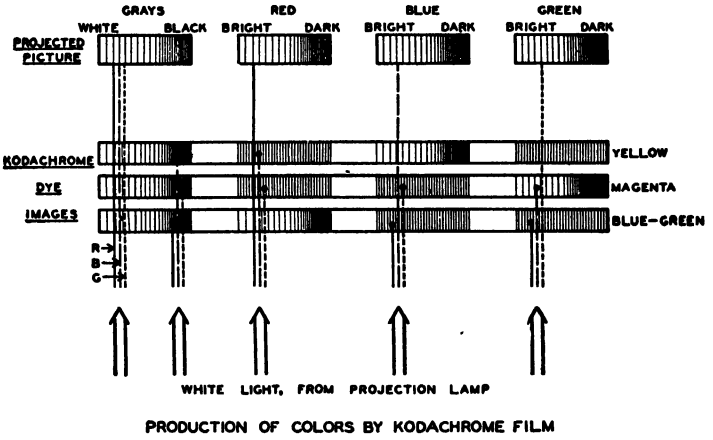


FIG. 210. (Courtesy, Eastman Kodak Co.)

If we place a piece of pure red glass before a lamp emitting white light, the glass absorbs all the spectrum except the red, which it transmits to the eye. By these two processes, reflected color and transmitted color, most of our colors are produced. The electric light in clear or frosted glass is not the white light of the sun, so that articles which are alike in color in artificial light appear different in sunlight. The lamps called "daylight bulbs" have a special glass bulb which absorbs certain portions of the spectrum so that the resultant color is more nearly the color of sunlight. One reason why we do not use the neon lamp for reading is that the color is orange-red, which is not a comfortable light for general use.

Just why the eye perceives color is still a matter of dispute. The ideas of Young and Helmholtz were that the retina contained special sensation centers which responded to the three sensations of red, green, and violet, transmitting these impulses to the brain as color.

Herman von Helmholtz (1821–1894) was a German physicist and physiologist. His work in sound and light was a great contribution to the field of science. He also made essential discoveries in the field of energy.

The theory assumed that if all three sets of nerve centers are stimulated, the sensation is that of white light. By mixing two or more types of these nerve centers, one should get the sensations of such colors as orange, blue, and yellow. A fact which gave support to this theory was the eye deficiency called color blindness. About 5 per cent of our population are color-blind, mostly red-blind, which means that such persons do not perceive red as a color. The theory of Helmholtz held that the cause of color blindness was the absence from the retina of red sensitive centers. Unfortunately, there is no evidence of the presence of such centers in the normal eye.

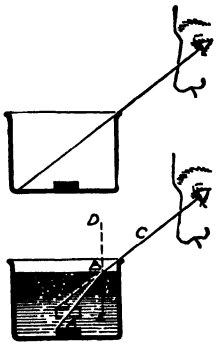


FIG. 211. An experiment illustrating refraction. The upper cup is empty. The lower is filled with water. In the lower cup the light moving upward from the object (*A*) is deviated at point *B* and reaches the observer along the line *C*. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

COLOR PHOTOGRAPHY

Until recently, the photography of objects in color was expensive and complicated. Color film has now been developed. In this film there are three gelatin emulsions. In the raw film (Fig. 209), the blue sensitive emulsion is colored yellow, so that blue light is absorbed and only the red and green get through. Only red gets through the green sensitive emulsion, the green being absorbed in this layer. The red rays act on the lowest layer. In processing the film, the images are reversed and dyed, the upper layer yellow, the center magenta, and the lowest layer blue-green. When white light passes through the film, the pictures emerge colored. The colored sections are indicated on the schematic diagram (Fig. 210).

REFRACTION

A boy learns while fishing that an object under water is really deeper than it appears to be. If it seems to be 3 ft. underneath, it is really about 4 ft. deep (Fig. 211). Likewise, a spoon placed in a tumbler of water appears broken at the surface when viewed from the side. Both of these experiments indicate that light travels more slowly in glass and water than it

does in air. This variation in speed causes refraction. The index of refraction of a substance is the ratio of the speed of light in air to the speed in the substance. For example, the index of a diamond is $\frac{186,000}{77,000} = 2.4$. The refraction of light in the unsteady atmosphere causes twinkling of stars Light refracted by water drops causes the rainbow.

Table 27

SPEED OF SODIUM LIGHT IN MILES PER SEC.

In water	140,000
In crown glass	124,000
In diamond	77,000
In polystyrene	115,000
In lucite	125,000

DISPERSION AND THE RAINBOW

All types of light travel at the rate of 186,000 mi. per sec. in free space, but the speeds of various wave lengths of light differ when passing through material substances. For example, the speed of sodium light, 5893 Å, in water is 140,000 mi. per sec., while the speed of violet light of wave length 3968 Å is only 138,000 mi. per sec. This is the cause of the phenomenon known as *dispersion.*

Perhaps the most common example of dispersion is found in the rainbow, one of the most beautiful spectacles in nature. Few persons have a true conception of the cause of this color spectrum which appears on so grand a scale. Briefly, the rainbow is caused by the refraction and dispersion of the sunlight by raindrops. In order to see a rainbow in a level region, the observer must face falling rain with the sun behind him and not more than 42° above the horizon. This means that rainbows occur either in the morning or afternoon. A complete explanation of the rainbow is outside the scope of this text. We shall describe only a simple type of bow. Let S (Fig. 212) represent the light coming from the sun in the west. D is a drop of water. The light is refracted at A as it enters the drop, is internally reflected at B, and is again refracted at C as it leaves the drop. The white light is separated into the spectrum colors, and as the observer faces east, inclining his head at an angle of 42°, he will see the red of the spectrum, and at an angle of 40° he will see the violet. It is, of course, evident that a series of raindrops at different heights is necessary if the observer is to see the complete spectrum. Any spray of water such as a waterfall or the mist of a lawn sprinkler can produce a rainbow under the proper conditions. Occasionally, there is a secondary rainbow with reversed colors (Fig. 213).

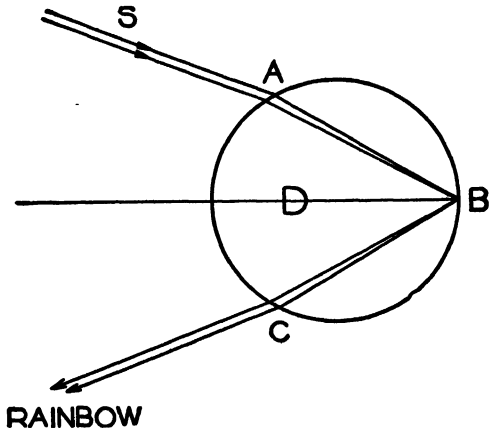


FIG. 212. Dispersion of sunlight by raindrops causes the rainbow.

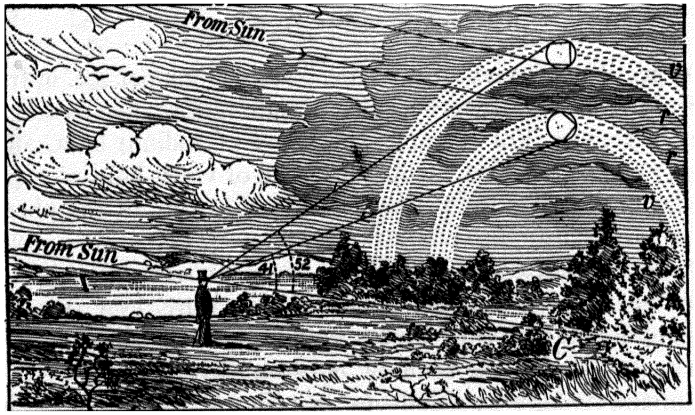


FIG. 213. The rainbow. *r* is the red and *v* is the violet boundary of the bow. (Courtesy, Chant and Burton: "A Textbook of Physics," New York, Henry Holt and Co., Inc.)

LENSES

The most important product of the principle of refraction is the lens. It is difficult for us in these modern times to visualize an age without lenses, the "Eyes of Science." We wear them as spectacles; we use them in the microscope to study bacteria; we study stars and planets by the lenses of telescopes. It is probable that the first lenses were made in China. Marco Polo found spectacles worn when he visited the Orient. In Europe, however, lenses were practically unknown until Galileo, by grinding lenses, constructed one of the first telescopes. The microscope was first used about 1630, but spectacles were not used until rather recent times.

Benjamin Franklin made some crude bifocals during the eighteenth century.

Lenses can be grouped under two types: those which spread out the light *(diverging)*, and those which focus light rays *(converging)*. If we hold a reading glass or the lens from a flashlight in the sunlight, a small real image of the sun will be formed on a white surface placed at the proper distance. In this case, *the distance from the lens to the image on*

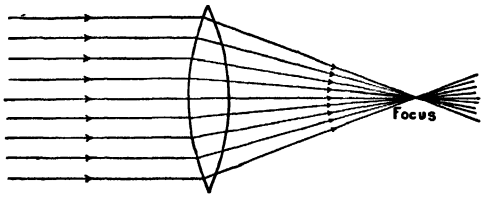


FIG. 214. The convex lens. The focal length is the distance from the center of the lens to the point marked focus.

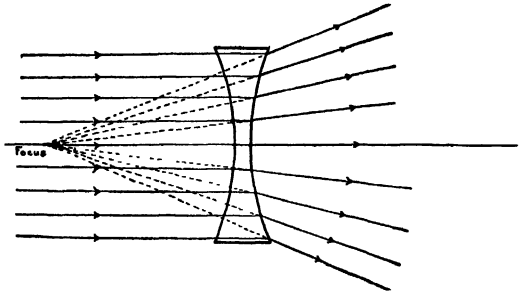


FIG. 215. The concave lens. Note that the emergent light is diverging. This lens does not form a real image.

the surface is called the focal length of the lens. The reading glass, being thicker at the center than at the edge, is a convex or converging lens (Fig. 214).

On the other hand, if one removes the eyepiece lens from the opera glass and attempts to form an image by means of the lens, none can be found. Such a lens is a concave or diverging lens, which produces a virtual image. This lens is thicker at the edge than at the center (Fig. 215). (Oculists classify lenses by the term diopter (power of a lens). *The diopter (power of a lens) is the reciprocal of the focal length in meters.)* A lens of 50 cm. (½ m.) focal length has a power of two diopters.) A convex lens is a *positive* lens; the concave lens is a *negative* lens. The modern lens system is usually a very complex combination of lenses designed to eliminate distortions of various kinds. (For a description of such lens systems, the reader may consult the references.)

Microscopes and Telescopes

Both of these instruments consist essentially of two convex lenses, the objective and the eyepiece. In the refracting telescope (see p. 13), the objective is a lens of long focal length and the eyepiece is one of short focal length. The magnification of an astronomic telescope *may be expressed as the ratio of the focal length of the objective to that of the eyepiece.*

The simple microscope (magnifying glass) is a lens of short focus. The object, AM, is placed inside the focus of the lens, BN, and the image formed, $A'M'$, is a virtual one (Fig. 216). The magnifying power is expressed as $\frac{\text{Reading distance}}{\text{Focal length}} + 1$. Since the reading distance for the normal eye is 10 in., a 5 in. focal length lens would make the object ap-

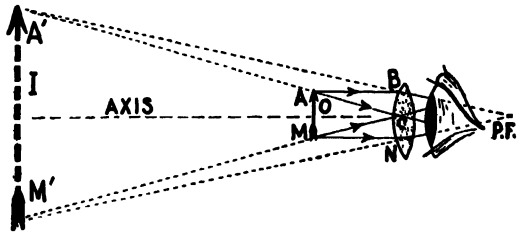


FIG. 216. The simple magnifier. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

pear three times as large. In the compound microscope, another convex lens[1] is used as the objective lens (the lens nearest the object), and the simple magnifier forms the eyepiece. One can determine the magnification by multiplying the magnifying power of the objective by the magnifying power of the eyepiece. An objective with a focal length of 4 mm. gives the highest practicable magnifying power in air, about 40. If the space between the objective and slide is filled with cedar oil, we may use an objective with a focal length of 1.8 mm. Such an objective gives a magnification of 100. When this objective is combined with an eyepiece of a magnifying power of 12.5, we can secure a magnifying power of 1250. This means that an object $\frac{1}{1250}$ in. in diameter appears to be 1 in. in diameter. The instrument is said to magnify 1250 diameters. In Fig. 217 the magnification of the objective is b/a.

[1] In practice, both the objective lens and the eyepiece consist of a train of lenses designed to eliminate various distortions.

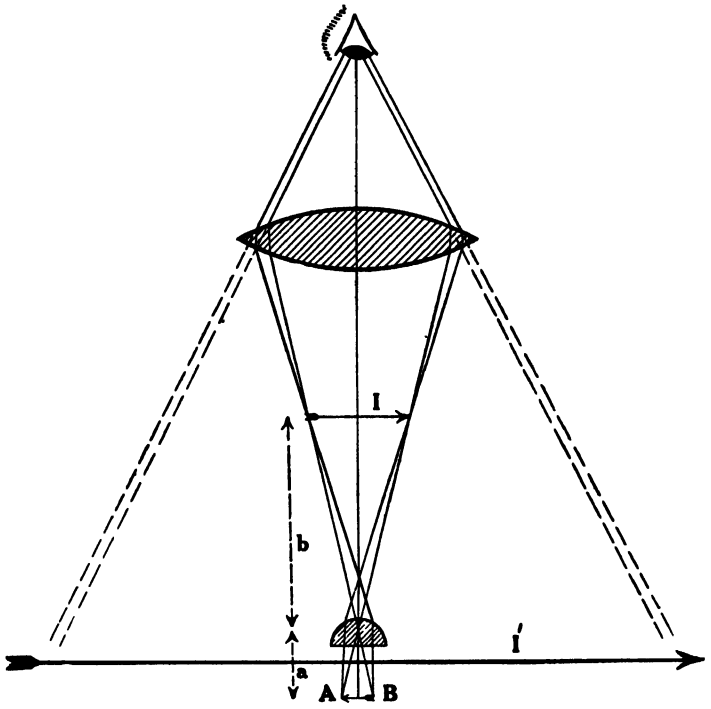


FIG. 217. The compound microscope. The objective lens produces the magnified image I of the object AB. The final virtual image I' is produced by the eyepiece. (Courtesy, Weld and Palmer. "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

A compound microscope is a very exact instrument and should have good care. Any beginner should consult some manual on the use and care of the microscope before attempting to use the instrument. As is stated elsewhere (see p. 183), one feature which must be considered in the use of the microscope is the resolving power. By using ultraviolet light and replacing the eye by a photographic plate, it is possible to secure information concerning very small objects invisible under ordinary light. A photograph by use of a microscope is called a photomicrograph (see p. 120).

The Electron Microscope

In 1927, Davisson and Germer at the Bell Telephone Laboratories made the discovery that electrons, when moving at high speeds, in addition to their other marvelous properties, act as if they possess a wave quality like light. The "wave length" of these high speed electrons can be measured. From this discovery has come the electron microscope. The instrument permits magnifications of 100,000 diameters with a resolving power

(see p. 183) 100 times greater than that of the best optical microscope. The instrument has been perfected so that it is in use by many scientific laboratories (Fig. 218). Fig. 219 is a photograph of staphylococcus aureus, magnified 35,000 diameters.

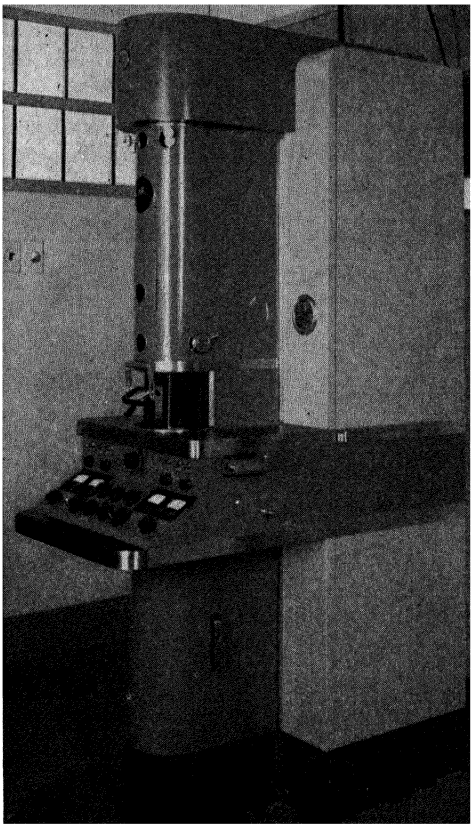


FIG. 218. The electron microscope. (Courtesy, RCA Victor Division, Radio Corporation of America.)

The Camera

A camera consists essentially of a light-proof box with a convex lens at one end and a photographic plate or film at the other. There is also a shutter and a diaphragm to regulate the amount of light which enters the box. The small box camera ("Brownie") has a fixed lens of short focus which requires no adjustment. Although part of the photograph is not in sharp focus, fairly satisfactory pictures can be taken. In most cameras the lens is mounted on a bellows so that the distance from the

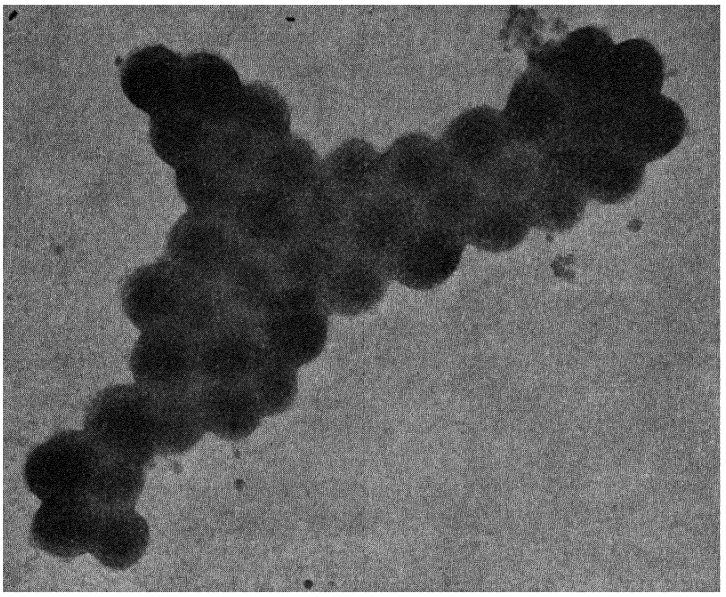


FIG. 219. Staphylococcus aureus. Magnification 35,000 diameters. (Courtesy, RCA Victor Division, Radio Corporation of America.)

lens to the film can be adjusted to secure the sharpest image. The lens-film distance is short for distant objects and long for near objects. As the pattern of light falls on the film, a chemical change takes place in the silver bromide emulsion (Fig. 220).

A photographic film is made by coating a plastic with hot gelatin in

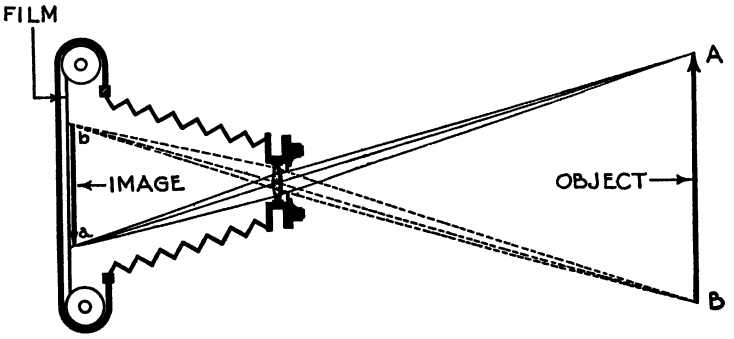


FIG. 220. The camera. The lens forms the inverted image ba of the distant object AB. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

which potassium bromide has been dissolved. Silver nitrate is added in the dark. The resulting reaction leaves crystals of silver bromide in the gelatin. The sensitivity of these crystals to light depends on their size (about 0.3 micron) and the presence of surface specks, probably composed of silver sulfide. In those grains which are exposed, the light transforms the silver bromide at the boundary of the speck into a very small amount of metallic silver. Then this silver facilitates the attack of the developer on the grain. This film is now placed in a solution (such as pyrogallic acid, hydroquinon, amidol, or metol) which develops by changing the exposed silver bromide to silver. The unchanged silver bromide is removed by immersing (fixing) the film in sodium thiosulfate (hypo). The result is a negative, so-called because the light parts of the object are the dark parts of the film (Fig. 221). In making a print, the film is placed between a light and a paper which is photosensitive. This paper, when developed and fixed, is the desired photographic print (positive) (Fig. 222).

By means of a diaphragm (iris), the amount of light entering a camera can be regulated. The diameter of the opening is expressed as a fraction of the focal length of the lens. For example, F/10 means that the diameter of the aperture is $\frac{1}{10}$ of the focal length of the lens. A small aperture admits less light but produces sharp images. For sharp pictures, it is advisable to use the smallest opening justified by the illumination. In general, F/11 or F/16 are the best for ordinary cameras. F/4.5 and F/6.3 must be used with caution.

The essential feature of a camera is a good lens. Camera lenses are sometimes very complex, being composed of several lenses in a train. Some of the types frequently used are rapid rectilinear, anastigmat, and portrait. (A rapid rectilinear lens gives an image which has the same shape as the object. An anastigmat lens gives an image free from distortion.) In some of the modern cameras, it has been found possible to use an anastigmat lens of as large an aperture as F/2 or F/1.8. Such lenses make photographs possible under very poor lighting.



FIG. 221. The stages of making a photograph. (Courtesy, Eastman Kodak Co.)

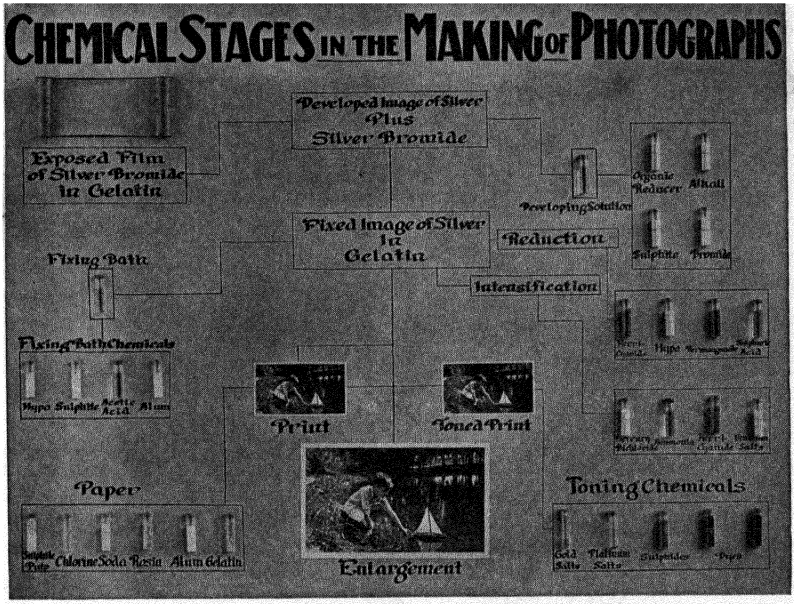


FIG. 222. (Courtesy, Eastman Kodak Co.)



FIG. 223. A photograph of a plaster bust made without visible light by the use of heated flatirons. This photograph was made by the Eastman Infra-Red film with an exposure time of fifteen minutes. (Courtesy, Eastman Kodak Co.)

During the past few years, there has been a marked improvement in the sensitiveness of emulsions. By means of special dyes, the film can be so treated that the silver bromide will be affected by both the visible and the infrared part of the spectrum. The oldest type of film is the orthochromatic, which contains the dye eosin. This film is sensitive from the ultraviolet to the yellow portion of the spectrum. Since the film is not affected by the red part of the spectrum, it can be developed in a room illuminated by red light. A newer film, the panchromatic, is sensitive to all parts of the visible spectrum and is developed in the dark. Recently a film that responds to the light of the infrared spectrum has been developed.

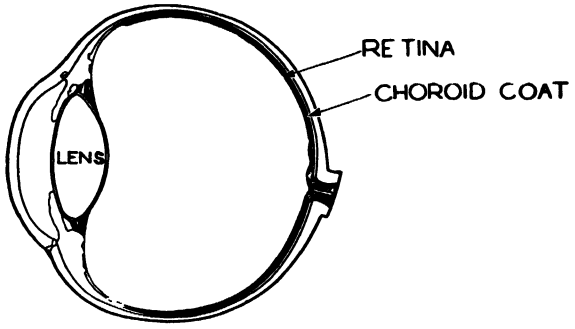


FIG. 224. The schematic eye showing lens, retina, and choroid coat only.

This is a very useful film for the experimenter in the heat region. A photograph can be taken of a hot object in complete darkness. Infrared films are very useful in the study of the constitution of planets (Fig. 223).

The Eye

The eye (Fig. 224) is a camera in which there are two convex lenses and a sensitive screen (retina). The eye lens is a double convex type made up of several layers. The cornea is a convex-concave type. To adjust the eye for distance vision, the controlling muscles decrease the curvatures of the eye lens surfaces, thus forming a long-focus lens. For near vision, the lens becomes one of short focus. The lens forms a real inverted image on the retina. The principle of the transmission of the light impulses to the brain is being studied intensively, but as yet the phenomenon of seeing is not well understood. It it known that the process is electrochemical in nature.

CORRECTION OF THE ERRORS OF THE EYE LENS. Optically, the eye is subject to several errors which can be corrected by spectacles. In the case of myopia (near sight), the patient does not have the ability to change

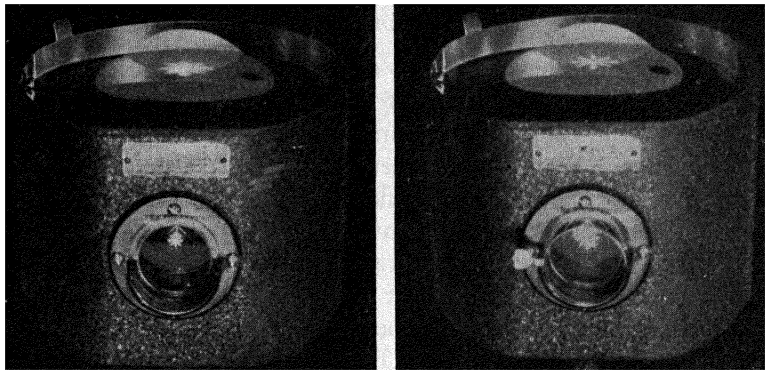


FIG. 225. Model of the eye to show correction for nearsight. (*Left*) The "eye" has the retina too far from the lens and the image is indistinct. (*Right*) The "eye" has a concave lens in front of the eye lens. Note that the image is now distinct and in focus.

the focal length of the eye lens sufficiently to see distant objects distinctly. The eye lens has too short a focal length. The oculist prescribes a concave lens (negative) which has the effect of producing a longer focal length so that the wearer has normal distance vision (Fig. 225). It is important to understand that the difficulty is not actually removed but is remedied. *Myopia* is quite common in young persons. In the opposite condition, *hyperopia* (far sight) the focal length of the lens is too great. To remedy this condition, a convex lens is prescribed.

Probably the most common error is *astigmatism.* This difficulty is due to a lack of symmetry of the eye lens. An astigmatic person finds that when some of the figures on a clock face are distinct, others seem blurred. There are two foci. The constant effort to overcome this condition produces headache and eyestrain. The teacher should be on the lookout for symptoms of this kind in children and should advise early correction. To remedy this condition, the oculist prescribes a lens cut from a glass cylinder.

A fourth condition, *presbyopia* (loss of accommodation) affects the person in middle age. The eye lens has lost the power of adjustment for near vision, so that glasses must be worn for reading. Most middle aged people wear bifocal lenses, the lower half for reading and the upper half for distance vision.

The newest type of spectacle lens is one which is placed under the eyelid directly on the eyeball. A thin film of salt solution on the ball prevents irritation. These lenses are invisible and are said to be quite comfortable for the wearer. Unfortunately, the cost is rather high at present. Most of these are formed from plastics (see p. 280).

Television

For centuries man has desired to enlarge his range of vision in order to be able to see events hundreds of miles distant. Various devices have been constructed in the past, but none of them gave satisfactory results. Within the last 10 years, the problem has been successfully solved by means of the photoelectric cell principle (see p. 195). In general, the problem of television is that of converting light energy into electrical energy, transmitting the energy by radio waves or by cables, and finally converting the energy back into light energy at the receiving station. The most successful methods seem to be the ones developed by Vladimir Zworykin and by Philo Farnsworth. Baird in England and an investigator in Germany have also produced successful television systems. To illustrate the general principle of television, we shall describe the apparatus of Zworykin. In order to do this, it is necessary to describe the retina of the eye.

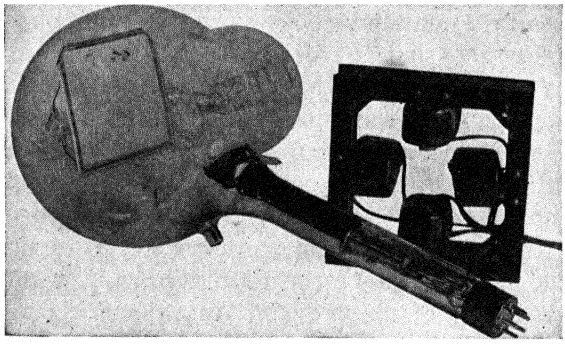


FIG. 226. The iconoscope. (Courtesy, Radio Corporation of America.)

The retina of the eye is a mosaic pattern of nerve elements consisting of three layers of neurons. The layer of nerve cells nearest the eye lens is composed of the optic nerve cells; the bipolar cells form a second layer; the layer against the choroid coat at the back of the eyeball is made up of rod and cone cells. This means that in the third layer the dendrites of the neurons are rods and cones. The rods and cones are very numerous, the number of cones in the yellow spot of the retina alone being about one million. Interlaced with the rods is a mosaic of pigment cells, the visual purple. When the image is focussed on the retina by the eye lens, the light waves pass through the retina to the rod and cone layer. These rods and cones are photosensitive and, when stimulated by light, produce impulses which pass through the optic nerve cells to the brain. It seems that the retina acts like a *self-restoring photographic film.* For our

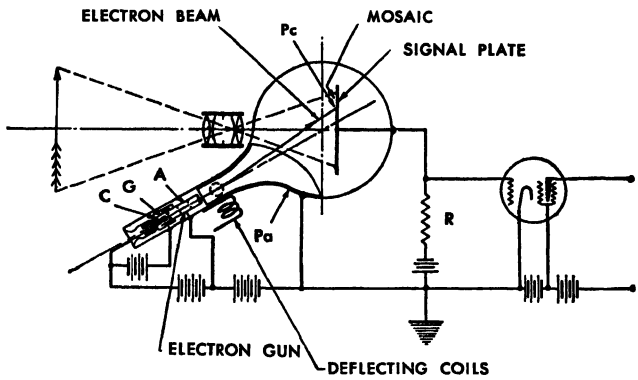


FIG. 227. Electrical circuit of the iconoscope. A, G, and C are elements of the electron gun. (Courtesy, Radio Corporation of America.)

purpose, we shall describe the retina as a mosaic of light-sensitive rods and cones.

Zworykin, imitating the action of the human eye, designed a photoelectric cell (Fig. 226) with a mosaic consisting of many thousands of tiny silver globules, each made photosensitive by a coating of cesium. These globules are deposited on an insulating enamel covering the metal plate (signal plate). The silver mosaic and the signal plate constitute an electrical condenser. The image is focused in the usual manner on the sensitive surface by a camera lens, thereby causing an emission of electrons. The number of electrons emitted by each element depends on the intensity of the illumination. When the electrons leave the globules, the globules are left positively charged. A beam of electrons shot out by the electron gun shown in Fig. 227 moves over the screen like a stream of water playing over a building. It thus neutralizes the positive charges. This process produces a current of electricity through *R*. This feeble current is amplified by radio tubes and is broadcast in the usual manner. This device, called the *iconoscope* (see an image), replaces the film of the camera. Many improvements have been made in the past few years and a large number of television units are now in operation. Television in color will soon be made practicable for commercial use.

In order that the eye may view the televised image with comfort, the complete image must change each $\frac{1}{30}$ of a second. This means that for a picture divided into 525 horizontal lines each having 550 elements, the electron beam must scan $550 \times 525 \times 30$ elements each second. This is one of the difficulties of modern television.

Sound Motion Pictures

Motion pictures combine two applications of light principles. The film contains a series of photographs taken of moving objects. In the pro-

jector, one picture of the film is jerked into position and stopped for viewing. A shutter now closes and covers the lens while the next picture is being jerked into position. The eye, because of the persistence of vision, registers these separate images as a continuous motion of the photographed object. Persistence of vision means that the retina retains an impression of an object for a fraction of a second after the object has been observed.

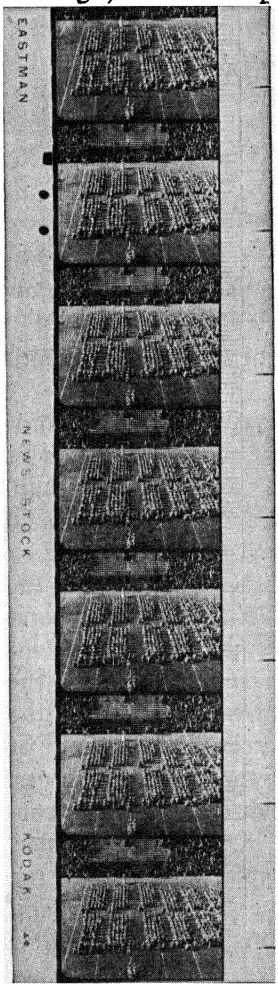


FIG. 228. Sound film.

Beside the picture strip is a narrow track, called a sound track, which is composed of a series of light and dark strips (Fig. 228). A tiny beam of light is focused on the strip and the emergent light strikes a photocell (see p. 195), producing a varying electrical current. This current is amplified by a radio amplifier, thus operating a loudspeaker. The sound track and the motion picture strip are synchronized so that the speech or song seems to come from the picture on the screen.

ULTRAVIOLET

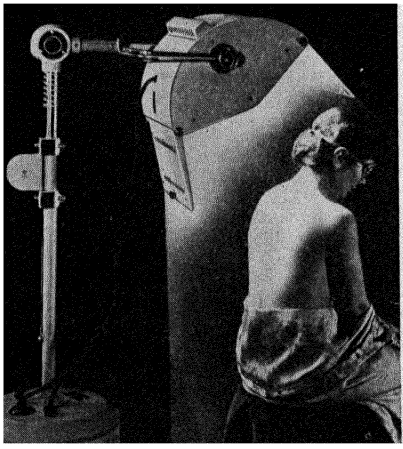
The part of the electromagnetic spectrum called the ultraviolet is usually associated with the visible spectrum. The visible spectrum, extending from 8,000 Ångströms to 4,000 Ångströms, continues into the invisible region. Some ultraviolet coming from the sun penetrates our atmosphere. Rays in the region of 3,000 Ångströms affect the growth of the body by assisting the process of bone calcification. One of the D vitamins is produced when ergosterol, which is found in such materials as cod-liver oil, cottonseed oil, and other fats, is subjected to ultraviolet for a time (see p. 241). Vitamin D is necessary in order that the bones absorb calcium and phosphorus and is thus effective in the treatment of rickets. Some milk companies are subjecting their product to ultraviolet, thus producing vitamin D in the milk. This makes it unnecessary to give cod-liver oil to small children. The ultraviolet rays from the sun are absorbed by window glass so that house dwellers get very little of this beneficial radiation directly from the sun and must supplement by the use of cod-liver oil or the equivalent in order to secure vitamin D. The ultraviolet rays extending from 3,000 to 3,200 Ångströms cause sunburn and tan (Fig. 229).

On the other hand, the ultraviolet in the region of 2,537 Ångströms has germicidal properties. This radiation can destroy such bacteria as B. typhosus, B. coli, and B. cholera in a few seconds. These rays are used in the treatment of various skin diseases such as lupus (a tubercular disease of the skin) (Fig. 230). Since they can injure healthy tissue, it is essential that the skin and eyes be protected from such radiations. Some mercury and carbon lamps are dangerous and should be used only upon the recommendation of a physician, but in most sun lamps the dangerous rays do not escape through the glass shield. Within the past few years, various types of glass have been produced which permit the passage of the harmless ultraviolet. Some of these glasses are Corex and Vita Glass.

A very important use of the ultraviolet is in the study of the fluorescence of rocks. As has been stated in Chapter 9 many rocks glow with interesting colors under ultraviolet rays. Zinc sulfide glows with a beautiful green and fluorite becomes a brilliant purple.

Polarized Light

For many years, scientists have believed that light waves are transverse. This means that the vibrations of the medium are perpendicular to the direction of motion of the wave. If this is true, the wave can be polarized, i.e., have vibrations in only one plane. The usual demonstration experiment is a rope passing through a series of picket fences (Fig. 231). If the pickets are upright, each vibration in a vertical direction can proceed through pickets. The wave between the two fences lies in one plane and is polarized. If the pickets of the third fence are horizontal, these



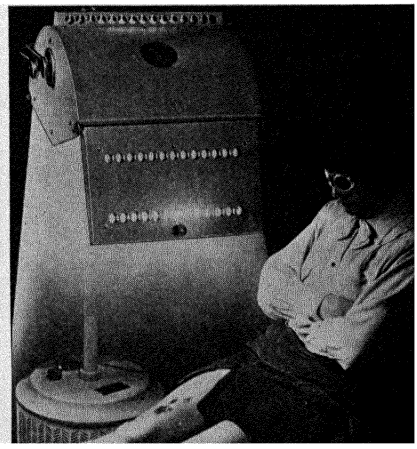


Fig. 229. (*Left*) Ultraviolet rays used in producing sunburn and tan. (Courtesy, Hanovia Chemical and Mfg. Co.)

Fig. 230. (*Right*) The use of short ultraviolet rays in the treatment of skin diseases. (Courtesy, Hanovia Chemical and Mfg. Co.)

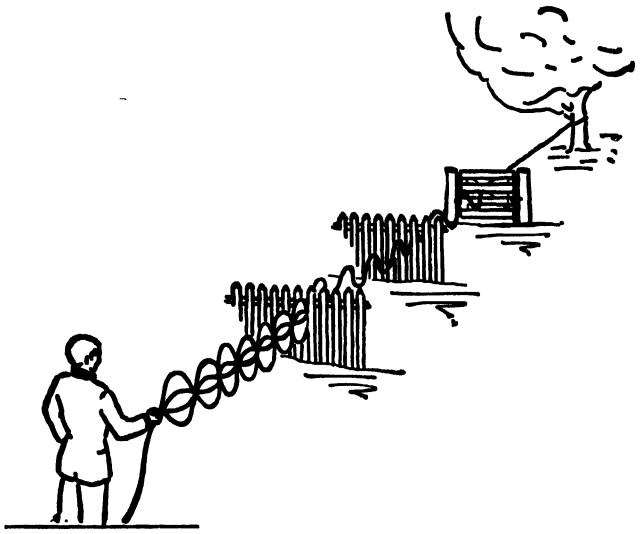


FIG. 231. A drawing of the rope analogy to polarized light. (Courtesy, Journal of the Franklin Institute.)

vibrations are stopped and no wave passes through. We must remember that we have no definite proof that light travels in a wave motion. Nevertheless, it has long been known that two pieces of the transparent mineral

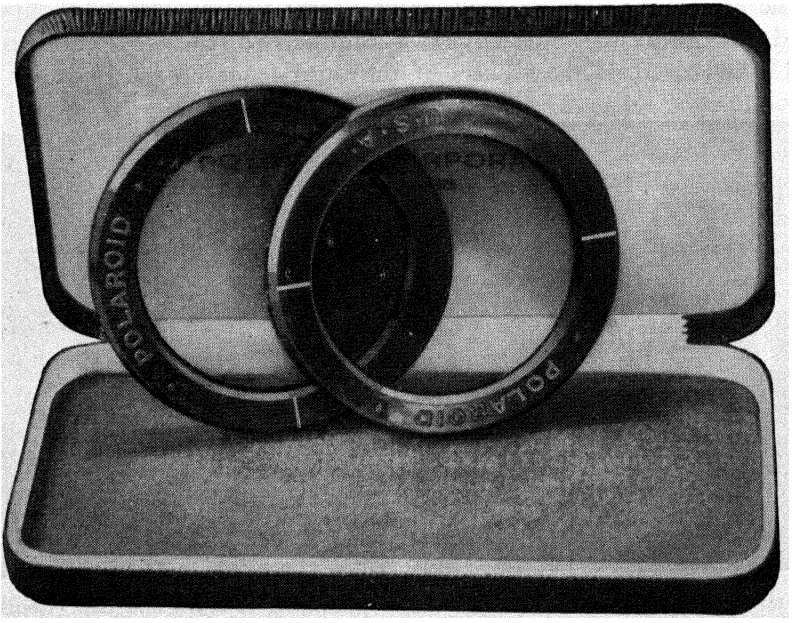


FIG. 232. Polaroid plates crossed to show extinction of light. (Courtesy, Welch Scientific Co.)

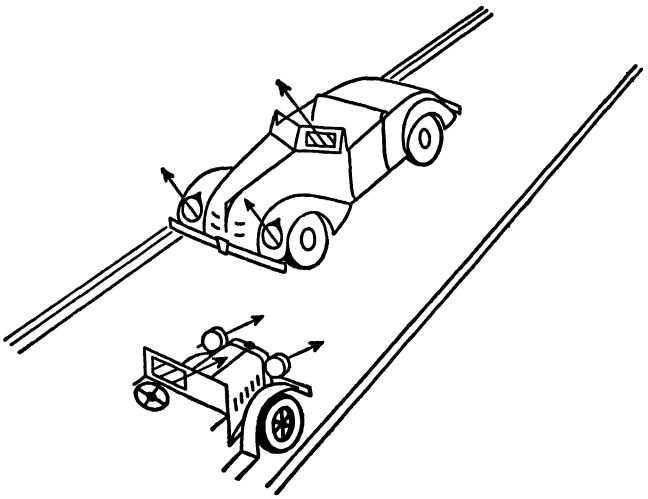


FIG. 233. Sketch showing the method of installing Polaroid in automobiles. The arrows indicate the polarizing directions. (Courtesy, Polaroid Corp.)

tourmaline, if placed in a certain position relative to each other, could prevent light from passing through. Up to 1930, polarized light was a laboratory curiosity.

For many years scientists had known that the solution of the headlight glare problem lay in the use of polarized light. In 1930, Edwin Land invented a material called Polaroid. It consists of cellulose acetate (cellophane) in which are embedded millions of submicroscopic, needle-like crystals of the mineral heraphathite, all lying parallel to each other. Light passing through this material becomes polarized in one plane. One modern form utilizes iodine atoms embedded in a plastic. Two pieces with the polarizing directions crossed cut off the light (Fig. 232). This material is being used for one way vision windows, for reading lamps, for sun glasses, and for the elimination of glare from headlights. Fig. 233 shows how the material is installed in an automobile. The headlight lenses and a portion of the windshield contain Polaroid. As two cars approach each other, each has clear vision of the road but the light of the approaching headlight is nearly cut off. There is no glare.

Modern science progresses at a breathtaking pace. Time after time scientific discoveries have become of great practical importance.[2]

REFERENCES

Bragg: "The Universe of Light," New York, The Macmillan Co.
Evans: "An Introduction to Color," New York, John Wiley and Sons.

[2] The interested reader will find the subject of polaroid treated in detail in the *Journal of the Franklin Institute*, September, 1937.

Foley: "College Physics," Philadelphia, The Blakiston Company.
Henney: "Color Photography for the Amateur," New York, Whittlesey House.
Houstoun: "Light and Color," New York, Longmans, Green and Co.
Houstoun: "Light and Color," New York, Longmans, Green and Co.
Luckiesh: "Light and Health," Baltimore, The Williams and Wilkins Co.
Mees: "Photography," New York, The Macmillan Co.
Saunders: "A Survey of Physics," New York, Henry Holt and Co.
Taylor: "Physics: The Pioneer Science," Boston, Houghton Mifflin Co.
"About Lenses," Eastman Kodak Co.

Questions and Problems

1. What is the difference between candle power and intensity of illumination?
2. What is meant by the efficiency of a light source?
3. Explain the process of taking and developing a picture.
4. To what is the color of an object due?
5. What causes a rainbow?
6. What is: a panchromatic film? an orthochromatic film?
7. What is a diopter? A lens of 2 m. focal length has what power? Answer: ½ D.
8. What is the illumination on a book when a 16 candle power lamp is 4 ft. away? Answer: 1 foot candle.
9. What is meant by television?
10. Explain how the eye is corrected for errors of vision.
11. What is meant by talking movies?
12. What is the difference between direct and diffuse reflection?
13. What is monochromatic light?
14. A compound microscope has an objective of magnification 40 times and an eyepiece of magnification 15. What is the magnification of the instrument? Answer: 600 diameters.

Visual Aids

To Greater Vision, Bausch and Lomb Optical Co. Film
Three films on "Light," Eastman Classroom Films

Topics for Discussion

Photography	The Rainbow	Spectacles
Color	Good lighting	Polaroid
Microscopes	Television	

Experiments

1. A Study of Lenses and Telescopes. Find the focal lengths and powers of the two lenses given you. Construct a telescope by using a thin lens (low power) as the objective and a thick lens (high power) as the eyepiece.

   Focus the telescope on a chalk scale on the blackboard. Keeping both eyes open, view the scale through the telescope with one eye, and view the board with the other. Count the number of divisions of the board scale that fit into the distance between two lines of the telescope scale. This is a measure of the magnifying power.

   Look at objects in the room through the model telescope and describe their appearance.

   Find the magnifying power of a reading telescope.

Use the thick lens as the magnifying glass and estimate the magnifying power by focusing on a small square on a sheet of paper.

2. A Study of the Process of Making Photographs. Remove the back cover of the camera, replace it with a ground glass screen, and adjust the lens until you secure the sharpest image. Examine variations in the image when the stop is opened and closed. Replace the back cover, insert the film or plate, and take photographs. If the day is dull, use a time exposure or a photoflash lamp. (In this case, it will be necessary to have the camera mounted on a tripod or table.) If the day is sunny, make snap shots, using different stops. Make exposures facing the sun as well as in the opposite direction.

   Make up two solutions, one for developing, and the other for fixing. As a developer use any standard developing powder or liquid and prepare the solution according to the directions on the container. Use any standard fixer and follow directions for the preparation of this solution. In a dark room, place the exposed film in the developer and, being careful not to touch the dull surface with the fingers, allow it to remain until the image begins to penetrate through to the back (shiny surface). Remove and wash in running water. Place the negative in the fixing bath and allow it to remain until all white material has disappeared. Wash for 10 minutes in running water. If time is limited, use alcohol as a final wash. Allow the negative to dry and make a print according to the directions on the package.

3. The Compound Microscope. Examine the microscope before making any adjustments. You will find that the objective lens is marked with the magnifying power and the numerical aperture number. The eyepiece tube is also marked with the magnifying power. The product of the two magnifying powers is the magnifying power of the lens combination.

   Next, insert a microscope slide, for example, an amoeba, on the table and rack the microscope *down carefully*, watching the lens to see that it does not touch the slide and break it. When the objective is close to the slide, begin to rack the tube *upward* and look through the microscope. When the object comes into view, use the slow motion rack to complete the adjustment.

   If you use the 4 mm. objective, you will need to be careful to rack slowly, since the distance of the lens from the slide is about 4 mm. (about $\frac{1}{8}$ in.). After you are familiar with the adjustment, use a millimeter scale on the stage and, using both eyes, view the scale in the microscope and the scale outside at the same time. Measure the magnification. (For this experiment, use the 16 mm. objective.)

4. Make a photomicrograph of the amoeba, using the camera in conjunction with the compound microscope.
5. Examine the colors of shells and soap bubbles.
6. Look at a bright light through nearly closed fingers. The lines are due to diffraction.
7. A method is now available for developing color films at home. The directions can be secured from the manufacturer.
8. Use a diffraction grating to examine the light of a neon bulb.

25. ELECTRICITY AND MAGNETISM

Too like the lightning, which doth cease to be
Ere one can say it lightens.

—SHAKESPEARE

It is quite probable that of all types of energy, electrical energy has contributed most to the progress and convenience of mankind. Although we live in an electrical age—riding on electric trains, warmed by electric heaters, talking by means of the telephone, seeing by television—few persons know anything about the fundamental principles governing this great servant to the human race. In the past 40 years, we have progressed from oil lamps to tungsten gas-filled bulbs and fluorescent lamps, from horse drawn vehicles to automobiles made possible by spark coils and storage batteries. The dentist uses an electric drill; the medical man uses x-rays and ultraviolet rays; the surgeon often uses an electric tool (cautery) instead of a scalpel; the muezzin of a mosque calls the faithful to prayer by a microphone and loudspeaker.

One of the reasons for this universal use is the ease with which electrical energy can be generated and transmitted. By means of generators, transformers, and wires, the energy can be silently and cheaply distributed to distant points. In the present chapter, we shall try to present some of the fundamental principles so that the reader may gain some familiarity with this form of energy. In the subsequent chapter, we shall describe some of the applications of electricity in everyday life.

ELECTRICAL UNITS

In beginning the study of the manifestations of electrical energy, it it necessary to define and explain some terms that will be used. The socket of an electric light bulb is sometimes marked 250 volts, 660 watts. These numbers mean that the socket can be safely used on wires in which the voltage (difference of potential) does not exceed 250, and in which the power consumption does not exceed 660 w. Under ordinary conditions, the electric wires in the house are at a potential difference of 120 v. The potential difference is a measure of the potential energy, somewhat as the difference of level between the reservoir and faucet is a measure of the potential energy of the water. By means of a pump (Fig. 234), water is raised to the higher level on one side of the tank. There is a difference of potential between A and B. If C is opened, water flows from A into B,

and the pump must again raise the level in *A* if the stream of water is to continue. In like manner, an electron pump must maintain a difference of potential. The agency producing this potential difference is called electromotive force. It is numerically equal to the total maximum potential difference of a circuit and is measured in volts. The electron pump may be a cell, a generator, a thermocouple, or a photocell. Electrical potential is produced by some agency which separates positive and negative charges.

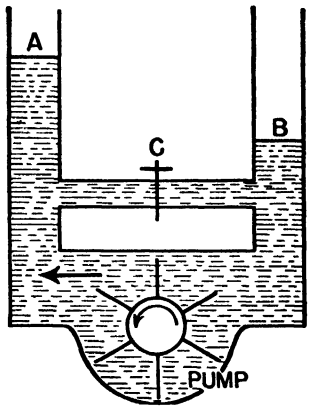


FIG. 234. Pump is analogous to the cell which sets up a difference of potential.

As the switch is turned on at the socket in which there is a 60 w. (120 v.) lamp, the 120 v. potential difference causes a current of ½ ampere to flow through the lamp. From this follows the definition of the watt: a watt equals one volt × one ampere.

Because the 120 v. lamp requires ½ amp. to light up brilliantly, it needs a 120 v. potential difference to give the proper illumination. A 6 v. storage battery will not light the lamp, since the resistance of the lamp is too high. The 60 w. (120 v.) lamp contains a fine tungsten filament which has a resistance of 240 ohms. These various facts are expressed by the fundamental law of electricity discovered in 1826 by George Simon Ohm, a German scientist. Ohm's law states that *the current in amperes equals the emf. in volts divided by the resistance in ohms or* $A = \frac{V}{O}$.

As enunciated by Ohm, the law states that the ratio of voltage to current in a metallic circuit is a constant, called resistance.

The terms ampere, ohm, and volt are interdependent and in order to describe any electrical apparatus all three must be considered. In the case of the lamp just described, ½ amp. equals 120 v. divided by 240 ohms. Using the analogy of water, the height of the water in the standpipe above the faucet may be compared to the emf.; the number of quarts of water flowing out of the faucet per second is analogous to the current; the friction of the water against the walls of the pipe bears a resemblance to the resistance.

Let us apply the law to a problem: In the complete circuit (Fig. 235), the cell supplies an emf. of 1.5 v. to 2 resistances of 4 and 3 ohms in series.[1] The current $I = \frac{1.5}{7} = .21$ amp.

[1] The internal resistance of the cell is neglected.

If the resistances are in parallel as is the case in the electric light circuits, the 110 v. of potential difference are applied across each resistance. In order to determine the current in each resistance, we divide the voltage by the resistance.

In order to interpret the meaning of electrical current, we shall use an imaginary experiment. Let us assume that we have the power of seeing the individual atoms of a copper wire (Fig. 236). Since the temperature of the wire is above absolute zero, the atoms will be in vibratory motion, jostling each other as they move about. In addition, we shall notice that there are some free electrons in the wire, which, owing to their kinetic energy, move about like gas molecules. These electrons collide with the

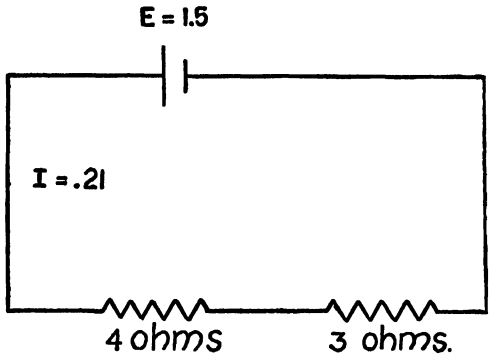


FIG. 235.

atoms and the result is a continual state of irregular motion. If we now connect a dry cell or other source of potential difference to the wire, the electrons, being negative, tend to drift toward the positive pole, since unlike charges attract each other. This electron drift is the current. We might define the current as the number of electrons passing a point in the wire per second. An ampere of current is flowing when 6×10^{18} electrons pass a point in a second.

An ampere is defined in practice as that current which will deposit .001118 Gm. of silver per sec. in an electrolytic cell. We determine the presence of a current by such effects as heating, electrolysis, magnetism, or muscular shock.

An electric current may be caused by a motion of electrons through a wire, by groups of electrons and positive ions meeting each other as in a lightning flash, by the motion of positive ions and negative ions through a liquid as in electrolysis, or by electrons moving in the vacuum space of an electronic tube.

As an analogy to electrical current, we might consider the current in a stream of water. By current we mean the number of gallons of water passing a point each second. If there are no tributaries, the same amount of

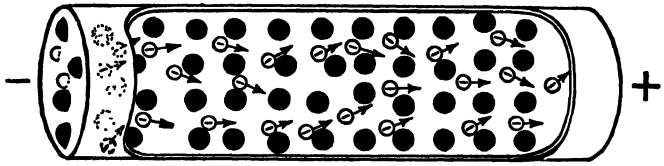


FIG. 236. Conduction. Black discs represent atoms. Hollow circles represent electrons.

water will pass all points of the stream each second. Likewise, the current in a series circuit is the same at all points. The current flows in a stream because the source is at a higher level than the mouth. The friction of the banks and bed is analogous to electrical resistance.

When the copper wire is replaced by an iron wire of the same size, the number of electrons passing a point in the wire each second will be less, although the potential difference remains the same. Apparently, there is more hindrance to electron motion in the iron wire than in the copper one. *Resistance is the measure of hindrance that materials offer to the passage of electrical current.* The unit of resistance is the ohm.

The ohm is defined as the resistance of a column of mercury 106.3 cm. long and 1 sq. mm. cross-section at a temperature of 0° C.

As we measure the resistance of various metals of the same size and length, we find that some metals, such as silver and copper, have a low resistance (they are good conductors of electricity), while other metals, such as iron, nickel, and many alloys, have high resistances. The high resistance of these materials is utilized in the manufacture of heating devices, such as the flat iron and the toaster. In the average toaster, an electrical current of 5 amp. at a potential difference of 120 v. flows through the coils. The power utilized by such a toaster is 600 w. By comparison, the power of a flat iron is 550 w., of a space heater 1,000 w., and of the average radio about 100 w.

The amount of heat generated per second depends both on the current and on the resistance. The number of calories per sec. $= 0.24I^2R$. I is the current in amperes and R is the resistance in ohms. In the toaster just described, calories per sec. $= 0.24 \times 5^2 \times 24 = 144$.

ENERGY. We pay for the electrical energy used in the home. This energy is expressed by the units *watt-hour*, and *kilowatt-hour*. A 60 w. lamp burning for 1 hr. uses 60 whr. of energy. If it burns for 10 hr., it uses 600 whr. or 0.6 kilowatt-hour (abbreviated to kwhr.). On our lighting bill, the cost is calculated per kilowatt-hour. For example, at a rate of 10¢ per kwhr., it will cost 30¢ to burn a 60 w. lamp for 50 hr., 3 kwhr. having been used.

FUSES. Referring again to Ohm's law, we note that, for constant voltage, as the resistance is decreased the current increases. Should the two

Table 28

POWER OF SOME COMMON DEVICES*

Electric iron	550 watts
Toaster	500 "
Washing machine	300 "
Electric range	3,000 "
Water heater	2,500 "
Average radio	100 "
Refrigerator	200 "

* These are average values.

terminals of a socket be connected (short circuited) by a wire of low resistance instead of a lamp, or should the two terminals of an extension cord touch in the plug or along the cord, a large current would flow and might damage the house wiring. In order to prevent such injury, fuses are placed in a fuse box in the circuit. This fuse is a piece of lead wire so made that the wire melts when the current exceeds a certain safe value. Since this is a safety device, neither pennies nor copper wires should replace the fuse plugs. Disregard of this precaution may cause fire or serious damage. On the other hand, there is no cause for alarm if the fuse does melt, since the circuit has been broken and no further damage will result.

SAFETY PRECAUTIONS

Persons who are ignorant of the principles of electricity are likely to be either of two types: timid and afraid of electrical apparatus or bold and careless. It is important to understand that if certain principles are observed, house wiring is not dangerous. The potential difference of 120 v. is usually harmless to the body because of the high resistance of the skin when dry. The resistance between dry hands averages about 30,000 ohms. If we divide 120 by 30,000, we find that only a small current (0.004 amp.) will flow through the body even though one wire is in each hand. The only effect will be an unpleasant shock. It is known that a dangerous body current is about 0.1 amp. The current is the factor that causes injury. Such newspaper statements as "2,000 volts coursed through the body" are unscientific.

However, should a person standing on a wet floor or sitting in a bathtub grasp a poorly protected socket, a large current might travel from the hand through the body to the ground (Fig. 237), because of the low resistance of the wet body. This would cause serious shock.[2] For this reason, sockets should never be placed in a bathroom near the tub. A person using an electric washing machine on a cement floor should exercise

[2] Electrical shock stops respiration. For this reason, artificial resuscitation is used.

great care that the wires are well insulated. A well-made socket is not a source of danger, but worn and inferior sockets are often not well protected and should be replaced. Because of the low resistance of the skin of children, they should be taught to avoid playing with electrical devices.

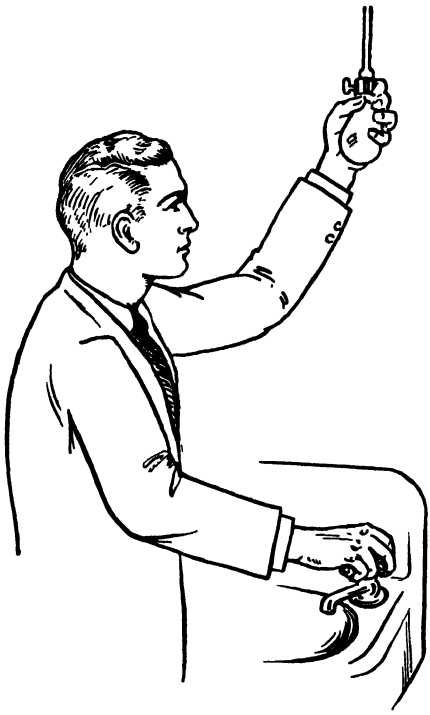


FIG. 237. The drawing illustrates one hand touching an electric light socket while the other touches a water pipe. This is dangerous as current may flow from the socket through the body to the ground.

STATIC ELECTRICITY

On p. 189, the experiment of rubbing a hard rubber rod with fur is described. As the fur is rubbed over the surface of the rubber or amber, some of the electrons will be removed from the fur and will cling to the rubber surface, thus giving the rubber molecules more than the normal number of electrons. This means that the rubber has a negative charge. The fur, having lost some of its electrons, is left positively charged. The charges held on insulators, such as rubber, fur, glass, sulfur, and amber are called static or stationary charges. These charges were studied in very early times. We have many examples of static charges. The body can be

charged by walking over a woolen rug. Upon touching a doorknob, a spark will jump between hand and knob. Cleopatra is said to have remarked that amber beads attracted the silk threads of her gown. Other examples are charged thunderclouds and the charge of the electric eel. The condensers[3] used in a radio set also store static charges. Benjamin Franklin (Fig. 238) studied these static charges in large quantities. In order to prove that the electricity of the lightning flash was of the same type as the elec-

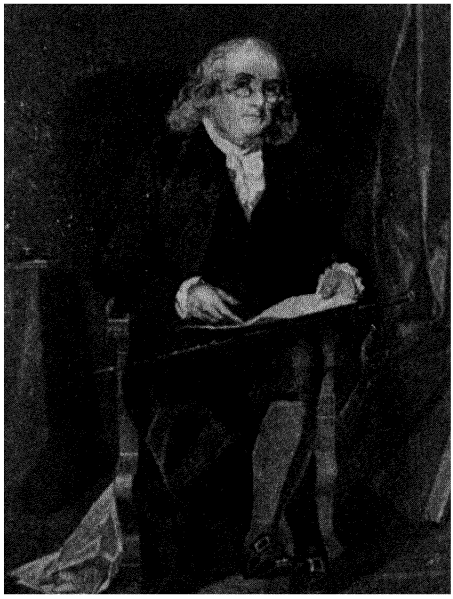


FIG. 238. Benjamin Franklin (1706–1790). Statesman, philosopher, and scientist. Studied electricity; invented the lightning rod. (Courtesy, Science Service.)

trical charge of the rubber rod, he flew a kite into a thunderstorm cloud and collected static charges from the cloud. These charges had exactly the same properties as the well-known static charges. Franklin took a great risk, as we now know, since a discharge from a cloud might have caused his death. A Russian scientist was killed while repeating the experiment.

In contrast to the insulators, there is another class of materials, principally the metals, upon which the charges will not remain. If a copper rod is held in the hand and rubbed with fur, no charge will be found. Such substances are called conductors. While studying these materials, Volta, an Italian scientist, placed a copper coin and a gold coin on his tongue and

[3] A condenser is a device consisting of metal surfaces separated by insulators called dielectrics.

touched the edges of two coins together. The result was a feeble shock. Following this, he built a pile of plates, alternately zinc and copper, separated by a cloth soaked in salt water. He found that he could produce electrical charges from the plates and that, by connecting the outside plates, one zinc and the other copper, by a wire, a spark was formed and the wire became hot. Here was the first device for producing a continuous stream of electrons in a wire, *an electric current.*

One can also show the presence of an electric current by holding a charged rubber rod near the ear or finger. The resulting spark is a flow of electrons to the body.

The Dry Cell

This cell, called "dry" because it is sealed so that the paste cannot escape, is a type of electron pump (Fig. 239). A zinc cup is filled with ammonium chloride (sal ammoniac) paste. In the center of the cup is a carbon rod. The ammonium chloride dissociates into ions (see p. 208) and, as a result of this dissociation, the carbon rod acquires a positive charge (loses electrons) and the zinc cup acquires a negative charge (gains electrons). An emf. of 1.5 v. is set up in the cell. When the cell is in use, the zinc is changed by chemical action into zinc chloride. When the zinc is exhausted, the cell is worn out and must be discarded. Such a cell is useful in apparatus where electrical current is needed for a short time, such as the flashlight or doorbell. The dry cell transforms chemical energy into electrical energy.

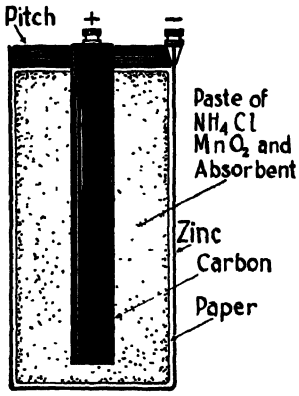


Fig. 239. The dry cell. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

The Storage Cell

Storage cells are secondary cells. This means that an electric current transforming electrical energy into chemical energy must first be passed through the cell. This operation is called charging. The cell will then have a potential difference and can act as a source of electrical energy. One type of storage cell (Fig. 240), consists of lead plates separated by insulators of wood or porous rubber. The electrolyte is dilute sulfuric acid. In order to charge this cell, it is connected to a source of direct current having a potential difference somewhat greater than the potential difference of the charged cell. As the current flows through the cell, the electrical energy supplied is transformed into chemical energy. Alternate plates become coated with brown lead peroxide (PbO_2) and have a positive charge. The other plates form spongy lead and have a negative charge. There is usually one more negative plate than positive plate in the cell.

For example, an 11 plate cell consists of six negative and five positive plates. Three such cells compose the ordinary 6 v. storage battery. The degree of charge is indicated by the specific gravity of the solution. A fully charged cell has a specific gravity of about 1.28. A storage cell, when properly discharged, may fall to 1.18 without injury.

Storage batteries should have good care. Distilled water should be added when necessary in order that the liquid covers the plates. The cells should not be allowed to stand in a discharged condition. In starting an automobile, a very large current (about 100 amp.) is drawn from the bat-

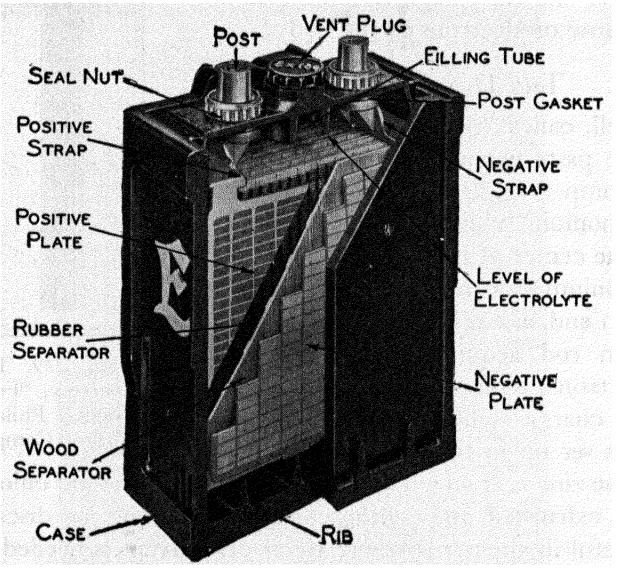


FIG. 240. A storage cell. (Courtesy, The Electric Storage Battery Co.)

tery for a short time. This current heats and warps the plates and may ruin the battery if the starter is used for more than a few seconds.

Another common cell in use is the Edison type. In this cell, we have iron oxide and nickel hydrate in a solution of potassium hydroxide.

LIGHTNING

As raindrops fall through the air, they acquire positive and negative charges due to the electrical field of the atmosphere. If these drops are driven upward by the rush of air, small negatively charged drops are broken off from the heavy positively charged drops. The negative drops form the top of the thunderstorm cloud and the heavy drops accumulate at the base of the cloud.

The result is a double cloud layer or separate clouds, the lower part containing a positive electrical charge and the upper part a negative charge (Fig. 241). Thus, a rapid uprush of air is essential to the production of

the electricity of a thunderstorm. Since a thunder cloud is caused by a very rapid evaporation of water and a subsequent accumulation of water droplets, the accompanying charge produces the lightning flash. Most lightning discharges take place from one part of a cloud to the other part or to an adjacent cloud of opposite charge. If the upper cloud rises to a great height, the discharge may take place between the lower cloud and the earth, which has accumulated a large negative charge underneath the cloud. (Occasionally the lower cloud has a negative charge.) The Empire State Building in New York City is struck many times each year. The discharge flows to the ground and does no harm to the building.

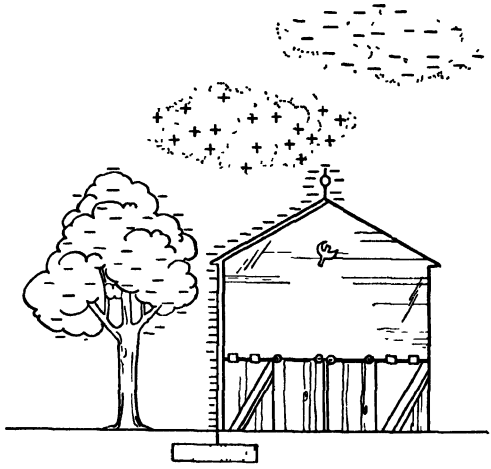


FIG. 241. Conditions which produce a lightning discharge. The lower cloud is positive and the upper negative. The ground, tree, and building have an induced negative charge. The discharge may take place either between the two clouds or between the cloud and building.

In order that a discharge may pass, the air must contain ions. One of the most difficult problems in the study of lightning is to account for enough ions to pass a flash several miles long. To produce these flashes, the potential difference between cloud and earth is of the order of millions of volts. A lightning discharge lasts for a time estimated to be from 0.002 to 1 sec. The current may be as great as 100,000 amp. (Fig. 242).

Most types of lightning are not well understood. Ball lightning has not received a satisfactory explanation and indeed many scientists doubt its existence. Sheet lightning is light reflected from distant clouds where flashes are occurring. The thunder which accompanies lightning has had many explanations, most of them ridiculous. The thunder is the noise caused by the compressional wave sent out by the rapidly heated air through which the discharge passes. The air expands, thereby causing an explosion. A good example is the explosion of a firecracker. When the

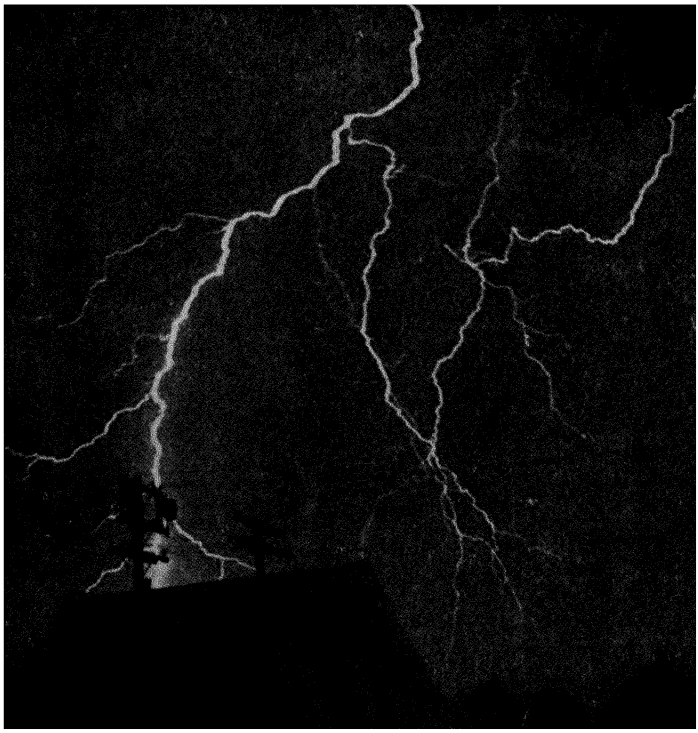


FIG. 242. A lightning flash. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

powder in the cracker burns, gases are formed which expand rapidly, blowing the paper container to bits. As as result, a wave travels out through the air and upon striking the ear gives us the noise.

Lightning rods have been the subject of much controversy. It is well established that they are of value only if they are carefully set up. A rod should be made of a good conductor and should have one end well connected to damp earth. Much of our modern information about the protective devices has been gained by the investigations of the General Electric Co., which has produced experimental flashes in the laboratory at a potential difference of 10 million volts. Some of the discharges were 60 ft. long (Fig. 243).

The lightning rod is valuable in that it has a pointed tip. From this pointed tip, the electrons from house and earth leak into the air, thus reducing the charge and the potential difference between the building and the cloud. In effect, we have a silent discharge, flowing into the air, which prevents the destructive heavy current of the flash. Nevertheless, because

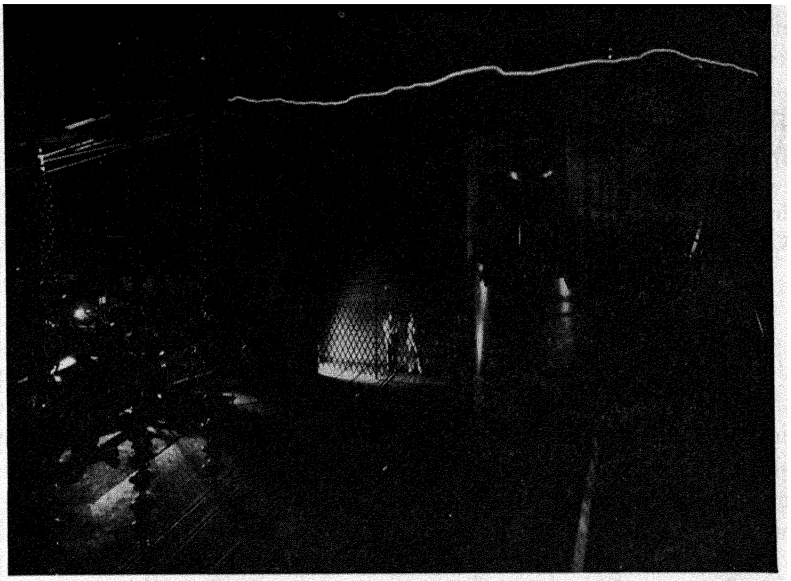


FIG. 243. A 10 million volt lightning flash. (Courtesy, General Electric Co.)

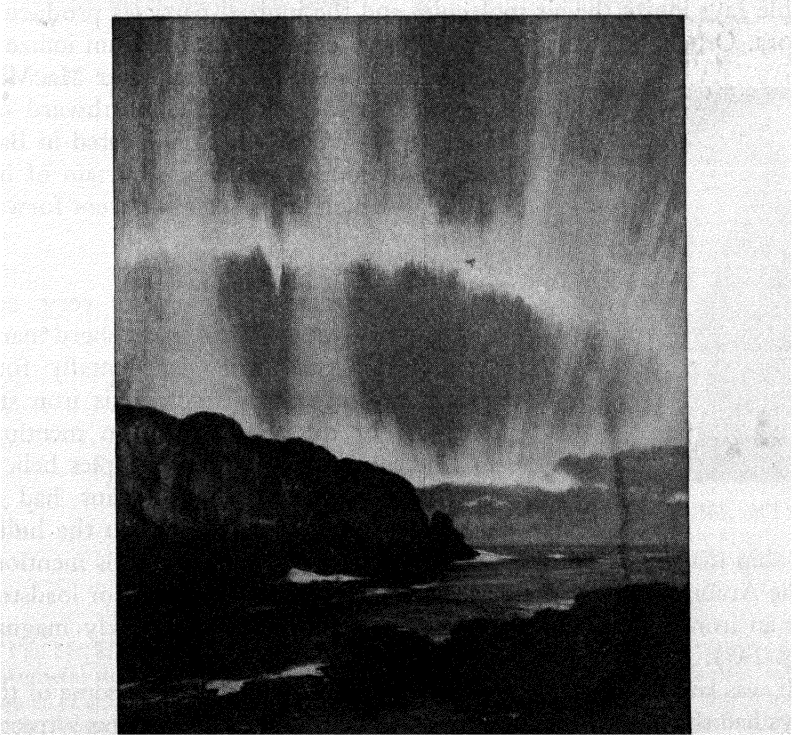


FIG. 244. The aurora borealis of August 12, 1919, as seen at Ogunquit, Maine. (Painting by Howard Butler Russell. Courtesy, American Museum of Natural History, New York.)

our knowledge of lightning is still incomplete, the presence of a lightning rod does not always make a building secure.

RULES FOR PERSONAL SAFETY

If possible, one should stay indoors where it is dry, away from chimneys, stoves, and metal objects.

In case one is caught out of doors, he should seek shelter in a deep valley, at the foot of a steep cliff, or in a dense grove of trees. An isolated tree is very dangerous.

Aurora

Another type of atmospheric electrical discharge is the aurora, called in the northern hemisphere the "Northern Lights." This is a peculiar glow in the region of the north and south magnetic poles, although the illumination is sometimes visible over a great part of the earth. The aurora resembles a curtain of light waving in the breeze (Fig. 244). The curtain is often curved like a horseshoe. Many colors of the spectrum are present although a greenish tint predominates. The spectrum is partly due to oxygen and nitrogen. One explanation is that the light is caused by ultraviolet rays shot out from the sun during a period of sunspots. These invisible rays ionize the air molecules and the ionized particles produce the aurora. Others believe that the electrons coming from the sun ionize the earth's atmosphere. The explorer MacMillan relates that as he travelled northward over the magnetic pole which is located in Baffin Land, the aurora was like a curtain of light through which he passed as he went forward.

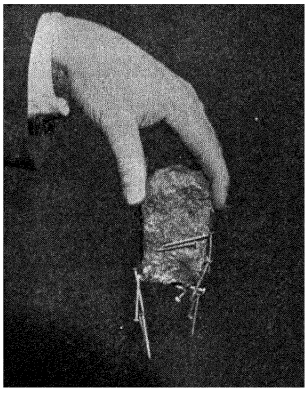


Fig. 245. Loadstone.

Magnetism

Magnetism was known in very early times. It is related that a shepherd named Magnus in Asia Minor accidentally found that a certain rock attracted his iron staff. The use of the compass is also mentioned in Chinese literature. Early peoples believed that certain magnetic mountains had the power of pulling the nails from the hull of any ship that sailed too close to the shore. Such a mountain is mentioned in the Arabian Nights. We now know this rock as magnetite or loadstone. It is an iron ore, an oxide (FeO–Fe_2O_3). This rock is weakly magnetic (Fig. 245).

It was later found that the metals iron, nickel, cobalt, and some of their alloys had the power of acquiring a magnetic property and thus attracting other pieces of magnetic materials. Modern research has shown that some

of these alloys produce very strong magnets. Such materials are used for wrapping ocean cables and for the magnets of radio speakers. Every child is familiar with the fact that a bar of magnetized steel will attract pieces of iron. Few persons realize that a complete explanation of this simple experiment involves a knowledge of the internal structure of magnetic materials that we do not yet possess. Magnetism is a very mysterious phenomenon.

It has long been known that the earth is a magnet (Fig. 246). It behaves as if a long bar magnet about 4,000 miles long were inserted in the centrosphere. Because we believe the earth to be intensely hot at the center, this simple explanation is not satisfactory, especially since red-hot iron is very weakly magnetic (paramagnetic). Perhaps currents of electricity traveling around the earth make the earth a magnet. Whatever the cause, the earth's magnetism makes possible the magnetic compass, which has guided man over the earth for centuries. A compass is a tiny magnet pivoted at the center. It points to the magnetic poles in the earth. Since

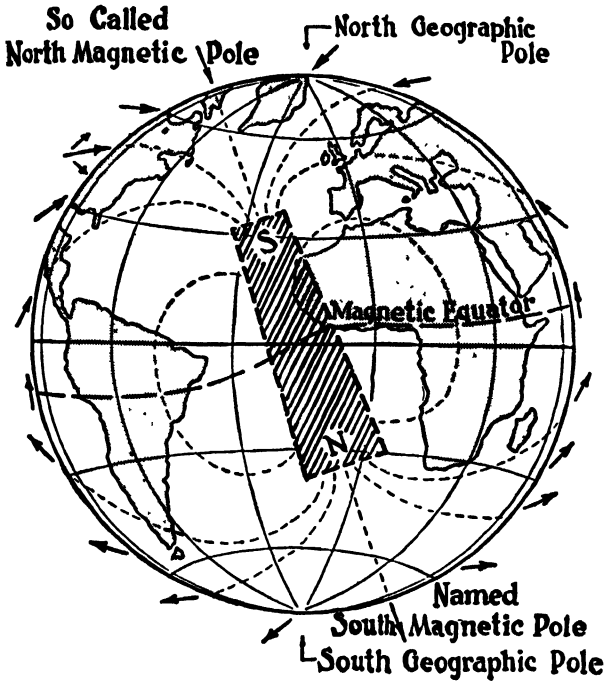


FIG. 246. If there were a huge magnet (N–S) buried in the earth, it would produce a magnetic field roughly similar to the earth's actual field. It is certain that no such magnet exists, but it is convenient to imagine it. Its N-pole is shown larger than its S-pole, because the lines of force in the southern hemisphere are more widely distributed than those in the northern hemisphere. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

these poles do not coincide with the geographic poles, a correction must be made by a mariner if he wishes to determine geographic north. The magnetic compass has been used recently to explode mines. The approach of a metal ship causes the needle to make an electrical contact in the bomb. Magnetic compasses are not very satisfactory when used in steel ships and in airplanes.

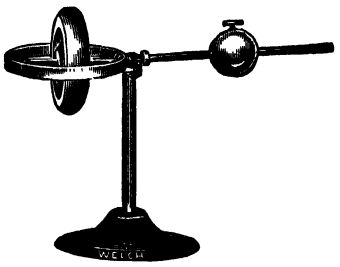


FIG. 247. The gyroscope. (Courtesy, Welch Mfg. Company.)

In modern times, the magnetic compass has been replaced largely by the gyroscopic compass (Fig. 247). This does not depend on the earth's magnetic property. From it one can determine geographic north.

ELECTROMAGNETISM

In 1819, a Danish scientist named Oersted discovered while lecturing to his class that a wire carrying a current had magnetic properties. Fig. 248 illustrates the experiment. The magnetic needle is placed under the wire. When current flows in the wire, the needle deflects because of the magnetism produced by the current. This important discovery gave the first clue to the meaning of magnetism.

As an interesting demonstration of the Oersted experiment, hold a long wire in a North-South direction about 1 in. above a compass needle. As a current of about 10 amp. is passed through the wire, the needle turns until it makes an angle with the wire. If the wire is now placed under the needle, the needle will reverse its direction.

We now believe that certain motions of electrons in the atoms produce magnetic properties. Since only iron, nickel, cobalt, and some alloys are strongly magnetic, it is probable that groups of atoms in these metals act as units giving the metals their property. Certain groupings are essential.

Fig. 249 (A) and (B) represents graphically a bar of iron with these discrete groups of atoms. We note that the magnetic directions of the groups are not uniform. As we apply a magnetic force to these groups, the magnetic poles of the groups tend to become organized. There is probably no actual readjustment of the atoms. Such motions would break up

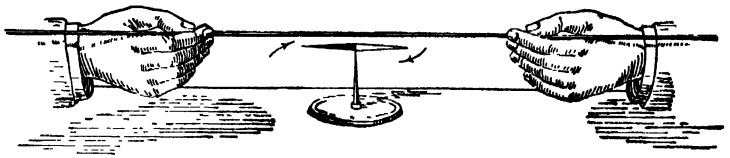


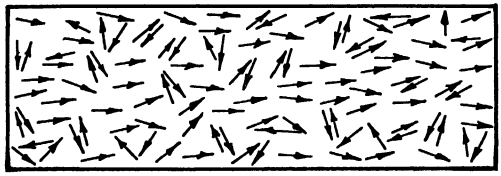
FIG. 248. The Oersted experiment. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

the metal. There is a change in magnetic property but not in structure. (Perhaps spinning electrons influence magnetic properties.)

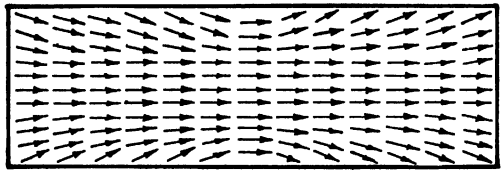
After the discovery of Oersted, men wound coils of wire on iron bars (Fig. 250), producing the electromagnet, one of the most useful tools in electricity. They are used in telephone receivers, loudspeakers, telegraph sounders, and electric bells. The surgeon uses an electromagnet to extract particles of iron from the eye.

Although there is a great gap between the tiny horseshoe magnet and the powerful magnets of the steel mill, we now know that the essential cause of magnetism is the electrons moving within the atoms of the metal.

On p. 10, it was noted that Hale discovered that sun-spots acted like huge magnets. He assumed that this magnetic property was due to the



A



B

FIG. 249. (A) A magnetic material in the unmagnetized condition. (B) The same bar in a magnetized condition. This sketch is based on theory and may not represent actual conditions in the metal. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

motion of an enormous number of electrons whirling about in the sun-spot.

Alternating Current

Up to this point, we have described a current of electricity as though the electrons always moved in one direction. However, most of our domestic sources of current use the alternating type. In this type, each pole of the generator is alternately positive and negative so that the electrons oscillate back and forth. Because the transformer operates with alternating current, as will be shown in the next chapter, this type is used generally in our lighting systems. The current reverses many times each second and is described as a 25, 40, or 60 cycle. Much of the apparatus

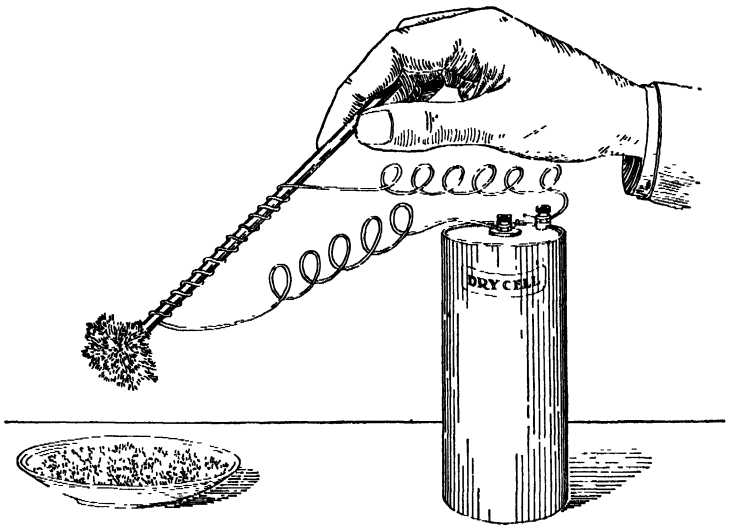


FIG. 250. A simple electromagnet. (Courtesy, Bowden: "Foundations of Science, Philadelphia, The Blakiston Company.)

to be described in the following chapter is of the alternating current type. A 60 cycle current means that the current flows in one direction for $\frac{1}{120}$ sec. and in the opposite direction for $\frac{1}{120}$ sec.

Thermions

A *thermion* is an electron which is produced by the action of heat. Such production is called *thermionic emission*. Were we able to see the particles in the interior of a lighted electric light bulb, we would find that the bulb contains many electrons which have "boiled" out of the white-hot tungsten filament. Likewise, when the filament of an electronic tube is glowing, electrons are in the bulb.

The basic principle of thermions was discovered by Thomas Edison while studying lamp filaments. He built a special electric lamp in which was inserted a platinum electrode having no internal connection to the filament. He found that electrons flowed from the filament to the electrode when the latter was connected to the positive pole of the battery. This was the predecessor of the modern radio tube (see p. 398).

REFERENCES

Collins: "A Book of Electricity," New York, D. Appleton-Century Co.
Croft: "Practical Electricity," New York, The McGraw-Hill Book Co.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
McCabe: "The Marvels of Modern Physics," New York, G. P. Putnam's Sons.
Saunders: "A Survey of Physics," New York, Henry Holt and Co.

Questions and Problems

1. What is the cause of the earth's magnetism?
2. How could you prove the earth to be a magnet?
3. What is the difference between static and current electricity?
4. Why do gasoline trucks often drag a chain?
5. Explain the operation of a lightning rod.
6. Explain the difference between the action of a storage battery and a dry cell.
7. A lamp is marked 25 w. 120 v. Explain what is meant.
8. A 6 v. storage battery is connected to a 30 ohm lamp. What current will flow? Answer. 0.2 amp.
9. What is the meaning of the term ampere?
10. What is: an insulator? a conductor?
11. Why not light the house with the automobile battery?
12. What is: a watt? a kilowatt-hour?
13. What causes thunder?
14. What is the cause of lightning?
15. What is the cause of the aurora?
16. For how many hours can we operate a toaster for the cost of 20¢? (In the calculation use the rate in your locality.)
17. Calculate the cost of operating a flat-iron for 10 hrs. if the rate is 10¢ per kwhr. Answer: 55 cents.
18. If the 120 v. socket is "shorted" by a wire of $\frac{1}{10}$ ohm resistance, what will be the current? Answer: 1200 amp.
19. Where is the safest location when lightning discharges are occurring?

Visual Aid

"Zeus," General Electric Co. film on lightning

Topics for Discussion

Boxing a Compass	The Atlantic Cable	Permalloy
Aurora Borealis	Ball Lightning	The Gyrostatic Compass

Experiments

1. Connect a dry cell, a rheostat (resistance), a key, and an ammeter in series. Read the ammeter. Vary the rheostat and note the effect on the ammeter reading. Does your result agree with Ohm's Law?
2. Connect a dry cell to a voltmeter. Read the potential difference.
3. Connect a cell, an ammeter, a key, and a rheostat in series and connect the voltmeter directly to the cell. Record the potential difference and the current for three values of the resistance. From the readings, calculate the values of the resistances by means of Ohm's Law.
4. Connect a cell, a key, an ammeter, and two resistances in series. Adjust the rheostats to one of the positions used in experiment 3 and note the effect on the current.
5. Using a lamp bank connected to the lighting circuit, connect an ammeter and a voltmeter to the circuit. Read the potential difference and the current through the lamp. Compute the resistance of the lamp. Repeat with two lamps in parallel. Use a toaster or iron. Calculate the watts for both the lamps and toaster.
6. Cut a dry cell in half and examine its structure.

7. Examine the plates of a discarded storage cell.
8. Cover a bar magnet with a sheet of paper and dust iron filings over the paper. The arrangement of the filings illustrates a magnetic field. Repeat the experiment with a horseshoe magnet. (If blueprint paper is available, make a permanent record of the filings.)

Note: Have the instructor check each wiring arrangement before you press the key. This precaution will prevent damage to the meters in case there is a short circuit.

26. ELECTRICITY IN OUR DAILY LIFE

Electricity, carrier of light and power, devourer of time and space, bearer of human speech over land and sea, greatest servant of man.
—CHARLES ELIOT

In the previous chapter, various fundamental principles of electricity were interpreted and a few pieces of electrical apparatus were described. We shall now describe some of the more modern methods for the production and utilization of electrical energy. Because a complete explanation of modern motors and generators belongs in a text in electrical engineering, it will be necessary to describe such machinery very briefly. There are many excellent texts to which the interested reader can turn for a more detailed description.



FIG. 251. A commercial electromagnet. *A*, *B*, and *C* are pole pieces. (Courtesy, Central Scientific Company.)

Historically, modern electrical engineering may be said to have begun with the discovery by Oersted that a wire carrying a current of electricity acts like a magnet (see p. 378). Electrons in motion produce magnetic fields. As has been said, Oersted held a wire, through which a current was flowing, over a compass needle and found that the wire had the properties of a magnet. The magnetic effect became stronger as the current was increased. If we bend the wire into a circle, the magnetic field will be strongest at the center. To further increase the strength of the field, we may wind a coil of many turns. With such a coil, a small current will produce a strong magnetic field. We may state this more accurately by saying that the field strength depends upon the number of turns and the number of amperes flowing in the coil. If the turns are distributed in the form of a spiral or helix, we have a coil having poles like a bar magnet. If, in addition, we place inside the coil a bar of soft iron, we have an electromagnet which is much more effective than a bar magnet (Fig. 251). The great advantage of such a magnet is that the magnetic property disappears when the current is turned off, since soft iron does not retain strong magnetism after the current has stopped. Some of the common uses for the electromagnet are in doorbells, in telegraph sounders, in lifting magnets, in surgical magnets, in automobile horns, in motors, in generators, and in transformers.

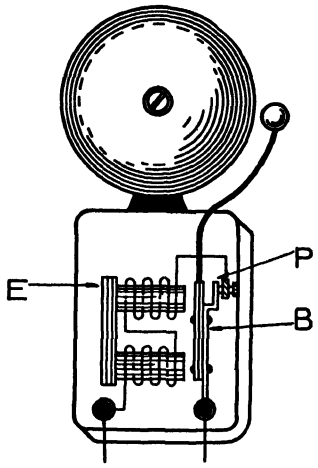


FIG. 252. The electric bell.

The doorbell has an electromagnet bent in the form of a U (Fig. 252). A bar of soft iron (*B*) is hinged above the magnet, being held in place by a spring. When the push button on the door is pressed, the circuit is completed and the magnet (*E*) attracts the bar (*B*). As the bar moves toward the magnet, it strikes the bell and at the same time the circuit is broken at *P*. The bar now flies back, closes the circuit, and is again pulled toward the magnet. The process continues as long as the push button is pressed.

In 1831, Michael Faraday (Figs. 253 and 254) made the very important discovery which made possible all of our present electric age. Inasmuch as Oersted had found that an electric current (electrons in motion) could produce a magnetic field, Faraday reasoned that, in some way, magnetism ought to produce electricity. In the course of his experimentation, he found that when a circle of wire was moved back and forth between the poles of a horseshoe magnet, a current flowed in the wire as long as the wire was moving (Fig. 255). While the wire was being pushed in, a current flowed in one direction. When the wire was being pulled

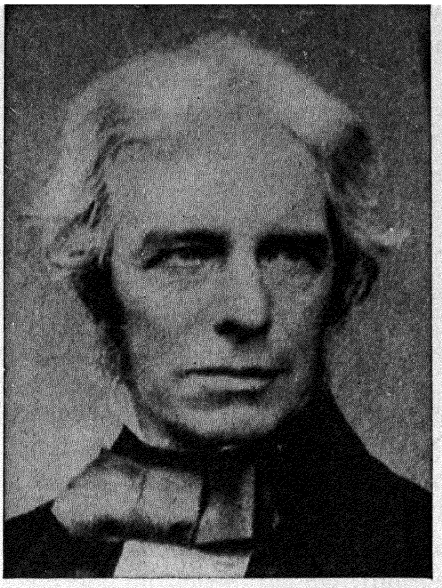


FIG. 253. Michael Faraday (1791–1867). One of the greatest of scientists. Discovered the laws of electrolysis, of induced currents, and of the relations of magnetism and light. (Courtesy, "Hackh's Chemical Dictionary," Philadelphia, The Blakiston Company.)

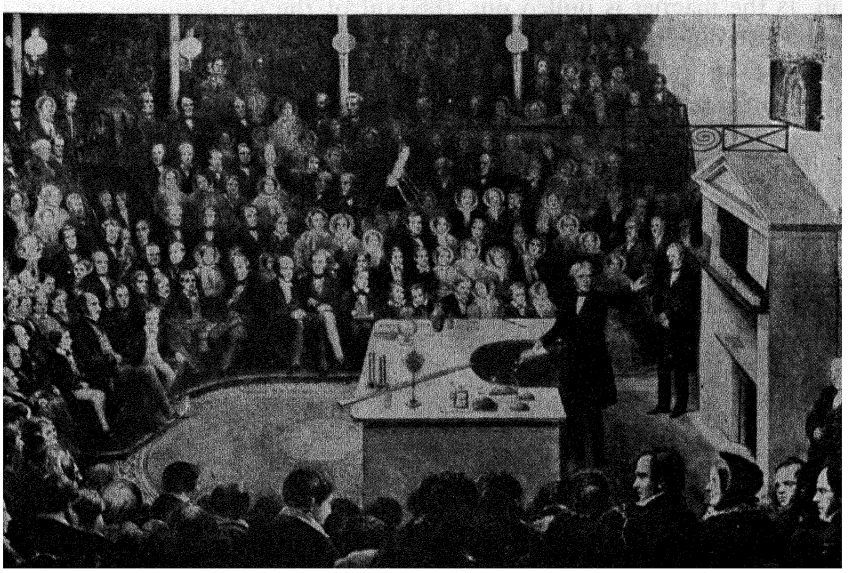


FIG. 254. Faraday lecturing to the Royal Society. (Courtesy, Central Scientific Co.)

out, a current flowed in the reverse direction. He also noted that there was no current in the wire when there was no motion. In order to observe the current, he connected the wire to a current-measuring instrument called a galvanometer. In the drawing, it will be noticed that with the north pole of the magnet underneath the wire, a motion of the wire inward causes a current to flow toward the right. When the wire is

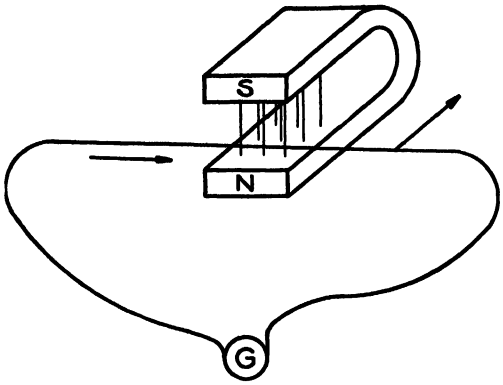


FIG. 255. *N* and *S* represent the poles of the horseshoe magnet. *G* is the galvanometer.

pulled out, a current flows to the left. If a coil of wire and a bar magnet are used as shown in Fig. 256, the same effects are observed. When the magnet is thrust into the coil, the galvanometer coil moves in one direction. If the magnet is pulled out, the coil of the galvanometer moves in the reverse direction. The motion of the magnet in and out causes a current to flow in two directions, thus constituting a cycle. As we have stated in the preceding chapter, this is called an alternating current.

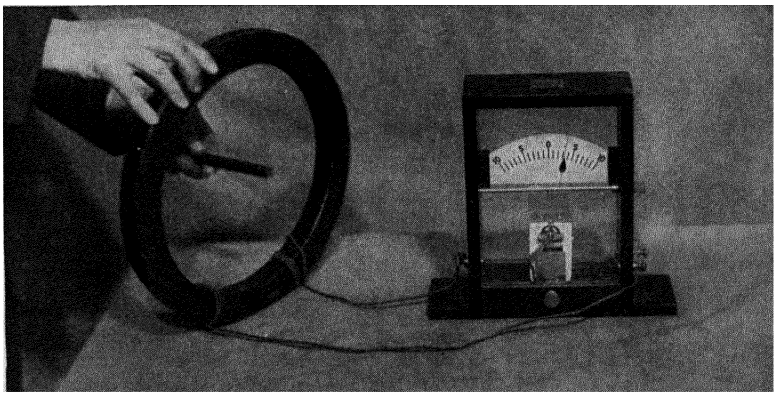


FIG. 256. A current induced by means of a bar magnet. Motion of the bar magnet to and fro induced an alternating current in the coil.

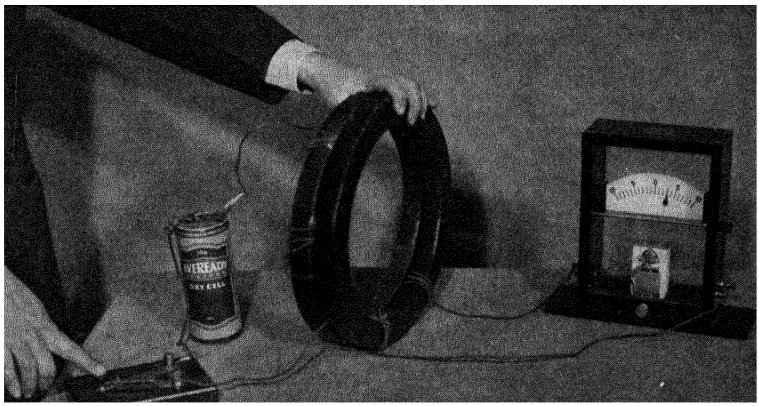


FIG. 257. Induced currents. The secondary coil is connected to the galvanometer. The primary coil is connected in series with a dry cell and a key. At the instant the key is pressed and released, a momentary current flows in the galvanometer.

If an electromagnet is used instead of the bar magnet, we get the same result. Moreover, a varying current in the electromagnet is just as effective as a moving magnet. The transformer utilizes this principle (Fig. 257).

A valuable method for the study of electromagnetic induction is to perform the experiments described below in the following order: Initially, thrust a straight wire which is connected to a galvanometer between the poles of a horseshoe magnet and note the deflection. Next, coil the long wire into a helix and thrust the bar magnet into the coil. Reverse the magnet and repeat.

Replace the bar magnet by an electromagnet. Open and close the circuit in the electromagnet.

It is hard for us to realize in these modern days that commercial electricity was unknown until about 1880. Before this time, only chemical batteries were available. Experimentation in electricity was slow for many years until stimulated by the demand for electric lighting. Although Michael Faraday in England and Joseph Henry in the United States discovered the fundamental principle of the generator, other inventors made the machine practicable. In the year 1860, only copper bars were available, copper wire being unknown. The copper bars were wound with strips of cotton cloth for insulation. The first generator made in the United States was constructed of these hand-insulated bars.

THE TRANSFORMER

In most forms of this machine (Fig. 258), two entirely separate coils of wire, one called the primary and the other the secondary, are wound on a common iron core. As the alternating current flows in the primary, an alternating current of the same frequency (cycles per second) is

produced (induced) in the secondary. It is not necessary that the current in the primary be alternating as long as it is varying. An example of this is the induction coil.

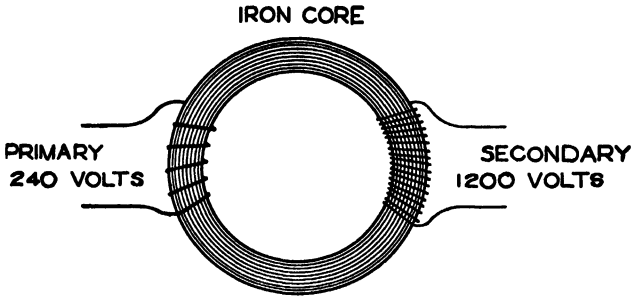


FIG. 258. Sketch of a transformer.

Since the transformer is a machine, we shall discuss it in terms of power. For an efficiency of 100 per cent, the watts output at the secondary would equal the watts input at the primary, or, in other words, the volts times the amperes in the primary would equal the volts times the amperes in the secondary. It will be noted that in Fig. 258 the number of turns of wire on the secondary is 5 times the number of turns on the primary. This means that 240 v. on the primary produce 1,200 v. on the secondary.

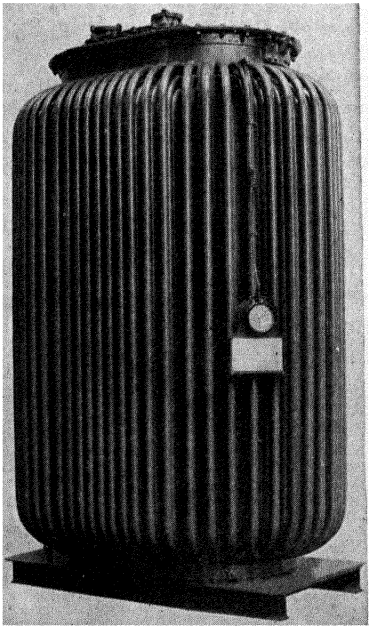


FIG. 259. A commercial transformer. (Courtesy, General Electric Company.)

$$\frac{\text{Turns primary}}{\text{Turns secondary}} = \frac{\text{Volts primary}}{\text{Volts secondary}}$$

If the transformer is a 12,000 w. machine, the maximum safe current will be 12,000/240 or 50 amp. In the secondary, the maximum safe current would be 12,000/1,200 or 10 amp. Such a transformer is said to be of the step-up type. (Actually, the efficiency is about 98 per cent, so that the watts output will be somewhat less than the watts input.) Because of the fact that a transformer is a machine that has no moving parts, it is one of the most efficient of all machines.

There are many applications of the transformer principle. The power

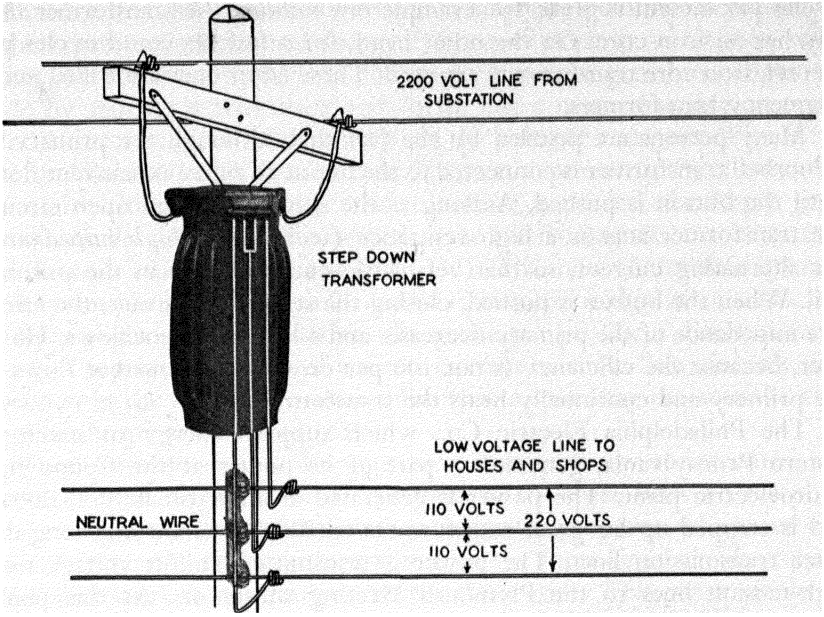


FIG. 260. A step-down transformer. (Courtesy, Heil: "The Physical World," Philadelphia, The Blakiston Company.)

company often wishes to step-up the voltage so as to transmit power economically over long distances. Large transformers (Fig. 259) designed for this purpose are familiar sights at power stations and along electric railways. In the high tension wires, which are supported on tall towers, the potential difference may be as high as 250,000 v. The higher the voltage for a given power distribution, the smaller the current. In consequence, the heat loss is less and greater economy results. The upper limit to the usable voltage is set by the insulators and supports. With very high voltage, a corona discharge[1] takes place through the air, thereby causing a loss of power.

One very important use for the transformer is in house lighting. The potential difference between the wires on the street poles is several thousand volts. Since this voltage would be dangerous in the house, a transformer is hung on the pole near the house (Fig. 260) and the potential difference is stepped down to 110 v. or, in some cases, to 220 v. Toy transformers transform 110 v. to 6 v. or less.

Transformers are also used on radio sets. Here, they are employed to increase the voltage, or current, or both. The frequency of the alternating current determines the type of transformer used. If the number of

[1] Corona discharge causes the blue glow seen at night around high-tension wires.

cycles per second is great, for example one million, the transformer usually has no iron core. On the other hand, for a few thousand cycles per second, iron core transformers are used. These latter ones are called audio frequency transformers.

Many persons are puzzled by the fact that, although the primary of a doorbell transformer is connected to the line at all times, no current flows until the button is pushed. As long as the secondary is an open circuit, the transformer acts as a high resistance (technically, *high impedance*) for alternating current, so that very little current flows in the primary coil. When the button is pushed, closing the secondary circuit, the effective impedance of the primary decreases and a larger current flows. However, because the efficiency is not 100 per cent, a small current flows in the primary and continually heats the transformer.

The Philadelphia Electric Co., which supplies energy to much of eastern Pennsylvania, generates a part of its power at the Conowingo hydroelectric plant. The power is generated at approximately 13,200 v. and is stepped-up by great transformers to 220,000 v. for the long-distance transmission lines. The power is transmitted at this voltage over high-tension lines to the Plymouth Meeting substation. At this point, there are 220,000 v. connections between the Philadelphia Electric Co. and the systems of the other power companies of the district. Part of the power is stepped-down to 66,000 v. for distribution to Philadelphia and the surrounding territory. At Philadelphia, the voltage is again stepped-down to 13,200 v. for substation supply and also to 2,300 volts for the street lines. Similarly, in the suburban territory, the voltage is stepped-down to 33,000 for substation supply and also to 4,400 for the street lines. For domestic use, there is a further step-down to 115 v. for safe house use. Because of the heat loss, there is a 6 per cent loss of energy in the long transmission system from Conowingo to Plymouth Meeting. Were it not for the high voltage, there would be a much greater loss. On p. 367 it was stated that the heating effect of the electrical current is I^2Rt where I is the current, R the resistance, and t the time in seconds. It is evident that economic transportation of electric power requires that the current be as small as possible. Hence the need for high voltage.

Were we to transmit 10,000 w. at 100 v., the current would be 100 amp. However, if the voltage is 10,000, the current is only 1 amp. Since the rate of heat loss is I^2R, the loss at the low voltage of 100 is 10,000 times that at the high voltage of 10,000.

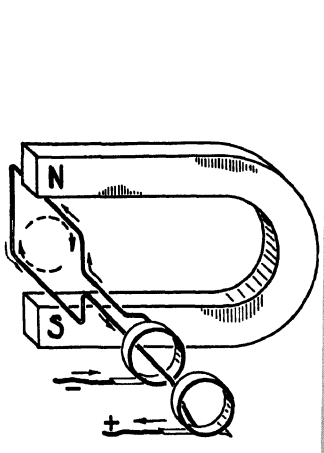
The Generator

To produce an alternating current, a machine called a generator or alternator is used. This is a device for converting mechanical energy into electrical energy. Its principle is a direct application of the discovery

of Faraday that the motion of a wire in a magnetic field produces energy at the expense of mechanical energy. The work done in moving the wire causes the electrons to flow in the wire. A simple generator might be made by moving a wire back and forth, but a more desirable arrangement is to rotate a coil of wire between the poles of a magnet (Fig. 261). The coil (armature) is turned either by water power or by a steam or gas engine. Inasmuch as only relative motion is needed, the larger generators are designed in such a way that the electromagnet (rotor) rotates and the coils (stator) are at rest (Fig. 262). The most common frequency is 60 cycles per sec., although 25 and 40 cycles are used in some cases.

By a slight change in design, the generator produces direct current (d.c.). The current output of a direct current machine flows in only one direction in the circuit. To accomplish this, a split ring replaces the two rings of the generator (Fig. 263).

To explain the action of a generator, it is necessary to introduce the idea of lines of magnetic force. We think of the space between the poles of the magnet as being filled with a magnetic property which we call lines of force. When the wire is thrust in, the force lines act like rubber bands and work is necessary to thrust them aside. This work results in



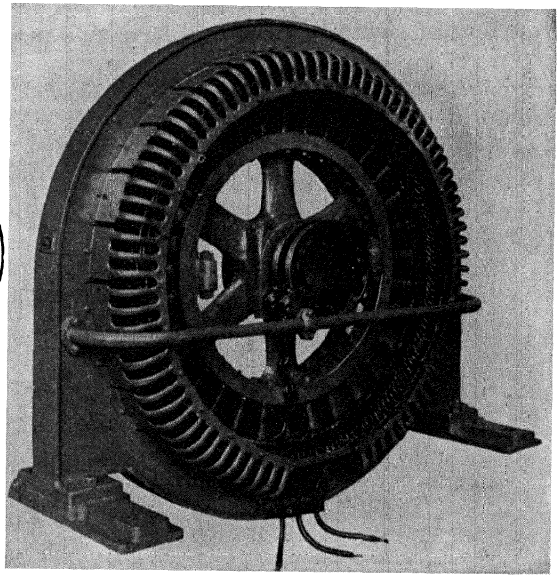
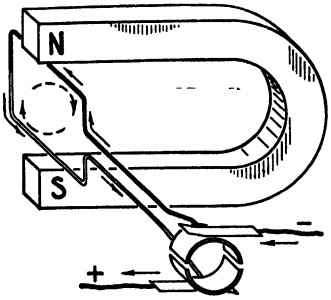


FIG. 261. (*Left*) Essentials of an alternating current generator, *N* and *S* represent magnetic poles. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

FIG. 262. (*Right*) An alternating current generator. (Courtesy, General Electric Company.)



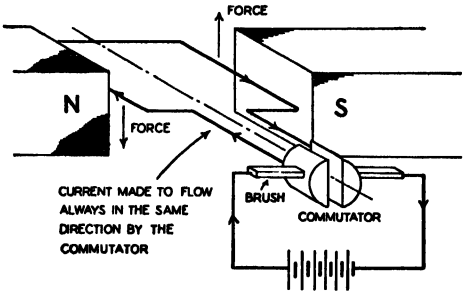


FIG. 263. (*Left*) Essentials of a direct current generator. *N* and *S* are poles of the horseshoe magnet. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

FIG. 264. (*Right*) A direct current motor. *N* and *S* represent magnetic poles. (Courtesy, Heil: "The Physical World," Philadelphia, The Blakiston Company.)

electron motion in the wire. The voltage produced in the wire depends on the speed with which we cut lines of force.

THE ELECTRIC MOTOR

To understand the principle underlying the motor, we must recall the discovery of Oersted that a wire carrying a current acts like a magnet. If we place between the poles of a horseshoe magnet a wire carrying a current of electricity, we will have two magnets acting on each other. As

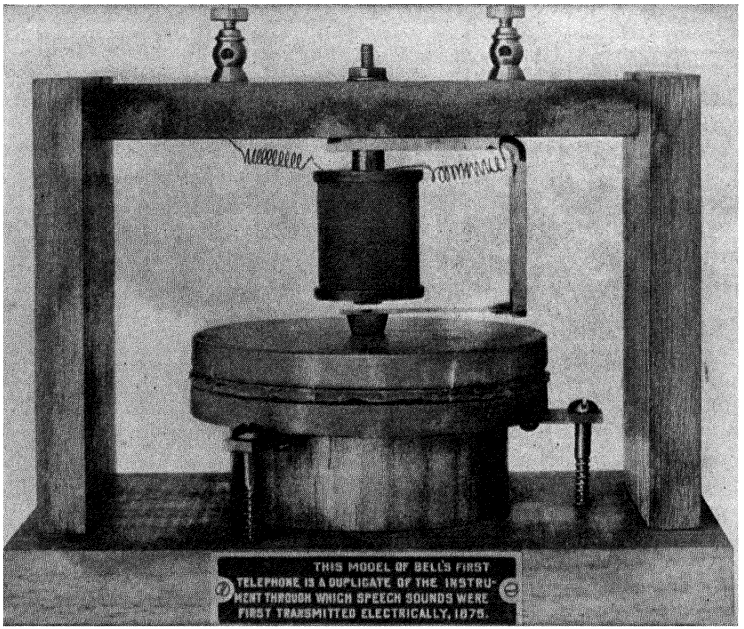


FIG. 265. Model of the original telephone. (Courtesy, Bell Telephone Co.)

a consequence, the wire will move in the field. The combination of a magnet and a wire carrying a current constitutes a motor. In Fig. 255, if the north pole of the magnet is underneath the wire, and if a current is flowing toward the right, the wire will be pushed forward. Instead of a straight wire, we usually use a coil rotating between the poles of a magnet. In Fig. 264 we see that the side of the coil moving down has a current moving into the page. The side moving up has a current moving out from the page. This causes a rotation and, by the addition of a commutator (split ring), the current can be caused to flow in such a way that the direction of rotation of the coil is continuous. The moving coil is called the *armature* and the magnet is called the *field.*

Heating Apparatus

A very important application of electricity is its use in heating devices. These pieces of apparatus contain some materials of high resistance; the flatiron and toaster contain a ribbon of the alloy chromel; the electric range often uses a mixture of iron and carborundum. Electrical heating devices are rather expensive to operate and at ordinary house rates usually cost more than other heating methods. Electricity at 1¢ per kwhr. has the same heating value as coal at about $30.00 per ton.

The Telephone

In 1870, Alexander Graham Bell invented a device by which he was able to transmit his voice to an adjoining room. The first historic words were "I want you, Watson." This first telephone was very crude (Fig. 265) and was improved by Edison, who devised the modern carbon grain transmitter.

The telephone transmitter (*T*) (Fig. 266) consists of a loose mass of granulated carbon (*C*) between two carbon blocks, one fixed and the other movable and fastened to the iron diaphragm (*D*). The sound energy of the voice causes the diaphragm to vibrate. This motion varies the pressure on the carbon grains. As a result, the resistance of the carbon changes, becoming lower as the pressure increases, and thus producing a varying

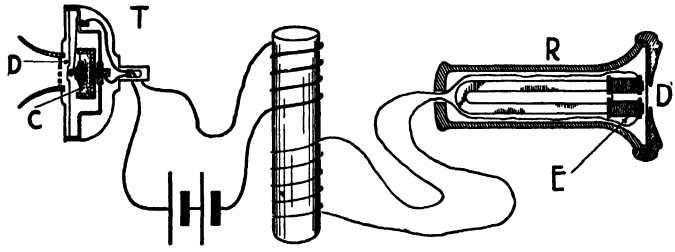


Fig. 266. Simplified diagram of a telephone circuit with a carbon-granule transmitter (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

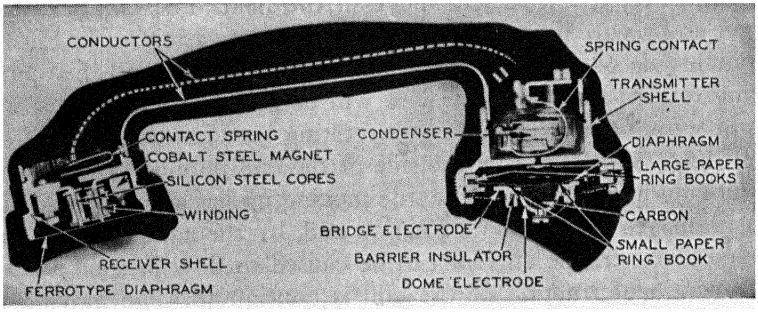


FIG. 267. The hand telephone. (Courtesy, Bell Telephone Co.)

current in the line. The varying current actuates the electromagnet in the receiver or earpiece (R). The receiver is a horseshoe magnet with an electromagnet wound on the poles. In front of the poles is an iron diaphragm (D). The varying current causes a varying magnetic field in the electromagnet (E) and this field pulls the iron plate back and forth, thereby reproducing the original sound. All carbon microphones and some magnetic speakers resemble this type of telephone. Fig. 267 shows the construction of the modern hand telephone.

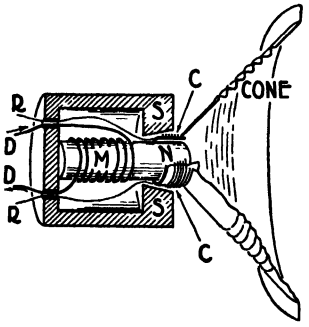


FIG. 268. Dynamic speaker. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

Early magnetic loudspeakers were limited in their output of energy. When the amount of energy delivered was too great, the quality of the tone became unsatisfactory. A modern type of speaker is the dynamic type. In this speaker (Fig. 268), there is an electromagnet (NS). Around this magnet is wound a coil of wire (C and R). As the varying current (D) flows in the coil, the coil moves back and forth and an attached paper cone is set into vibration. Many modern speakers of this type have a permanent Alnico magnet instead of the electromagnet.

ELECTRICAL RADIATIONS AND RADIO

One of the most amazing results of scientific research is the frequency with which some laboratory experiment becomes of great scientific importance and commercial value. Radio may be said to have been born in the brain of Clerk Maxwell (Fig. 269). Maxwell was a mathematical physicist who, in the course of his studies, became convinced that light was a form of electromagnetic radiation. He reasoned that if this were true, there ought to be a type of electrical radiation which could be sent from place to place in the same way that light travels. During the course of

his calculations, he devised a model of an ether in which these waves of electrical energy could travel. In this he followed the initial ideas of Faraday and Newton.

In 1888, Heinrich Hertz first produced these radiations in the laboratory and was able to send them from one room to another. He constructed the first wireless transmitter and receiver.

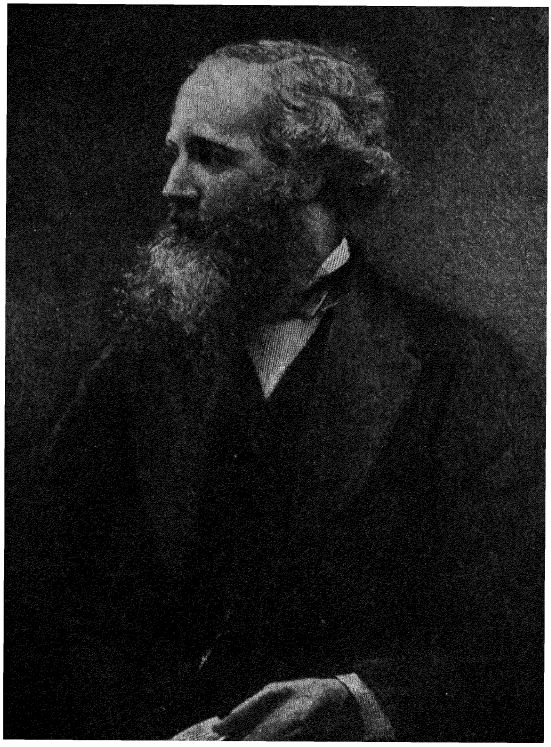


FIG. 269. James Clerk Maxwell (1831–1879). A famous physicist and mathematician; one of the originators of the theory of electromagnetic waves. (Courtesy, Millikan, Gale, and Edwards: "A First Course in Physics for Colleges," Boston, Ginn and Co.)

Before describing the experiment of Hertz, we shall explain the meaning of the term *oscillation.* In order to do this, we shall use the pendulum as an illustration. If we suspend a ball from a cord and pull it aside and allow it to swing, it will return to its original position, overshoot the mark, and swing up the other side of its path. As the swings continue, the size of the swings (amplitude) slowly decreases and the ball will come to rest. This type of motion is called a *damped oscillation.* The pendulum has lost its energy as it moved to and fro. On the other hand, in the clock

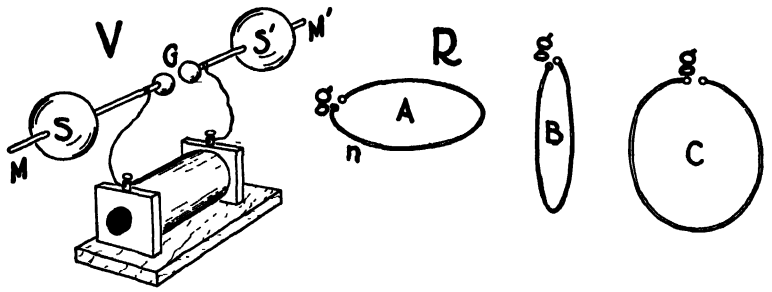


FIG. 270. The type of apparatus used by Hertz. *V* represents the transmitter; *R* is the receiver in three positions, *A*, *B*, and *C*. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

pendulum all oscillations are maintained by the spring or weights, so that all of the swings have the same amplitude. The number of vibrations per second is the frequency. In the pendulum, the energy alternates between the potential and kinetic forms as the pendulum swings.

Let us suppose that we have two balls S and S′ connected to rods (Fig. 270) so that a small gap exists between the rods. If we connect the rods to a source of high potential, one ball will acquire a negative charge and the other a positive charge. When the charge becomes too great, a spark will jump the gap (*G*) and the balls will lose their charge. However, a rotating mirror will show that the balls discharge again but in the opposite direction. This charging and discharging will continue for a small fraction of a second until the energy stored up in the balls is used up as heat, or is radiated out into space as electromagnetic waves. The high voltage source charges the balls again and the process is repeated. These rapid reversals of charge produce damped oscillations (Fig. 271). We find that all electric sparks, including lightning discharges, are oscillatory, the frequency usually being very high. The energy is alternating between the electrical (potential) and the magnetic (kinetic) forms. Radio frequencies are expressed in kilocycles per second or megacycles per second.[2]

Hertz used two plates between which there was a spark gap. His plates were charged by an induction coil. At the other side of the room, he used a loop of wire having a small adjustable gap. He found that sparks jumped the gap of his loop whenever there was sparkling between the balls of the sending system. Each time a spark jumped the gap, oscillations were set up between the plates and, as a result, electrical waves passed out from the apparatus. He found that the waves could be reflected and refracted, thus proving that they had similar properties to light waves. Actually, the system consisted of a condenser, a spark gap, and an inductance. If the condenser and the inductance are large enough,

[2] A megacycle is one million cycles.

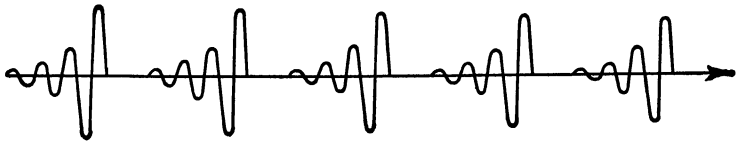


FIG. 271. Damped oscillations. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

we find that the spark has a musical note, indicating that the frequency is in the audible range. By adjusting the value of the inductance or the capacitance of the condenser, we can change the pitch of the note.

Marconi made possible long-distance transmission and reception of electric waves. He used an antenna for one plate. A plate imbedded in the ground was a substitute for the other plate of the Hertzian apparatus. By means of his apparatus, he was able in 1910 to send signals from England to Newfoundland. Such damped oscillations were rather difficult to maintain. With the invention of the vacuum tube (audion), a series of undamped waves (C.W.) could be sent out from a transmitter. Two outstanding scientists in this field were Ambrose Fleming and Lee DeForest. To these men we owe the invention of the modern electronic tube.

Actually, there are three essential parts of every modern electrical oscillator, a condenser, C (Fig. 272), an inductance, L (Fig. 273), and a vacuum tube. The frequency of the oscillations is determined by the following equation:

$$\text{Frequency} = \frac{1}{2\pi\sqrt{LC}}$$

If, for example, the inductance L is 0.0001 henry, and the capacitance is 500 micro-micro-farads (500×10^{-12} farad), the frequency emitted will

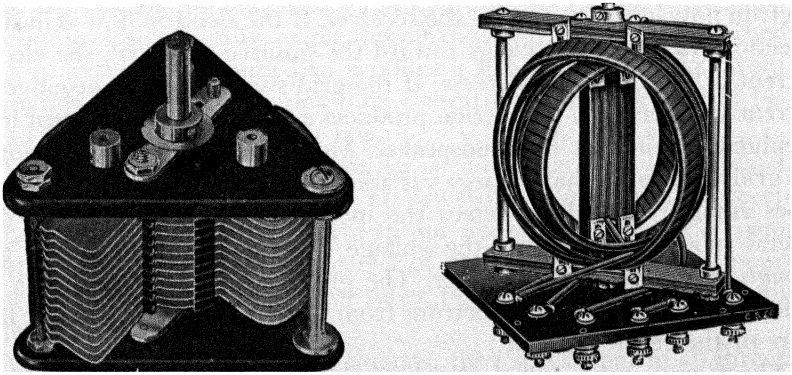


FIG. 272. (*Left*) Condenser of variable capacity. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

FIG. 273. (*Right*) A variable inductance. (Courtesy, Weld and Palmer: "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

be about 730,000 cycles per sec. or 730 kc. per sec. To reduce this to wave length, divide the velocity of electrical waves, 3×10^8 meters per sec., by the frequency, 73×10^4. The result is 410 meters. Such a wave is in the broadcast band. The longest electrical waves are several miles in length and the shortest have a length of about $\frac{1}{25}$ in. (see p. 199).

THE RADIO TUBE

The triode (three element tube) consists of a source of electrons, a plate which collects them, and a grid which regulates the electron flow. In Fig. 274, *F* is the emitter, *G* the grid, and *P* the plate. The "*A*" battery lights the filament and the "B" battery is the potential source for the plate current (Fig. 275). In the previous chapter, mention was made of the discovery of thermions—electrons emitted by heat. Later, it was discovered that the emission of electrons is much more copious when the metal is coated with such a material as barium carbonate. The coating makes electron emission possible even with the emitter at dull red heat.

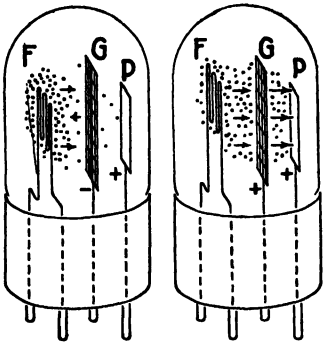


FIG. 274. Sketch of a radio tube. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

A current flows in the circuit as a result of the electrons moving across the space between the emitter and the plate. The wire mesh *G*, the grid, influences the flow of electrons. If it is at a positive potential, it will tend to increase the electron flow. When it is sufficiently negative with respect to the emitter, it may stop the current entirely. The electric waves from the broadcasting station produce a rapidly alternating electron flow in the antenna of the receiver. If the electron flow is in such a direction that the grid swings toward the positive potential, the electron current in the tube will increase. If the grid swings further negative, the current will decrease. The action produces a varying direct current in the telephone receiver or the loudspeaker. Moreover, the slight variations in the grid voltage produce a large variation in the plate current, so that the tubes amplify as well as detect the incoming radio current. By using several tubes in succession, the voltage and power can be made great enough to operate a loudspeaker. The grid may be compared to a gate which controls the flow of electrons from the emitter to the plate. It is the heart of the receiving tube.

The vacuum tubes called tetrodes and pentodes contain more than one grid. These grids, called screen, suppressor, and control, have certain effects which make the tubes much more sensitive than the triode tube. Whereas the triode (01A) has a voltage gain of about 5, the screen grid

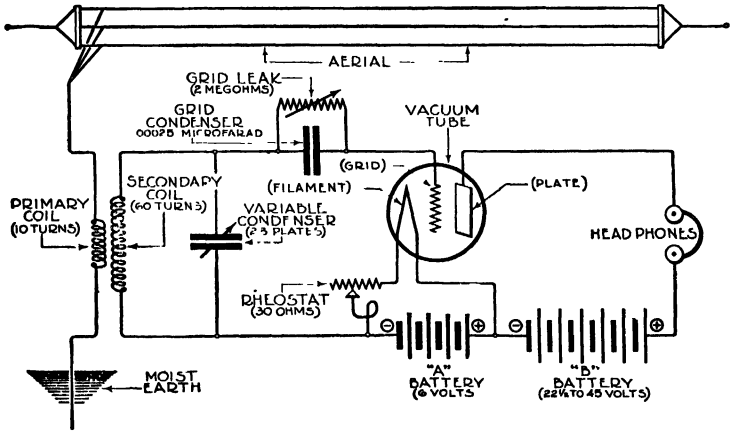


FIG. 275. Sketch of a one tube receiving set. (Courtesy, Bowden: "Foundations of Science," Philadelphia, The Blakiston Company.)

tube (24A) has a voltage gain under certain conditions of nearly 600. This is one of the reasons why the modern receiver has a very high sensitivity, although the number of tubes is less than the number in the receivers of a decade ago.

With the advent of radio, people wished to be able to operate the set from the alternating current of the home. For several years, this was not possible because the alternating current produced a loud hum in the receiver which made clear reception impossible. Since it was realized that the only function of the filament was to emit electrons, it was found possible to place the filament in a nickel alloy (konel) sleeve coated with the oxides of barium and strontium. The filament, heated by alternating current, heated the sleeve, which in turn became a steady emitter of electrons. Because of the necessity of heating the sleeve, the usual radio set does not go into operation at the instant the filament current is turned on. Devices were also perfected to produce a steady plate voltage from the alternating current. From this time forward, the receiver could be operated from the house current line.

Within the last 15 years, there has been a remarkable improvement in radio receivers. A great number of new tubes with excellent reception properties has brought the world to our doors. One need only compare the receiver of 1949 with the receiver of 1934 to realize the great improvement in reception. We find fewer tubes, better tone quality, and simplified tuning.

When radio waves leave an antenna, they spread out in all directions, as shown in Fig. 276. Part of the energy travels along the ground (ground wave). The balance is radiated out into space, whence some of it is reflected back to earth by the ionosphere. The ionosphere consists of sev-

eral layers of electrons and positive ions. When a radio wave strikes these layers, its direction may be changed and it may return to the earth as a reflected wave.

In the case of low frequency waves, 50 to 500 kilocycles per sec., the ground wave travels great distances with little loss. The sky wave is somewhat variable, depending on the time of day and the height of the ionosphere.

The ground wave of the broadcast band (550 to 1,500 kilocycles) has a range up to 200 miles, which gives constant reception at any time of day or night. The sky wave is absent in the daytime but it gives long distance reception at night.

The short-wave band—200 meters to 10 meters (1,500 to 30,000 kilocycles) has no ground wave but has an extremely long-range sky wave which is quite dependable. International broadcasts and amateur transmission are in this band.

The waves of the microwave band (100 to 30,000 megacycles per sec.) travel in straight lines, being neither ground wave nor sky wave. The range is limited to the straight line distance from the receiver to the antenna. Fig. 277 is a laboratory model of a microwave transmitter.

The new frequency modulation (F.M.) band is in the range 96 to 102 megacycles per sec. Most television bands are in the region of 50 megacycles per sec.

A direct application of microwave transmission is the wartime uses of radar-radio direction and ranging. The principle of radar depends on the phenomenon that very high frequency waves, 100 megacycles and higher,

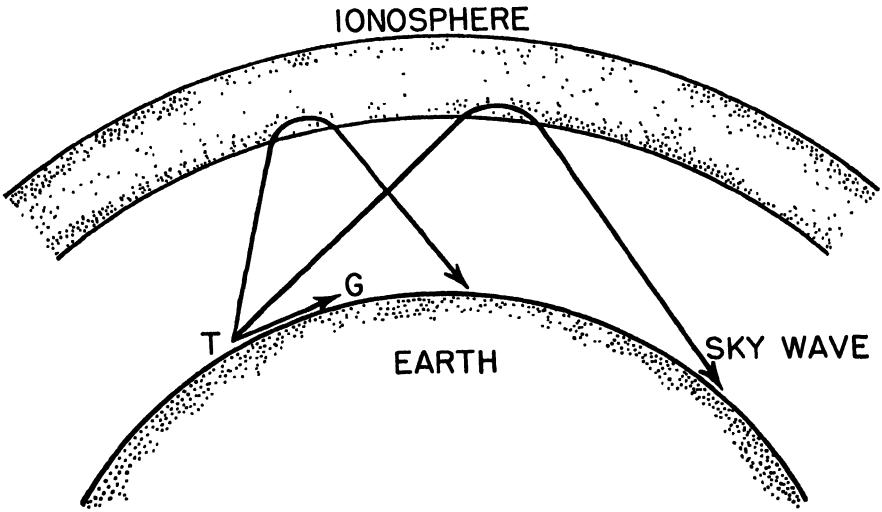


FIG. 276. Radio wave propagation. *T* represents the transmitter and *G* is the ground wave.

can be reflected by objects in their path somewhat like an echo in sound. Just as the distance of a hill can be determined by the time interval for a sound to travel to the hill and return, so the distance of an obstacle can be determined by radar.

The radar energy is transmitted in very short pulses of 1 to 50 microseconds[1] spaced at intervals of about $\frac{1}{1000}$ of a second. If an object is 93

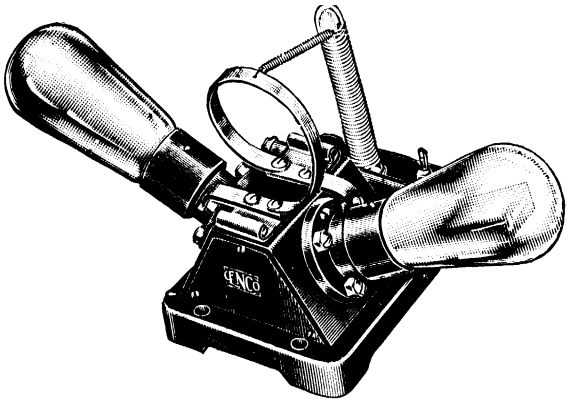


FIG. 277. A short-wave transmitter. (Courtesy, Central Scientific Co.)

mi. distant, the pulse requires 0.001 sec. for the complete path. One recent use of radar consisted of receiving reflections from the surface of the moon. The frequency used was 111 megacycles per sec. The distance to the moon was determined and was found to agree with the previous astronomic results.

REFERENCES

Everitt: "Fundamentals of Radio," New York, Prentice-Hall Inc.
Foley: "College Physics," Philadelphia, The Blakiston Company.
Ghirardi: "Radio Physics Course," New York, Radio Technical Publishing Co.
Heil: "The Physical World," Philadelphia, The Blakiston Company.
Marcus and Horton: "Elements of Radio," New York, Prentice-Hall Inc.
Meister: "Magnetism and Electricity," New York, Charles Scribners Sons.
Moyer and Wostrel: "Radio," New York, The McGraw-Hill Book Co.
O'Neil "First Principles of Radio," New York, Oxford Book Co.
Watson: "Understanding Radio," New York, The McGraw-Hill Book Co.
The magazines *Radio News* and *QST*.
The R.C.A. Radiotron Manual.

QUESTIONS AND PROBLEMS

1. Describe a telephone receiver.
2. What is the purpose of the grid in an audion?
3. What is a damped oscillation?

[1] One microsecond is 1 millionth of a second.

4. Why do power companies use high-tension wires to transmit power over long distances?
5. What is the purpose of the filament in a radio tube?
6. Why is a radio tube often called a valve?
7. A radio station is broadcasting on a frequency of 550 kc. What is the wave length? Answer: 545 m.
8. A short-wave station in England broadcasts on a frequency of 9.5 megacycles. What is the wave length? Answer: 31.6 m.
9. Describe two types of loudspeakers.
10. What is the difference between a motor and a generator?
11. Explain the action of a transformer.
12. What is meant by a coated filament?
13. A transformer is rated at 10 kw. The primary is 2,400 v. and the secondary 120 v. Compute the maximum safe current in the primary and the secondary. Answer: 4.1 and 83.2 amp.
14. Why is alternating current rather than direct current used for long distance power lines?
15. How much energy in kwhr. is used by a 100 w. lamp burning for 2 hr.? Answer 0.2 kwhr.

Topics for Discussion

New Radio Tubes Dynamic Speakers The Modern Telephone Exchange

Experiments

1. Construct a simple, one-tube receiver. Some of the references describe the method and give explicit details of construction. Such material can be secured at any radio parts store.
2. One of the instrument companies can furnish a simple short-wave transmitting set modeled after the apparatus of Hertz. Measure the wave length of the electric wave emitted by the apparatus.
3. Make a study of induced currents.
   a. Connect a coil of wire to a galvanometer. Thrust the north pole of a bar magnet into the coil and note the size and direction of the deflection. Pull the magnet out and note the deflection of the galvanometer. Repeat the operation, using the south pole of the magnet. Try to make a general statement concerning the current and the direction of motion of the magnet.
   b. Construct a transformer by winding two coils of wire on a soft iron bar. One coil may be 100 turns and the other 200 turns. Connect the primary (200) in series with a cell and a key. Connect the secondary to a galvanometer. Close and open the key and note carefully the deflections of the galvanometer. Explain the result.
   c. Connect a simple generator (St. Louis type) to a galvanometer. Rotate the armature carefully and watch the galvanometer.
   d. If the armature has a split ring (commutator), connect a dry cell to the terminals and operate the machine as a motor. Consult the instructor and the references for details.

27. X-RAYS AND RADIOACTIVITY

Science moves but slowly, slowly,
Creeping on from point to point.
– ALFRED TENNYSON

Many years previous to the discovery of x-rays, laboratories in all parts of the world had been using Crookes tubes to demonstrate the marvelous effects of cathode rays (beams of electrons). Crookes tubes

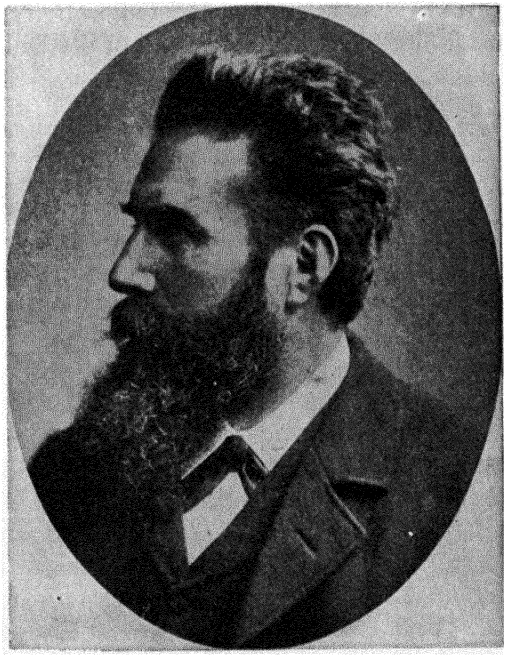


FIG. 278. Wilhelm Konrad Roentgen (1845–1923).
A German physicist; the discoverer of x-rays.

were first designed by Sir William Crookes. They are vacuum tubes having two electrodes. These tubes are made in many peculiar shapes and give spectacular colors when a high-voltage source is connected to the electrodes. Various gases are used in the tubes.

Up to the time of Roentgen's (Fig. 278) discovery in 1895, no one had ever happened upon the fact that an invisible ray coming from some of the tubes was capable of fogging photographic plates which were wrapped in black paper. With the discovery of x-rays (Roentgen rays), it was soon realized that these rays, passing through the hand or foot, would leave a shadow of the bones on a photographic plate, in much the same manner that the sun casts a shadow of a tree on the ground. Medicine and surgery had been advancing rapidly since the discovery of antiseptics and anesthesia. Yet the medical specialists were still compelled to guess at many body ailments, often operating in an attempt to discover the real difficulty. With the coming of x-rays, the surgeon could take a shadow picture and thus could determine exactly the proper procedure necessary. It is significant that the discovery of radioactivity by Henri Becquerel and the isolation of radium by Pierre and Marie Curie came at almost the same time that x-rays were discovered by Roentgen.

These two great discoveries, x-rays and radioactivity, working hand in hand, are valuable not only in the sciences of medicine and surgery, but also in the fields of chemistry and physics.

X-ray Tubes and Apparatus

The first type of x-ray tube was a crude device consisting of a curved aluminum plate (*cathode*) and a plate of platinum (*anode*) enclosed in a partially evacuated glass bulb (Fig. 279). X-rays were emitted from the platinum plate when a high-voltage source (40,000 to 60,000 v.) was connected to the two terminals, the platinum being positive. These tubes were very unsteady; it was difficult to maintain the proper vacuum; and, because of the variety of rays emitted, they were dangerous to the operator. Many of the early experimenters received burns, which developed into a necrosis and cancer, by continued exposure to the rays.

X-rays are a band of electromagnetic waves (see p. 198). The very short waves (hard rays) having a wave length of about 0.1 Ångström (10^{-8} mm.) are very penetrating, but do not harm tissue as much as the longer waves of about 2 Ångströms. These latter rays are called "soft" x-rays. In 1912, Dr. W. P. Coolidge of the General Electric Co. replaced the curved cathode of the x-ray tube by a tungsten wire (Fig. 280). The tube was exhausted to the highest possible vacuum and the filament, when heated, emitted electrons which were caused to move to the plate (target) by a voltage source (60,000 to 120,000 v.). With this type of tube, it was possible to adjust the conditions so that only certain wave length bands would be sent out. Moreover, it has been found that lead glass shields around the tube can be used for protection against burns.

The nature of the continuous radiation (white rays) emitted is determined by the voltage applied to the tube. The relation is a direct application of the quantum theory (see p. 195). Thus, eV equals $h\nu$ where e is the charge on the electron. V is the applied voltage, h is the quantum constant, and ν is the frequency of the radiation. If one wishes to produce hard radiations, it is necessary to apply a high voltage to the tube. The simple relation between wave length in Ångstroms and applied voltage can be stated as follows:

$$\text{wave length} = \frac{12{,}345}{\text{volts}} \quad \left(\text{e.g., for 100,000 volts, } \lambda = \frac{12{,}345}{100{,}000} = 0.12 \text{ Å}\right)$$

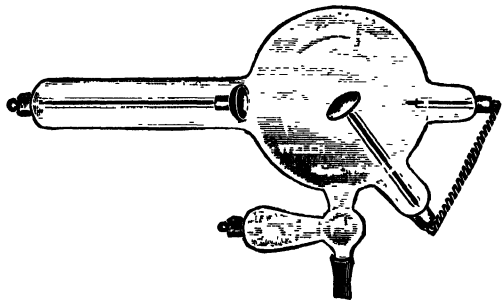


FIG. 279. An early form of x-ray tube. (Courtesy, Welch Manufacturing Co.)

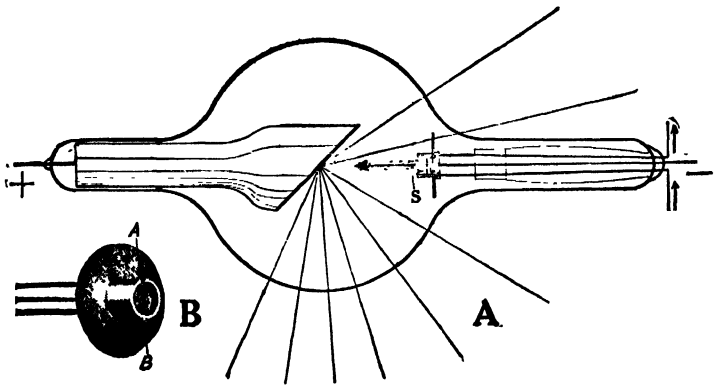


FIG. 280. (A) Diagram of Coolidge x-ray tube. (B) Cathode, showing spiral of tungsten wire (A) and collar (B).

NATURE OF X-RAYS

For many years, the nature of x-rays was in dispute. At present, it is known that the electrons leave the heated filament and move with a speed nearly that of light toward the high-voltage anode. Upon striking the target, some of the electrons penetrate far into the atoms of the metal.

Because of their great energy, they are able to eject one or more electrons from the inner shells of the atoms. Other electrons drop into these inner shells with the result, according to Bohr's theory of atomic structure, that quanta of great energy, which we call x-rays, are ejected.

Since the frequency depends upon the energy of a quantum, we have very high frequency radiations. These radiations have a very short wave length far below the range of the human eye. They do, however, affect a photographic plate as does light.

Perhaps the reader is confused by the fact that we mix the terminology of the quantum theory and the wave theory. It is unfortunate that this is done. As yet we do not have a sufficiently clear picture to enable us to express our ideas clearly in either the quantum theory or the wave theory. At present, we speak of the frequency of a quantum and we discuss the frequency of a wave. This is due to our ignorance of the true nature of the quanta. The theory that moving particles have wave properties gives a clue to the problem. The electron microscope (see p. 349) utilizes this principle.

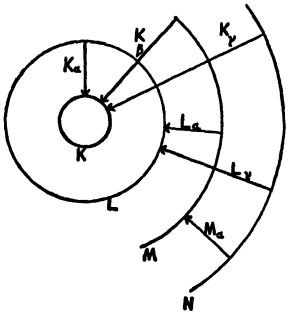


FIG. 281. A sketch illustrating the production of characteristic x-rays. *K*, *L*, *M* and *N* are electronic shells.

Under certain conditions, we can produce x-ray line spectra called characteristic x-rays, as well as the continuous spectrum. As an example of the method by which an atom produces x-ray spectra, let us consider a tungsten atom model (Fig. 281). The innermost shell (*K*) contains two electrons; the next shell (*L*) has eight. If an electron is ejected by some means from the *K* shell, we get the hardest x-rays (*K* radiations) when another electron enters the vacated space. If an electron is ejected from the *L* shell, we have *L* radiations. These radiations are like the line spectra discussed in Chapter 1.

X-RAYS IN THE SCIENTIFIC LABORATORY

In Chapter 13, it was stated that we could not see an atom by means of a microscope because the type of light gave the instrument insufficient resolving power. As the wave length of the light is made shorter, the resolving power of the microscope increases. In 1914, Laue, Friedrich, and Knipping discovered that x-rays, because of the short wave length, could be used in the study of atoms. A narrow beam of x-rays passed through a crystal of the material to be studied. The scattered x-rays then fell on a photographic plate. Fig. 282 is the negative secured by passing a beam of x-rays through a crystal of calcite (calcium carbonate). The scattered

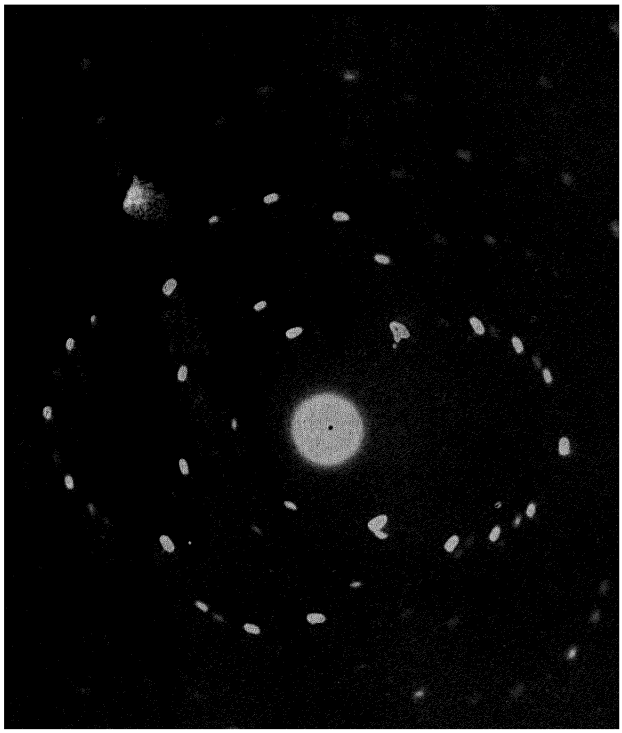


FIG. 282. A Laue photograph of calcite. The x-ray beam was passed through a crystal of calcite, falling on a photographic plate.

spots are distributed in such a way that the arrangement of the atoms in the crystal can be studied. By this means, it is possible to study the atomic arrangements in the minerals. Somewhat later, Bragg discovered that a crystal could be used as a diffraction grating to study x-ray spectra.

A diffraction grating replaces the prism in most modern spectroscopes. We shall not attempt to give a description of the grating in this text. The reader may consult any physics text for an explanation of its operation.

With modern apparatus, the wave length of x-ray spectrum lines of an element can be measured with almost the accuracy of the optical line spectra of an element such as hydrogen. The modern x-ray spectrometer is now a common laboratory instrument. All experimentation indicates that there is no essential difference between x-rays, visible light, and ultraviolet. All are electromagnetic radiations differing only in wave length.

In the field of industry, x-rays are used in the detection of hidden flaws

in metals, in the examination of the structure of alloys, in a study of electrical insulation, in detecting hidden goods at the custom house, in verifying the authenticity of old paintings, and in fitting shoes.



FIG. 283. X-ray photograph of a broken bone. (Courtesy, "Foley's College Physics," Philadelphia, The Blakiston Company.)

X-RAYS IN MEDICINE AND SURGERY

In the hospital, an x-ray examination precedes nearly every operation. Broken bones and dislocations are studied in all parts of the body (Fig. 283). In the case of the digestive tract, the patient is given a meal of barium sulfate. This material makes the stomach and intestines opaque to x-rays (Fig. 284). The kidneys, gall bladder, and heart can be studied by introducing some inert material such as methyl iodide into the blood or into the digestive tract. With modern technic tuberculosis in young children can be detected by a study of lung tissue. By the use of two tubes set at an angle, stereoscopic depth photographs which give the surgeons the exact location of the affected parts can be secured.

Some success has also been secured in the destruction of abnormal tissue by x-rays. Such treatment depends on the fact that normal body cells are more resistant to x-rays than are embryonic cells in some malignant growths such as cancer. However, the reason for this is not understood and the work is still in an experimental stage. Because of the danger involved, such treatments should be undertaken only by experienced operators. To trust oneself to an x-ray treatment by a charlatan is extremely dangerous. It is important to operate the tube in such a manner that the patient does not receive an x-ray burn. The burns received from the rays are different from ordinary burns in that they do not heal rapidly. Apparently, in such burns the recuperative power of the skin has been destroyed.

Recently x-ray tubes which operate at 2 million volts have been in-

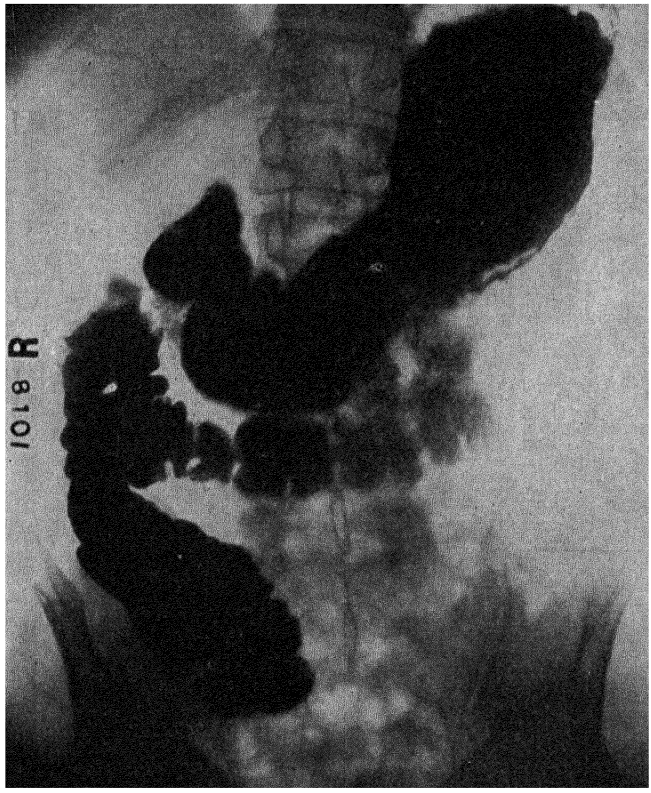


FIG. 284. An x-ray photograph of the intestines. (Courtesy, Weld and Palmer, "Textbook of Modern Physics," Philadelphia, The Blakiston Company.)

stalled (Fig. 285). The rays emitted from these tubes resemble the gamma rays from the radioactive materials (see p. 412). In fact, it is estimated that one of these tubes may be as effective as several grams of radium. No one can foresee the future of these magical rays of invisible light.

RADIOACTIVITY

At about the same time that Roentgen made his great discovery, another scientist, Henri Becquerel, was studying phosphorescence.

When some materials are illuminated with intense light, especially ultraviolet, for a time, they continue to glow after the light has been removed. This is phosphorescence. A common example is luminous paint.

One day, it is related, Becquerel placed some uranium ore on a photographic plate which was enclosed in the usual black paper. Imagine his surprise when a few days later he found the plate fogged as though it had

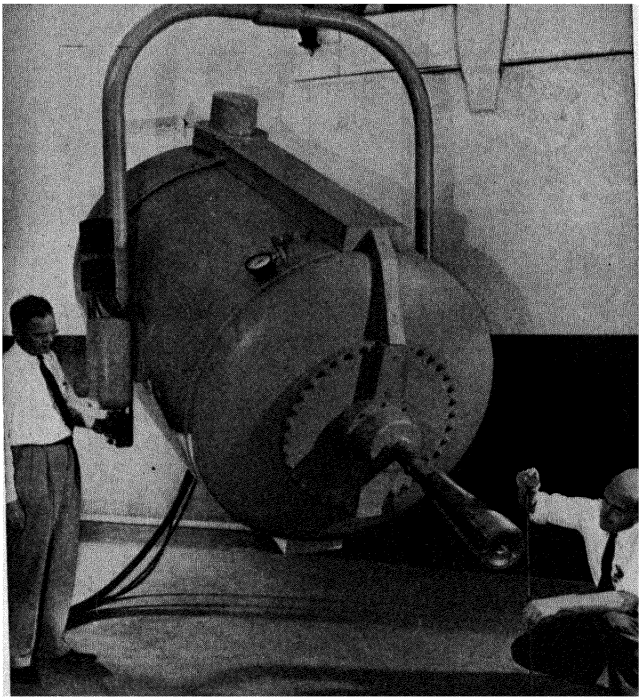


FIG. 285. A two million volt x-ray tube. (Courtesy, General Electric X-ray Corp.)



FIG. 286. Photograph of keys by radium minerals. The keys were placed on the outside of the envelope of the plate and the minerals were laid on the keys. (Courtesy, Dr. E. T. Wherry, University of Pennsylvania.)

been exposed to weak light (Fig. 286). Becquerel, being too busy to follow up the incident, detailed the task to a young couple, Pierre and Marie Curie (Fig. 287). These people secured a ton of pitchblende from Bohemia —pitchblende being a mineral especially rich in uranium ores—and carried on an experiment almost unique in scientific annals. By dint of several years of arduous toil, they separated from the ton of ore a small amount of a salt which showed intense radioactivity. Finally, in 1898, the Curies secured a few grains of two substances, which they called *radium* and *polonium*. These substances were new elements which had startling properties. The compound, radium chloride, looked like table salt but glowed when placed in the dark. The Curies found that the radium salt produced sores on the skin which were difficult to heal. They also found that 1 Gm. of radium can melt its weight of ice each hour. It could destroy bacteria and fog photographic plates even when they were enclosed in thin sheets of lead. Rays from the material have the power to destroy some cancer cells. Today, radium is a necessity in all hospitals. The only commercial sources of radium are the uranium ores. Most of the radium was formerly produced from ores in the Belgian Congo but in 1932 prospectors in Northern Canada discovered a deposit of pitchblende at Great Bear Lake near the Arctic Circle. At present, the total supply of refined radium in the world is about 3 pounds. It has a market value of many millions of dollars. Most of the radium is in the form of radium chloride or radium bromide in solution.

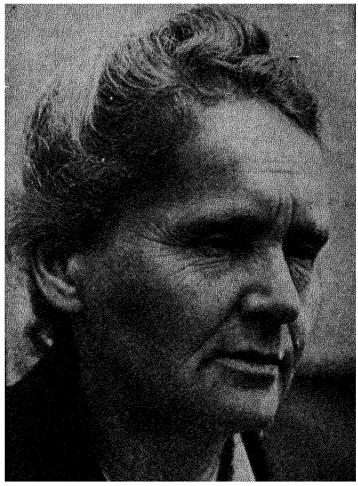


FIG. 287. Marie Curie (1867–1936). Discoverer of radium and investigator of radioactive materials. Nobel Prize winner in 1903. (Courtesy, Jones: "Inorganic Chemistry," Philadelphia, The Blakiston Company.)

Ernest Rutherford investigated radium and found that as a result of a long series of transformations, uranium atoms change into radium atoms. Uranium atoms emit helium ions (alpha rays) from the nucleus. In a gram of *uranium*, about 12,000 atoms disintegrate each second. According to modern ideas, the nucleus of *radium* consists of 88 protons and 138 neutrons. As the *radium* atom "explodes," it in turn ejects a helium nucleus (2 protons and 2 neutrons) and a gamma ray and becomes an atom of *radon* of atomic weight 222. Radon is a chemically inert gas and undergoes transformation rather quickly. The final product of the long series of transformations is the element *lead* (Appendix VII).

At some stages in the disintegration, both helium ions and electrons are evolved. Also, some radioactive transitions are accompanied by gamma rays (short electromagnetic waves of about 0.04 Ångström). It appears that the emission of the electron from the nucleus is due to a change of a neutron into a proton. A gram of radium is changed into radon at such a rate that one half of it disintegrates in 1,600 years. These transformations go on continuously. Each radioactive element has a definite rate of decay and many calculations of the age of the earth have been made by a study of the uranium- radium- lead content of rocks (see p. 72). It has been postulated that radioactivity may in some way account for the heat of the sun. Most of the effects of radium are due to the radon which is always present.

It has been found that radon is very effective in the treatment of cancer because of its emission of alpha particles. The gas radon is pumped out of the radium solution and is sealed in tiny gold tubes called seeds. These seeds are placed in the growth. Although the life of radon is short, its use makes it unnecessary to handle the precious and dangerous radium. The principal uses of radium compounds are for cancer treatment, for luminous paints, and for studies in nuclear physics.

Just as in the case of x-rays, radium must be handled with great care. If a tube containing a few milligrams of radium chloride were brought near the skin for a short time, a sore would develop which would be very difficult to heal and could become malignant. Another result may be pernicious anemia.

MODERN RADIOACTIVITY

After the discovery and isolation of radium, much work was carried on in an attempt to find other radioactive elements in nature. With the exception of the elements thorium and actinium, it seemed that no other elements had this property to any extent.

However, in 1919, the scientist Ernest Rutherford of Manchester University bombarded the gas nitrogen by alpha particles (helium nuclei) from radium. He found that he had caused the ejection of protons from the nitrogen nuclei. He carried this work forward and was able to transmute the nuclei of other atoms besides nitrogen.

The experiment verified the belief that charged protons constitute at least part of the atomic nucleus. Since the atomic number of an atom (the number of protons) is usually less than one half the atomic weight, it was apparent that some particles besides the protons were also in the nucleus. Apparently the nucleus has a complex structure.

The alpha particles used in the experiment are ejected from radioactive atoms such as radium with speeds of the order of 6,000 mi. per sec. They are the nuclei of helium atoms.

The Cyclotron

Rutherford performed his experiments using alpha particles coming from the natural radioactive elements. It was apparent that the scientist needed some method of producing high-speed particles capable of control in the laboratory if the work of disintegration was to be extended to the heavier atoms.

One of the most important methods for producing such particles is the cyclotron, developed by Ernest Lawrence and his associates. A crude analogy of the cyclotron is the sling shot or the centrifugal clothes dryer.

Fig. 288 is a photograph of the instrument. It consists of a powerful electromagnet with flat pole pieces a few inches apart. Between these pole pieces is placed a circular can divided into two halves called "dees." These dees are enclosed in a vacuum chamber. A small amount of one of the gases, hydrogen, heavy hydrogen (an isotope of hydrogen), or helium, is placed in the chambers. By ionization methods, the positive particles, protons, deuterons, or helium ions, are produced. The dees are connected to an oscillator which produces a voltage of about 50,000 v. at a frequency of 10,000,000 cycles per sec. Because of the accelerating voltage and the

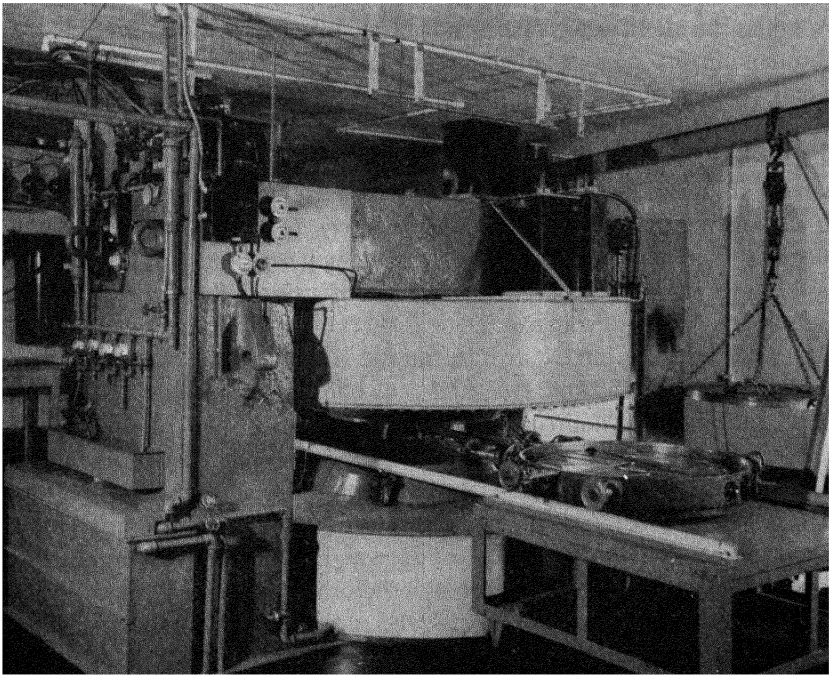


FIG. 288. The cyclotron. The large flat drums constitute the magnetic field. The flat cylinder on the track is the system from which are emitted the desired rays. (Courtesy, Cancer Research Foundation of the Franklin Institute.)

strong magnetic field, the positive particles describe semicircular paths in each dee, gradually spiraling toward the outside of the chamber. The accelerating voltage is applied to each dee at the proper instant to continually accelerate the particles. The effect is the same as if a potential of several million volts were applied to the particles at one time. The high-speed particles finally emerge in much the same manner as that in which water drops leave the centrifugal dryer. One might think of these particles as "bullets" for the "atom smashing" apparatus.

In using the cyclotron, Lawrence found that when a sodium salt was bombarded with high speed deuterons (see p. 430), the salt became strongly radioactive, having an active life of about 20 hr. We now realize that man can actually produce radioactive isotopes at will in the laboratory. Most elements have been made radioactive in this manner. Such radioactive materials may replace radium in medical practice in the near future. The number of radioactive atoms is increasing almost daily.

There are about 40 cyclotrons in use at present. The largest one is located at Berkeley, California.

ARTIFICIAL TRANSMUTATION

In 1932, various investigators, among them James Chadwick, Frederick Joliot and his wife, Irene Curie, the daughter of Madame Curie, discovered that when the element beryllium was bombarded with alpha particles from radium, a curious new radiation was ejected. The method used was to mix a small amount of radium or radon with beryllium. At first the radiation was supposed to be gamma rays resembling x-rays. Later, it was proved that the radiation was really a stream of fast moving particles which were uncharged. These particles are called neutrons. The neutron is said to have the atomic number zero. The nucleus seems to consist of neutrons and protons. There are no electrons in the nucleus. Neutrons and protons possibly represent different manifestations of a single fundamental particle, the *nucleon*. The hydrogen nucleus is merely a single proton.

On the basis of such particles in the nucleus, one may visualize an atom of uranium of atomic weight 238 as being composed of 238 nucleons (92 protons and 146 neutrons) and 92 electrons outside the nucleus.

After the discovery of neutrons, it was soon realized that such an uncharged particle would make an excellent bullet for nuclear disintegration. Since it has no electrical charge, the neutron can penetrate any nucleus, even those of elements of high atomic weight. As the neutron enters the nucleus, it may distribute its energy to the other particles so that the entire group is set into violent motion, with the result that either another neutron may be ejected, gamma rays may be emitted, or some other disturbance may take place.

In order to explain the process of nuclear disintegration, the scientist

has introduced a curious new type of equation. If an atom of bromine captures a neutron, the result may be expressed by the equation:

$$Br^{79} + N^{1} \rightarrow Br^{80} + \text{gamma ray}$$

Bromine plus neutron becomes bromine isotope

The numbers are atomic weights. Such an equation means that a bromine nucleus has captured a neutron and has become a bromine isotope nucleus with an additional neutron. Energy has been emitted in the form of gamma radiation.

If the metal beryllium is bombarded by alpha particles, a similar equation shows that a neutron has been ejected and that a new element, carbon, has been produced. Here is an example of *atomic transmutation*, the dream of the alchemist.

$$Be^{9} + He^{4} \rightarrow C^{12} + N^{1}$$

Beryllium plus alpha yields carbon plus neutron

It was found in 1932 that if lithium is bombarded with protons (hydrogen nuclei), helium atoms are formed and a large amount of energy is emitted. The reaction is shown by the equation:

$$H^{1} + Li^{7} \rightarrow 2He^{4} + \text{Energy}$$

Proton plus lithium yields helium

The energy produced in the formation of the two helium atoms from the disintegration of 1 lithium atom is 27×10^{-6} erg, whereas the energy released in the formation of one molecule of carbon dioxide from one atom of carbon is only 6.5×10^{-12} erg. This means that the heat evolved in the nuclear disintegration of the lithium atom is about 4 million times the heat produced by the burning of 1 atom of carbon. This is a startling statement. In the disintegration of one atom of lithium weighing 11.5×10^{-24} Gm., 3×10^{-26} Gm. of mass has been changed into energy according to the mass-energy equation of Einstein. The combined mass of the proton and the lithium atom is greater than the mass of the two helium atoms by 3×10^{-26} Gm. This excess is transformed into energy.

$$\text{Energy} = \text{Mass} \times c^{2}$$

$$27 \times 10^{-6} \text{ erg} = 3 \times 10^{-26} \text{ Gm.} \times 9 \times 10^{20}$$

In the equation, c is the velocity of light in cm. per sec.

The erg is a very small unit of energy. It is the kinetic energy of 2 Gm. moving with a velocity of one cm. per sec. However, for atomic reactions the erg is a large unit and it is customary to express nuclear energy in millionths of an erg (10^{-6} erg). For example, 1.6×10^{-6} erg is equivalent to 1 million electron volts (1 mev.), the energy acquired when an electron moves under the influence of a potential difference of 1 million volts.

One startling fact in connection with nuclear disintegration was discovered by Enrico Fermi, an Italian physicist, and the German physicists Hahn and Strassman in the period 1934–1939. They found that if uranium atoms of atomic weight 235 are bombarded by very slow neutrons,[1] under certain conditions the nuclei of the uranium atoms may break up by splitting apart into two nearly equal parts, forming other elements. This splitting is accompanied by the evolution of a great amount of energy in the form of heat. The energy of 200 million electron volts (200 mev.) produced by the splitting of one uranium atom (235) is nearly 50 million times that produced by the burning of 1 atom of carbon. What is more important, during the splitting process (fission), several neutrons (two or three) are produced which have sufficient energy to split other nuclei. It has been calculated that the disintegration of 1 pound of uranium can supply as much energy as is produced by the combustion of many tons of coal.

This is a type of chain reaction, since the initial neutrons start the process along like spontaneous combustion, provided the sample of uranium (235) has the proper size, perhaps about 100 lb.

Neutrons are capable also of transmuting atoms of uranium 238 into the new element plutonium (239), which can be separated chemically from uranium (238).

These discoveries have made possible the production of atomic energy in the form of the atomic bomb. An atomic bomb is a device containing several pounds either of the uranium isotope (U 235) or some radioactive product of uranium such as the element plutonium (Pu 239), so constructed that the splitting of the atoms of the entire mass takes place in a fraction of a second with explosive violence.

One may imagine that a possible method for atom bomb construction is to place two separate chunks of plutonium in a container. In order to detonate the bomb the masses are forced together by some mild explosive. An atomic bomb is equivalent to several thousand tons of high explosive such as TNT (see p. 216).

During the explosion, the temperature rises to several million degrees C., so that the target is exposed to a quantity of radiation heretofore unknown on the earth. A great mass of radioactive materials is produced, as well as gamma rays and ultraviolet and visible light. All these effects produced in a fraction of a second make the bomb very destructive. One bomb can destroy all life and property in a medium sized city. The radioactive isotopes produced make the region dangerous for a long time after the actual explosion occurs.

There are many peacetime uses for radioactive elements. Radioiodine can track down cancer cells which have escaped from the thyroid gland.

[1] The velocity of a slow neutron is about 10,000 ft. per sec. A fast neutron has a velocity of perhaps 10^8 ft. per sec.

Radiosodium enables the physiologist to study cell conditions in any part of the body. The production of radioactive elements has recently become a new industry.

In addition, the energy produced in atomic fission may make new industrial methods possible. Power plants are being designed which will operate by atomic energy.

Cosmic Rays

For some years, it has been known that a penetrating radiation of some sort is constantly striking the earth. The source of the radiation is unknown except that the energy seems to come from interstellar space. As a result of the intensive work of many observers, among them Millikan (Fig. 289), Kolhorster, Compton, and Swann, we know that the rays are electrically charged particles, probably protons. When the charged particles, called primary cosmic rays, strike the upper atmosphere, they bombard molecules of the air and as a result we get secondary rays, which have less energy than the primary ones. The secondary rays seem to consist of electrons and mesons. Mesons are charged particles having a mass several hundred times that of the electron.

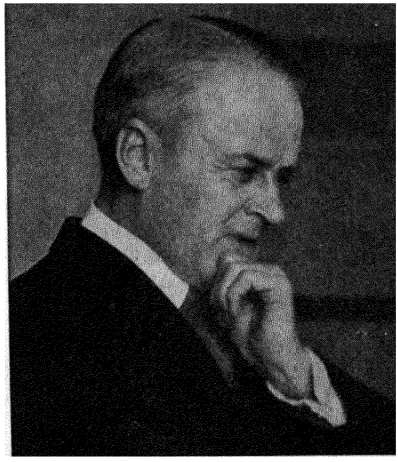


Fig. 289. Robert Andrews Millikan (1868–). Prominent American physicist; investigator of electrons and cosmic rays. (Courtesy, Science Service.)

Early in 1948, mesons were produced in the laboratory, using a large cyclotron. The work is still in an experimental stage and a complete explanation of the properties of mesons is not yet available for publication.

The Positron

In 1933, Carl Anderson of the California Institute of Technology discovered by means of the cloud chamber (see p. 189) a new particle which is called the *positron*. It is a twin of the electron except that it has a positive instead of a negative charge. The positron seems to have a very short life, combining readily with electrons to form photons of energy.

References

Bazzoni: "Energy and Matter," New York, The University Society.
Cork: "Radioactivity and Nuclear Physics," New York, D. Van Nostrand Co.
Darrow: "Atomic Energy," New York, John Wiley and Sons.

Gamow: "Mr. Thompson Explores the Atom," New York, The Macmillan Co.
Gamow: "Atomic Energy," New York, The Macmillan Co.
Harrow: "The Romance of the Atom," New York, D. Van Nostrand Co.
Lemon: "From Galileo to the Nuclear Age," Chicago, University of Chicago Press.
Millikan: "Electrons Plus and Minus," Chicago, University of Chicago Press.
Newman and Miller: "The Control of Atomic Energy," New York, Whittlesey House.
Pollard and Davidson: "Applied Nuclear Physics," New York, John Wiley and Sons.
Pullin and Wiltshire: "X-rays Past and Present," London, Ernest Benn, Ltd.
Robertson: "Radiology Physics," New York, D. Van Nostrand Co.
Westinghouse Engineer, November, 1945.

Questions and Problems

1. Who was Roentgen? Write a biographic sketch.
2. What is: a neutron? a proton? an electron? a deuteron?
3. What is an atomic pile? Where are they located in the United States?
4. Why are x-rays dangerous?
5. What are the principal sources of radium in North America?
6. What is meant by the term *plutonium?*
7. For what was Madame Curie noted? For what is her daughter Madame Joliot noted?
8. Is it possible to operate our power plants by uranium at the present time? Is it possible that we shall have atomic power in the near future?
9. What is an atomic bomb? Why is it different from the bombs using trinitrotoluene (TNT) as an explosive?

Visual Aids

The large electrical corporations have films and posters of all types which are valuable teaching aids in the field of radioactivity. Most of this material is made available without charge

Topics for Discussion

The Atomic Pile
X-rays in the Treatment of Cancer
Cosmic Rays and Mesons
Production of Plutonium and Curium
New Atomic Energy Plants
Sources of Uranium and Radium

Experiments

1. Visit the local hospital for an x-ray demonstration.
2. Any large hospital can provide radon seeds which are partly exhausted. They will operate an electroscope or a Geiger counter. The instructor should conduct these experiments.
3. Examine a luminous watch dial in a dark room, using a low power lens. Scintillations will be seen as dancing flashes of light.
4. It is possible to purchase an inexpensive Geiger counter circuit which will record the presence of cosmic rays or radioactive substances. If such a device is available, count the number of cosmic rays passing through some part of your body each minute.

28. THE FUTURE OF SCIENCE

We are standing on the threshold of the era in which atomic power will be developed, surely to be the most important engineering achievement of the next generation.

—EDWARD CONDON

In the preceding pages, we have described some achievements of the physical sciences as they relate to the everyday life of the reader. Each topic has been chosen with a view to the coordination and expansion of the student's knowledge. No doubt there are many other topics which should have been included.

WHAT OF THE FUTURE OF SCIENCE?

The student has without doubt discovered that many of the phenomena which have been discussed still lack a satisfactory explanation. It is probable that "ultimate truth" is beyond the ability of man, inasmuch as each new scientific discovery opens a complete new field of investigation. Someone has compared a scientific investigator to a person placed in a room having many closed doors. By patient effort a key is found which opens one door. However, this opened door simply leads to another room also full of closed doors, each needing a special key.

Nevertheless, we can describe with some assurance some of the problems that the scientist of tomorrow must face. As this is written, the world is suffering from an unsatisfactory distribution of food. Some people have too much food and clothing, while millions of persons go hungry and ill-clad. The chemist is working vigorously on the problem of food synthesis. He knows that in some manner CO_2 and water combine in the presence of the catalyst chlorophyll and sunlight to form starch. If the chemist can discover a way of producing starch cheaply in the laboratory, there will be plenty of food. Likewise, a synthesis of protein and fats might free us from the high cost of meats and oils. There arises the question, will man be able to adjust his social structure so as to distribute this abundance properly? The trained mind of the future must meet this problem.

While studying this book, the thinking student has without doubt been amazed at the rapid progress which science has made in constructing devices for our comfort. We ride in luxurious automobiles, trains, and airplanes. We live in electrical homes where we can have our choice of

climate at the flip of a switch. We now have our choice of the entertainment of the world by the radio, and we see great events by television. Our foods are rushed from all parts of the world to our table. We eat in winter, luscious fresh fruits and vegetables which are prepared by the "dry ice" process. The medical specialists perform miracles in saving human life and in making our lives more comfortable. Despite all these marvels, most of us are not happy.

The hospitals and sanitoriums are filled with mentally ill people who have not been able to withstand the pressure of our modern civilization. Although science has increased the life expectancy of man by saving the lives of most young children and by repairing the decay of middle age, it has not made the world a happy place in which to live. We live in an atmosphere of fear for the future. Despite the luxuries which science has provided, most of us are not certain that we can escape poverty as we grow older. Science has provided luxury and comfort for some; it must now devise means for making a measure of comfort available to all.

Many diseases remain unconquered. Cancer and heart disease seem to be increasing. Infantile paralysis (poliomyelitis) and other infectious diseases are still unconquered. The common cold still remains a puzzle. Scientists have now realized that medicine must enlist the aid of physics and chemistry as well as biology, if it is to solve the problems of the future. Many scientists are now working in groups, each adding his knowledge and ingenuity to the complex problem.

We may expect great advances in the healing art in the future. This is to be expected since the sciences of inert objects have thus far outstripped the science of the human body and the mind. Man will learn to understand himself better within the next few years.

RESEARCH OF THE FUTURE

In the future the research facilities of the world will undoubtedly increase. At present many millions of dollars are spent each year in scientific and medical investigation. The great research laboratories, and the various college and university laboratories are producing marvelous results in all fields of science. Science will in the future no doubt offer a wider field of opportunity for the trained student than in the past.

It is still true that the student who has mastered the fundamental principles of science will be able to adjust himself to new technical developments. For example, a scientist with an excellent background in chemistry will be valuable to any new industry which may develop in that field. The man who has learned to think will be of value to society in the future as in the past.

One might list a few of the new developments of the past decade:

Television perfected
Artificial radioactivity and the atomic bomb
New alloys and plastics
Cell mutation by the use of x-rays
Electronic devices of all types
Radar
"Sulfa" drugs
Penicillin

EDUCATION OF THE FUTURE

There is great unrest in the field of education. The citizens of communities are analyzing the cost of education and are inquiring whether the present methods of education justify the money expended. Most parents desire that their children shall receive all the education possible. Does our modern college fulfill this need or will the educational plant of the future be radically different?

Certainly there are students who do not satisfactorily respond to the present curriculum. Will the college of the future be able to provide for all students who wish to secure an education? Will there be ample opportunities for vocational work and practical skills as well as for mental discipline? Educational research indicates that the college of the future will set up other standards for admission than secondary school credits. In fact, the new ideas will permeate the secondary schools, for here also there are many maladjusted students.

The scientist must solve this problem of mass education in the very near future if our present social order is to continue. However, one may look with confidence to the future, believing that science will continue to provide better means for happier living.

Appendix I

This course may be greatly enriched by the use of films, displays, and other visual material. "One picture is worth a thousand words." It is impossible to evaluate all of the visual material offered the teacher of science. For this reason, only a few motion pictures are listed at the end of some of the chapters. Some of these have been used by the author and found to be very instructive.

A few general sources of visual material are listed here, from which a teacher may select:

Eastman Classroom Films (16 mm. safety film) may be purchased from the Eastman Kodak Co. They may be rented from the Bucknell Classroom Film Library (Bucknell University, Lewisburg, Pa.) and from the Massachusetts Department of Public Instruction, Boston, Massachusetts.

"Enriched Teaching of Science in the High School," Woodring (Bureau of Publication, Teachers College, Columbia, New York), contains a wealth of suggestive free and low cost materials of many kinds.

The University of Chicago is making a number of films of interest to science teachers.

Valuable films and other material may be secured from various State Departments of Public Instruction and Public Health, and Bureaus of Mines.

Educational Screen is a monthly magazine on educational films published at 64 E. Lake St., Chicago, Illinois. It also publishes "One Thousand-and-one Film List."

Other sources of educational films include the Keystone View Co., Meadville, Pa.; the American Optical Co., 19 Doat St., Buffalo, N. Y.; the Westinghouse Electric Corporation motion picture catalogue; General Electric Motion Pictures, Catalogue APB-21; "Service for Teachers" (A free booklet of the General Electric Co.); and "Teaching Aids" (A free booklet of the Westinghouse Electric Corporation).

Appendix II

WEIGHTS AND MEASURES

1 inch = 2.54 centimeters
1 mile = 1.609 kilometers
1 cubic inch = 16.387 cubic centimeters
1 ounce = 28.3495 grams
1 pound = 453.59 grams
1 quart = 0.946 liter
1 gallon = 3.785 liters

1 meter = 39.37 inches
1 kilometer = 0.62 mile
1 cubic meter = 35.314 cubic feet
1 kilogram = 2.2 pounds
1 liter = 1.06 liquid quarts
1 cubic centimeter = 0.061 cubic inch

UNITS

Wave length of sodium light = 0.00005896 centimeter.
1 Horse Power = 550 foot pounds per second.
1 Ångstrom = 1000 X-units = 10^{-8} centimeter.
1 Light Year = 6 million million miles.
1 Gram Atom contains 6×10^{23} atoms.
Diameter of an atom about 10^{-8} centimeter
Mass of an electron = 9×10^{-28} gram.
Diameter of an electron = 10^{-13} centimeter.
Velocity of light = 3×10^{10} centimeters per second.

Appendix III

Relative Humidity by Wet and Dry Bulb Determination

Dry Bulb	*Difference between Dry and Wet Bulb Thermometer*																	
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*20*
	Per Cent of Relative Humidity																		
30	89	78	67	56	46	36	26	16	6										
32	89	79	69	59	49	39	30	20	11	2									
34	90	81	71	62	52	43	34	25	16	8	1								
36	91	82	73	64	55	46	38	29	21	13	5								
38	91	83	75	66	58	50	42	33	25	17	10	2							
40	92	83	75	68	60	52	45	37	29	22	15	7	0						
42	92	85	77	69	62	55	47	40	33	26	19	12	5						
44	93	85	78	71	63	56	49	43	36	30	23	16	10	4					
46	93	86	79	72	65	58	52	45	39	32	26	20	14	8	2				
48	93	86	79	73	66	60	54	47	41	35	29	23	18	12	7	1			
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5	0		
52	94	87	81	75	69	63	57	51	46	40	35	29	24	19	14	9	4		
54	94	88	82	76	70	64	59	53	48	42	37	32	27	22	17	12	8	3	
56	94	88	82	76	71	65	60	55	50	44	39	34	30	25	20	16	11	7	0
58	94	88	83	77	72	66	61	56	51	46	41	37	32	27	23	18	14	10	3
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	6
62	94	89	84	79	74	69	64	59	54	50	45	41	36	32	28	24	20	16	9
64	95	90	84	79	74	70	65	60	56	51	47	43	38	34	30	26	22	18	12
66	95	90	85	80	75	71	66	61	57	53	48	44	40	36	32	29	25	21	15
68	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	31	27	23	17
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	20
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	34	31	28	22
74	95	91	86	82	78	74	69	65	61	58	54	50	47	43	39	36	33	29	24
76	96	91	87	82	78	74	70	66	62	59	55	51	48	44	41	38	34	31	26
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	36	33	28
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	29
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45	42	39	36	31
84	96	92	88	84	80	76	73	69	66	62	59	56	52	49	46	43	40	37	32
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47	44	42	39	34
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48	46	43	40	35
90	96	92	89	85	81	78	74	71	68	65	61	58	56	53	50	47	44	41	37
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50	48	45	42	38
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49	46	43	39
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50	47	44	40
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53	51	48	46	41

Example: The wet bulb reads 70 and the dry bulb reads 78. There is a difference of 8°. We read down the left column to 78 and then across to the column headed 8. The figure 67 is found at the junction of the two lines, therefore the relative humidity is 67 per cent. In other words there is just 67 per cent as much moisture as it is possible at a temperature of 78°.

Appendix IV

Vapor Pressure Table

Temperature Centigrade	*Pressure Millimeters*	*Temperature Centigrade*	*Pressure Millimeters*
0 0	4 6	99 40	744 0
10 0	9 0	99 48	746 2
20 0	17 5	99 55	748 0
30 0	32 0	99 63	750 5
40 0	55.3	99 70	752 2
50 0	110 2	99 78	754.7
60 0	149 5	99 84	756 3
80 0	354 2	99 92	758.0
90 0	525 0	100 00	760.0
99 03	734 0	100 07	762 0
99 10	736.0	100.15	764.0
99 18	738 5		
99 25	740 0		
99 33	742 5		

Vapor Density Table

Temperature		*Water in Grams per cu. m.*	*Temperature*		*Water in Grams per cu. m.*	*Temperature*		*Water in Grams per cu. m.*
C.	*F.*		*C.*	*F.*		*C.*	*F.*	
0	32 0	4 84	14	57 2	11 96	27	80 6	25 49
1	33 8	5 13	15	59 0	12 71	28	82 4	26 93
2	35 6	5 54	16	60 8	13 50	29	84 2	28 45
3	37 4	5 92	17	62 6	14 34	30	86 0	30 04
4	39 2	6 33	18	64 4	15 22	31	87 8	31 70
5	41 0	6 76	19	66 2	16 14	32	89 6	33 45
6	42 8	7 22	20	68 0	17 12	33	91 4	35 27
7	44 6	7 70	21	69 0	18 14	34	93 2	37.18
8	46 4	8 21	22	71 6	19.22	35	95 0	39 18
9	48 2	8.76	23	73 4	20 35	36	96 8	41 30
10	50 0	9 33	24	75 2	21 54	37	98.6	43 50
11	51 8	9 93	25	77 0	22.80	38	100 4	45.80
12	53 6	10 57	26	78 8	24 11			
13	55 4	11 25						

1 cu. m. = about 1.3 cu. yd.

For example, at 10° C. the saturation density of water vapor is 9.33 Gm.

Appendix V

Table of Elements*

Name	*Symbol*	*Atomic Weight*	*Atomic Number*
Actinium	Ac	227 *ca.*	89
Alabamine (now *Astatine*)	Ab	211	85
Aluminum	Al	26.97	13
Americium	Am	.....	95
Antimony (*stibium*)	Sb	121.76	51
Argentum. See *Silver.*			
Argon	A	39 944	18
Arsenic	As	74.91	33
Astatine (formerly *Alabamine*)	At	211	85
Aurum. See *Gold.*			
Barium	Ba	137.36	56
Beryllium (formerly *Glucinum*)	Be	9.02	4
Bismuth	Bi	209 00	83
Boron	B	10 82	5
Bromine	Br	79 916	35
Cadmium	Cd	112 41	48
Calcium	Ca	40.08	20
Carbon	C	12 010	6
Cerium	Ce	140 13	58
Cesium	Cs	132 91	55
Chlorine	Cl	35 457	17
Chromium	Cr	52 01	24
Cobalt	Co	58 94	27
Columbium (*niobium*)	Cb	92 91	41
Copper (*cuprum*)	Cu	63 54	29
Cuprum. See *Copper.*			
Curium	Cm	. . .	96
Cyclonium. See *Illinium.*	Cy	146 *ca.*	61
Dysprosium	Dy	162 46	66
Erbium	Er	167 2	68
Europium	Eu	152.0	63
Ferrum. See *Iron.*			
Florentium. See *Illinium.*	Fl	146 *ca.*	61
Fluorine	F	19 00	9
Francium (formerly *Virginium*)	Fa	224 *ca.*	87
Gadolinium	Gd	156 9	64
Gallium	Ga	69 72	31

* Courtesy, "Blakiston's New Gould Medical Dictionary."

TABLE OF ELEMENTS—(*Continued*)

Name	*Symbol*	*Atomic Weight*	*Atomic Number*
Germanium	Ge	72.60	32
Glucinum. See *Beryllium.*			
Gold (*aurum*)	Au	197.2	79
Hafnium	Hf	178 6	72
Helium	He	4 003	2
Holmium	Ho	164 94	67
Hydrargyrum. See *Mercury.*			
Hydrogen	H	1 0080	1
Illinium (to be renamed)	Il	146 *ca.*	61
Indium	In	114 76	49
Iodine	I	126 92	53
Iridium	Ir	193.1	77
Iron (*ferrum*)	Fe	55.85	26
Kalium. See *Potassium.*			
Krypton	Kr	83.7	36
Lanthanum	La	138 92	57
Lead (*plumbum*)	Pb	207 21	82
Lithium	Li	6 940	3
Lutecium	Lu	174 99	71
Magnesium	Mg	24.32	12
Manganese	Mn	54.93	25
Masurium (now *Technetium*)	Ma	.. ....	43
Mercury (*hydrargyrum*)	Hg	200 61	80
Molybdenum	Mo	95.95	42
Natrium. See *Sodium.*			
Neodymium	Nd	144 27	60
Neon	Ne	20 183	10
Neptunium	Np	239 *ca.*	93
Nickel	Ni	58 69	28
Niobium. See *Columbium.*	Nb		
Niton. See *Radon.*			
Nitrogen	N	14 008	7
Osmium	Os	190 2	76
Oxygen	O	16 0000	8
Palladium	Pd	106 7	46
Phosphorus	P	30 98	15
Platinum	Pt	195 23	78
Plumbum. See *Lead.*			
Plutonium	Pu	239 *ca.*	94
Polonium	Po	210 *ca.*	84
Potassium (*kalium*)	K	39 096	19
Praseodymium	Pr	140 92	59
Promethium. See *Illinium.*	Pm	146 *ca.*	61
Protactinium	Pa	231	91
Radium	Ra	226 05	88
Radon	Rn	222	86
Rhenium	Re	186.31	75
Rhodium	Rh	102 91	45
Rubidium	Rb	85 48	37

TABLE OF ELEMENTS—(*Continued*)

Name	*Symbol*	*Atomic Weight*	*Atomic Number*
Ruthenium	Ru	101.7	44
Samarium	Sa, Sm	150 43	62
Scandium	Sc	45 10	21
Selenium	Se	78 96	34
Silicon	Si	28 06	14
Silver (*argentum*)	Ag	107 880	47
Sodium (*natrium*)	Na	22.997	11
Stannum. See *Tin.*			
Stibium. See *Antimony.*			
Strontium	Sr	87 63	38
Sulfur, sulphur	S	32 066	16
Tantalum	Ta	180.88	73
Technetium (formerly *Masurium*)	Te	. . . .	43
Tellurium	Te	127 61	52
Terbium	Tb	159.2	65
Thallium	Tl	204 39	81
Thorium	Th	232 12	90
Thulium	Tm	169.4	69
Tin (*stannum*)	Sn	118 70	50
Titanium	Ti	47 90	22
Tungsten (*wolframium*)	W	183 92	74
Uranium	U	238 07	92
Vanadium	V	50 95	23
Virginium (now *Francium*)	Vi	224 *ca.*	87
Wolframium. See *Tungsten.*			
Xenon	Xe	131 3	54
Ytterbium	Yb	173.04	70
Yttrium	Y, Yt	88 92	39
Zinc (*zincum*)	Zn	65 38	30
Zincum See *Zinc.*			
Zirconium	Zr	91.22	40

Appendix VI

Glossary of Nuclear Physics Units

Alpha Particle. A helium nucleus. It consists of two protons and two neutrons.

Deuterium. A heavy hydrogen atom having twice the mass of an ordinary hydrogen atom.

Deuteron. An ion of heavy hydrogen (deuterium).

Electron. A unit of negative electrical charge. Its mass is $1/1835$ that of the proton. Its charge is 1.6×10^{-19} coulomb.

Gamma Ray. A radiation emitted by some radioactive substances and having a very short wave length.

Isotope. Best explained by an example. The metal uranium is composed of three isotopes (atoms having the atomic weights of 238, 235, and 234), although each atom of uranium has the same atomic number, 92. Most elements are made up of several isotopes. The isotopes of an element are chemically alike. Atoms of two isotopes have the same number of protons in their nuclei.

Meson. A mass particle which is about 200 times the mass of an electron. It is found as a positively $(+\epsilon)$ and as a negatively $(-\epsilon)$ charged particle. It is found in cosmic radiation and has been produced in the laboratory.

Neutron. A particle having no electric charge. The mass is nearly that of the proton, having a value of 1.675×10^{-24} Gm. It is a constituent of atomic nuclei.

Nucleon. A nuclear particle either neutron or proton.

Photon. A quantum of energy.

Plutonium. An element not found in nature. Its atomic weight is 239 and its atomic number is 94. It was discovered in the process of nuclear disintegration research.

Positron. A particle having the mass of an electron but with a positive charge equal to that of the electron.

Proton. A hydrogen ion of mass 1.6×10^{-24} Gm.

Appendix VII

The Uranium Radioactive Series

Element	*Symbol*	*Half Life*
Uranium	$_{92}U^{238}$	4×10^9 years
Thorium	$_{90}Th^{234}$	24 days
Protactinium	$_{91}Pa^{234}$	1.2 minutes
Uranium	$_{92}U^{234}$	2.6×10^5 years
Thorium	$_{90}Th^{230}$	8×10^4 years
Radium	$_{88}Ra^{226}$	1600 years
Radon	$_{86}Rn^{222}$	3.8 days
Polonium	$_{84}Po^{218}$	3 minutes
Lead	$_{82}Pb^{214}$	26 minutes
Bismuth	$_{83}Bi^{214}$	20 minutes
Polonium	$_{84}Po^{214}$	1.5×10^{-4} second
Thallium	$_{81}Tl^{210}$	1.3 minutes
Lead	$_{82}Pb^{210}$	22 years
Bismuth	$_{83}Bi^{210}$	5 days
Polonium	$_{84}Po^{210}$	139 days
Lead	$_{82}Pb^{206}$	Stable

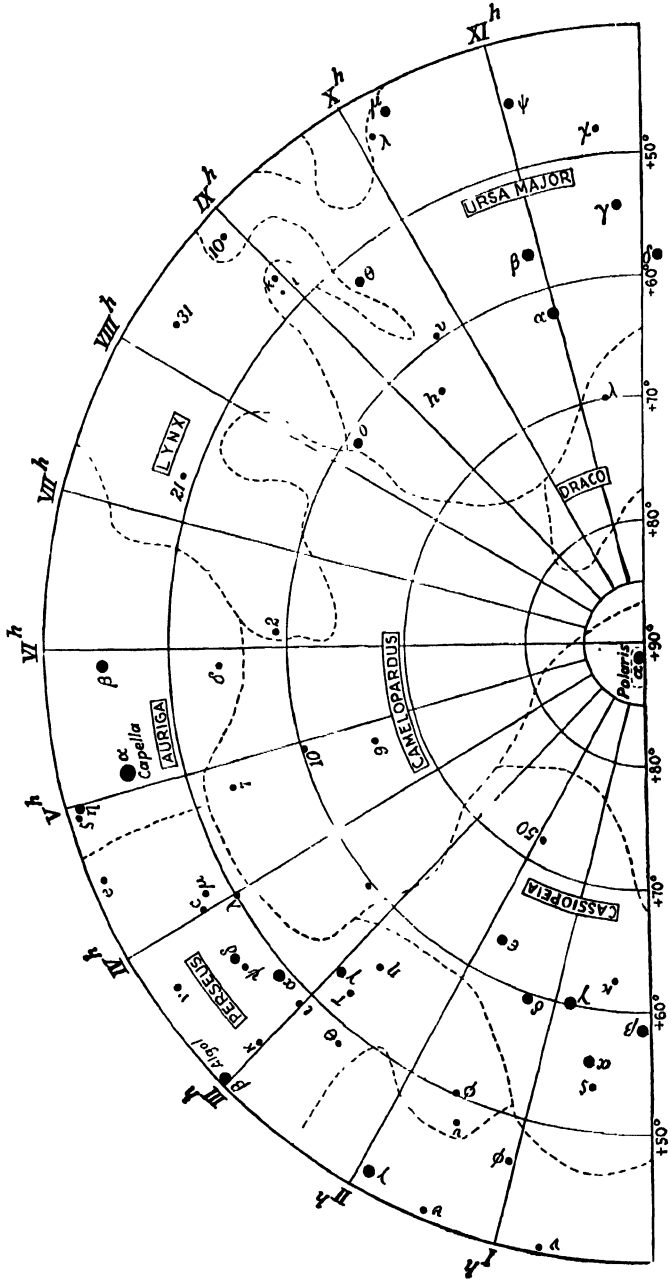


CHART 1. The north circumpolar group. *(Fath: "Elements of Astronomy," The McGraw-Hill Book Co.)*

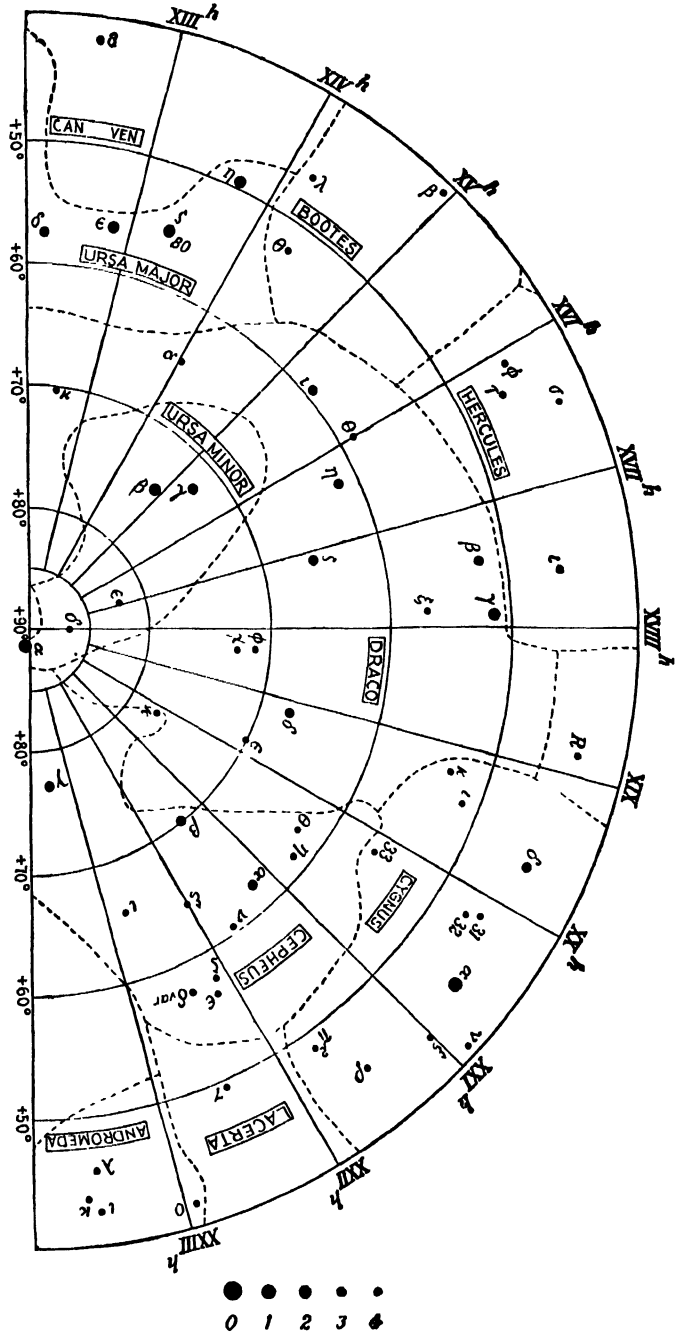


CHART 2. The north circumpolar group. *(Fath: "Elements of Astronomy," The McGraw-Hill Book Co.)*

Review Questions

Note. Some of these questions require reference reading.

CHAPTERS 1–7

1. Why do some stars rise and set?
2. Why do some stars never set?
3. A star rising at 7 P.M. April 1 will rise at what time June 15?
4. Do all parts of the earth have a full moon during the same 24 hours?
5. Would it be correct for the people of Chile to say that winter was due to the fact that the sun was furthest from the earth?
6. What is the cause of twilight?
7. Would the earth have tides if there were no moon?
8. What is the cause of a ring around the moon?
9. Many telescopes are placed on mountains. Why?
10. What is meant by a light year?
11. Many modern telescopes use a concave mirror rather than an objective lens. Why?
12. What is meant by the Vernal Equinox? Where is it?
13. What reasons did Galileo give for his belief that the sun rather than the earth is the center of the solar system?
14. Describe some methods by which astronomers measure great distances.
15. What is the Milky Way?
16. Some nebulae are believed to be millions of light years distant. How do we know this?
17. If the sun were to become cooler, how would this affect our habits of living?
18. Calculate the time required for light to reach the earth from Jupiter and Neptune.
19. Is the sun a gas or a liquid? Explain.
20. Why do we not use the Nebular Hypothesis?
21. How was Pluto discovered?
22. How do we know that no air exists on the moon?
23. What planets may have life? Explain.
24. Why are "shooting stars" hot?
25. What proofs have we that the earth rotates on its axis?
26. Does the sun ever reach the zenith at latitude 45° North? At longitude 75° West?
27. Are tides ever observed in solid rock?
28. Distinguish between rotation and revolution.
29. How rapidly does the earth rotate?
30. What is the Ecliptic? Where is it?
31. What parts of the sun are visible at the time of a total eclipse?
32. How does the astronomer determine the composition of the sun?
33. How can we determine the temperature of the sun?
34. At what time of year are we at aphelion?
35. At what point on the earth's surface will the sun be directly overhead on March 21?
36. Are earthquakes prevalent in volcanic regions?
37. What are some of the causes of earthquakes?

38. What types of material issue from a volcano?
39. Are there any volcanoes active in continental United States?
40. If you were in an earthquake zone, what type of building would you erect? Why?
41. Why do we see only one side of the moon?
42. It is often said that "the planets nod to each other as they pass." What is meant?
43. Why do stars twinkle?
44. Why is the sun red at evening and yellow at noon?
45. Why do stars differ in color?
46. How can we prove that the sun rotates?
47. What is the Zeeman effect? What importance has it in astronomy?
48. List the planets in order of distance from the sun.
49. What are novae?
50. The diameters of several stars have been measured. Find out how this was done.
51. What is the difference between a constellation and a cluster?
52. What is: a galaxy? a star universe?
53. List 10 constellations that you have learned to know.

CHAPTERS 8–12

1. The statement is often made that the equinoxes are times of stormy weather. Is this true?
2. Does carbon dioxide benefit man? Explain.
3. Could we live without nitrogen?
4. Just why do we think that the earth is very old?
5. Why is pure aluminum not used in structural work?
6. What is meant by the term steel?
7. How can we measure the thickness of the atmosphere?
8. What is to hinder a rocket from leaving the earth and moving out into space?
9. What are the causes of volcanoes?
10. How can we explain the presence of coal in the Antarctic?
11. On a hot day a fully inflated tire sometimes leaves the rim. Explain.
12. Just what does a barometer measure?
13. Why does the air become warmer when snow is falling?
14. What is the difference between a tornado and a cyclone?
15. What causes sea breezes at the sea shore?
16. How can the Weather Bureau predict weather?
17. Why do we believe that the centrosphere may contain much iron?
18. What is a fossil? Name some.
19. What is meant by the term *unconformity?* What does it teach us about earth structure?
20. Can you account for the disappearance of the dinosaurs of the Mesozoic Era?
21. Why is there coral and limestone in continental United States?
22. Explain the causes of coal formation in the United States?
23. For what is the Paleozoic Era noted?
24. Does the Milky Way change its position relative to the stars?
25. How many stars are there in our galaxy?
26. Name the geologic eras and give the periods of each.
27. In what era do we find the oldest limestone? the first fossils? the first vertebrate life? the first true man?
28. In what era did life first appear?
29. Is a vacuum empty of all material?
30. What were the achievements of Lavoisier?

31. Is gasoline a compound? Explain.
32. How are limestone caves formed?
33. Give two important uses of clouds.
34. What causes winds to spring up?
35. What is the cause of highs?
36. Distinguish between rocks and minerals.
37. Describe the manufacture of glass.
38. What is meant by: Bessemer steel? open hearth steel?
39. How does hardness differ from brittleness?
40. Draw a diagram of the forces on an airplane.
41. What is meant by the statement "Nature abhors a vacuum."
42. Describe an aneroid barometer.
43. The cap on a gasoline tank has a hole in it. Why?
44. Describe a siphon.
45. Why does a swimmer who stays in water for several hours sunburn even though the day be cloudy?
46. Why is mercury better than water for barometers?
47. Why can we suck soda through a straw?
48. Explain how a balloonist descends.
49. What are causes of ground water?
50. What purpose does dry farming accomplish?
51. What is the cause of an artesian well? Have you seen such a well?
52. Explain the cause of a geyser. Where do we find geysers?
53. Draw a diagram of a rock structure which would make an artesian well possible.
54. Where do we find glaciers in the United States?
55. Where do we find regions of extensive glaciation?
56. Name several types of glaciers.
57. How can you distinguish between: feldspar and limestone? quartz and feldspar? quartz schist and mica schist?
58. What is a mesa? How was it formed?
59. What is the average ocean depth?
60. Distinguish between minerals and rocks. Name four of each.
61. Will the Antarctic continent ever be valuable?
62. Is pure gold useful?

CHAPTERS 13–20

1. Are cathode rays the same as x-rays?
2. For what is Millikan noted?
3. What does the word *quantum* mean to you?
4. Does every object contain electrons?
5. What are two theories of light propagation? Explain the difference between them.
6. What are: molecules? atoms?
7. What is a Crookes tube?
8. Describe the process of catalysis.
9. Distinguish between element and compound.
10. What is hydrogenation? Give a commercial use.
11. Name 10 chemical compounds that you can buy in a grocery store.
12. Write a biography of Priestley.
13. What do the following terms mean: oxidation? element? combustion? spontaneous combustion?
14. What two types of hard water exist? How do we make each type useful in industry and in the home?

15. What is an ion? How does it differ from an atom? Give four examples.
16. What is a detergent? Give examples.
17. Why is a 1 per cent solution of hydrochloric acid more acid than a 1 per cent solution of acetic acid?
18. Explain the process of plating a spoon with silver.
19. Give biographical sketches of four Nobel prize winners.
20. What is: nitroglycerine? mustard gas? TNT? bakelite? penicillin? streptomycin?
21. What is electrolysis?
22. What is osmosis? Give examples.
23. Describe the principle of dissociation.
24. What is meant by the statement that a soap is 99.44 per cent pure?
25. How would one identify a liquid as a solution or a colloid?
26. List some explosives and give their properties.
27. How would you remove an ink spot?
28. Why are eyes blue?
29. How is the water in your community purified?

CHAPTERS 21–26

1. Do all bodies really fall with the same acceleration?
2. Gravitation helps to keep the moon in its orbit. Explain.
3. Would a man weighing 150 lb. on earth weigh more on Mars?
4. In what direction does the mud thrown from a moving wheel travel?
5. Does a body ever lose its weight?
6. Why not replace a fuse plug by a penny?
7. Name four conductors and four insulators?
8. Why does a compass point north?
9. How does a bar magnet differ from an ordinary iron bar?
10. Why do we use high voltage on long distance transmission lines?
11. Of what use is a photocell in sound movies?
12. How is the temperature of the body kept constant?
13. Is the law of conservation of energy always true?
14. Can a temperature exist which is below −453° F.?
15. Will boiling water always injure the skin?
16. Why is "dry ice" called dry?
17. Why are we sometimes chilled by a fan?
18. For what was Marconi famous?
19. Why does a motion picture machine jerk just 24 pictures per second across the screen?
20. What is mean by weight?
21. Why is skidding the result of rapid turning?
22. Name and describe the different types of coal.
23. On high mountains food will not cook if the water is boiled in open vessels. Explain.
24. Why is a perpetual motion machine improbable?
25. Make a list of energy transformations in the home.
26. Why do we not need a carburetor on a Diesel engine?
27. Can you explain why we see objects erect although the image on the retina is inverted?
28. Why must we be careful not to pour boiling water into a thick tumbler?
29. When pumping up a tire with a hand pump, we notice that the pump becomes hot. Why?

30. Would it be satisfactory to open the refrigerator door to cool the kitchen in summer?
31. What is the length of a closed organ pipe that emits a pitch of 300 vibrations per second when the velocity of sound is 1200 feet per second?
32. What is the intensity of illumination of a 100 candle power lamp at a distance of two feet?
33. What is the speed of light: in a vacuum? in water? in crown glass?
34. What are some uses of ultraviolet rays?
35. What is an electrical condenser? Where do we find them?
36. Write biographies of Alexander Graham Bell and Heinrich Hertz.
37. Why not use a door bell transformer as a home lighting transformer?
38. What does 85° F. represent in centigrade?
39. Inasmuch as perpetual motion is improbable, why does the earth continue to rotate and revolve?
40. What is the principle of a wedge?
41. Why do we shift gears when we climb a hill?
42. Can we "let in the cold"?
43. Why do clothes freeze dry on a cold windy day?
44. Why do we find snow on mountain tops in summer?
45. Is a "magnetic" person really magnetic?
46. Why can birds sit safely on a high tension wire?
47. How much energy has a 5 lb. brick on the roof of a house 30 ft. high?
48. Is friction always useful?
49. Does the weight of a body vary during the day?
50. Explain the action of a rotary sprinkler.
51. Give four examples of centrifugal force in the home and on the farm.

INDEX

A

Abrasion, 269
Absolute humidity, 166
  magnitude, 30
  zero, 148, 302
Acceleration, 286
Acetate, 278
Acetic acid, 212
Acetylene, 221
Acids, 212
Acoustics, 327
Adrenaline, 242
Aeration, 250
Agassiz, Louis, 105
Agate, 89
Air, 143
  brakes, 154
  conditioning, 178–180
  extent of, 150
  masses, 173
  pressure, 151
  weight of, 150
Airplane, 157, 291
Alchemy, 202
Aldebaran, 22
Alizarin, 225
Alloys, 138
Alnico, 141
Alpha Centauri, 23
  ray tracks, 188
  rays, 411, 430
Alternating current, 379, 386
Alternator, 390
Altimeter, 154
Aluminum, 137, 140
Amber, 89
Amethyst, 115
Ammonia, 144, 311
  refrigerant, 246
Ammonium cyanate, 219
  hydroxide, 256
Ampere, 365
Anastigmat, 352
Anderson, Carl, 417
Andromeda, 21, 35
Aneroid barometer, 154
Ångström, A. J., 197, 358, 401
Annular eclipse, 43
Anode, 211
Anthracite, 122
Anticline, 86
Anticyclone, 166
Aphelion, 62
Apogee, 38
Apparent magnitude, 30
Archeozoic era, 90
Archimedes, 1, 248
Arctic drift, 99
Arcturus, 31
Argillaceous rocks, 118
Argon, 339
Aristotle, 1, 12, 183
Aromatics, 222
Arrhenius, Svante, 209
Artesian well, 101
Artificial transmutation, 414
Asbestos, 132
Asphaltum, 119
Aspirin, 225
Asteroid, 52
Astigmatism, 355
Astral period, 96
Astrology, 49, 71, 203
Atmosphere, 66, 143
  experiments, 158
Atom, 183
  bomb, 416
  experiments, 201
  fission, 416
  models, 186
  radioactive, 414
  size of, 183
  solar system, 191
  transmutation, 414
Atomic weights, 207
  table of, 427
Audion, 397
Aurora, 11, 376
Autumnal equinox, 64
Azoic period, 90

B

Bacteria, 109, 359
"Bad Lands," 107
"Baily's Beads," 38, 43
Bakelite, 280
Baking soda, 214
Balloons, 156

Barometer, 153
Basalt, 121
  layer, 67
Bases, 212
Beats, 331
Becquerel, Antoine H., 186, 404
Bell, Alexander Graham, 393
Bemberg, 277
Benedict's reagent, 243
Bentley, Wilson, 170
Benzene ring, 223
Benzine, 129
Beryllium, 200, 414
Betelgeuse, 7, 21, 24
Bethe, Hans, 19
Bituminous coal, 118
Blake deep, 96
Blast furnace, 205
Bohr, Niels, 196
Boiling point, 309
Borax, 252
Boric acid, 214
Boyle's Law, 148
Brachiopod, 92
Brass, 140
Breccia, 118
British thermal unit, 302
Broadcasting band, 400
Bromine, 214, 415
Brontosaurus, 94
Bronze, 140
Brooke's comet, 57
Brownian motion, 185
Buoyancy, 155, 248
Byrd, Admiral Richard, 105

C

Caesar, 81
Caisson, 154
Calcareous rock, 118
Calcite, 116, 406
Calcium carbonate, 115
    chloride, 257
    hydroxide, 213, 252
Calendar, 81
Calendar reform, 81
Calm belts, 161
Caloric, 301
Calorie, 302
Cambrian Period, 92
Camera, 350
Canaries current, 99
Cancer, constellation of, 49
Candle power, 339
Capella, 23, 29
Carbohydrates, 230
Carbolic acid, 223
Carbon bonds, 220
    bulb, 51, 144
    compounds, 221
    dioxide, 144, 204
    monoxide, 204
    tetrachloride, 222, 269
Carbonaceous rock, 118
Carbonates, 115
Casein plastics, 279
Cassiopeia, 30
Castor oil, 225
Catalyst, 19, 130, 275
Cathode, 404
  rays, 403
Celanese, 277
Celestial equator, 24, 80
Cellophane, 277
Cellulose, 277
  acetate, 277, 361, 380
  nitrate, 277
  products, 277
Cement, 133
Cenozoic era, 94
Centigrade thermometer, 304
Centrifugal force, 288
Centrosphere, 66
Cepheid variable, 33
Ceres, 52
Cesium, 195
Chadwick, James, 414
Chalcedony, 89
Chamberlin, Thomas, 58
Change of state, 307
Charles' Law, 148
Chemical energy, 202
    experiments, 217
    formulas, 206
    symbols, 206
    table, 214
    warfare, 215
Chemistry, 202
  experiments, 217, 229
  organic, 219
Chlorination, 250
Chlorine, 214
Chloroform, 222
Chlorophyll, 144, 342
Chloroprene, 227
Chromium steel, 140
Chromosphere, 8
Circumpolar whirl, 164
Citric acid, 210, 214
Civil day, 77
Cleansing, 265
  experiments, 271
Cleavage of rocks, 111
Clock, 82
Clothing, 272

Clouds, 170
cumulo-nimbus, 166
Coagulation, 250
Coal, anthracite, 123
bituminous, 119
Coal products, 131
Sack, 23
tar, 132
Cochineal, 225
Cochlea, 326
Coke, 132
Cold front, 174
Colloid, 90, 185, 259
Brownian motion in, 185
experiments, 264
formation of, 261
preparation of, 261
Color, 342
blindness, 344
photography, 344
Combustion, 204
Comet, 55
Compass, 377
Compound microscope, 349
Compressed air, 154
Compton, A. H., 417
Concrete, 133
Concurrent forces, 290
Condenser, 357, 370, 397
Conduction of heat, 312
Conductor, electrical, 371
Conglomerate, 118
Conjunction, 42–43
Conservation of energy, 284
Consonance, 332
Constellations, 21
Contact lens, 355
Convection, 312
Coolidge, W. P., 339, 404
Coolidge tube, 405
Copernicus, 1, 53, 65, 121
Copper, 136–140
Cordite, 215
Corex, 134
Cornea, 354
Corona, 8, 389
Corpuscle, 196
Cosmic rays, 417
Cotton, 274
Cotton-seed oil, 130
Cottrell process, 262
Crater,
lunar, 40
Meteor, 40
Crater Lake, 67
Crisco, 232
Cro-magnon man, 95
Crookes tubes, 403
Crystallography, 112
Crystals, 112
Cubic crystals, 112
Cullinan diamond, 114
Curie, Irene, 414
Marie, 404, 411
Current, alternating, 379, 386
direct, 366, 371
Cycle, 398
Cyclone, 164
Cyclotron, 200
Cygnus, 413

D

Dalton, John, 183
Date line, 80
Davisson, C. J., 349
Davy, Humphrey, 208
Dead spots, 329
Decibel, 326
Declination, 28, 80
DeForest, Lee, 397
Density of air, 151
Destructive distillation, 142
Detergents, 268
Deuterium, 430
Deuteron, 200, 430
Devonian Period, 93
Dew, 168
point, 169
Diabase, 121
Diamonds, 113
Diastrophism, 84
Diatonic scale, 331
Diesel engine, 318
Diet, 230
Diffraction grating, 194, 197, 336
Digestion, 202, 232
Diopter, 347
Diorite, 126
Diplodocus, 94
Direct current, 391
Dirigible, 157
Dirt, 265
Dispersion, 345
Distillation, 250
Doldrums, 162
Dolomite, 118
Doorbell, 384
Doppler principle, 9, 51
Double Star Theory, 59
Dowmetal, 140, 149
Drifts, ocean, 96
Drought, 167
Drugs, 225
Dry cell, 371
cleaning, 269
ice, 310

Duco, 219
Duralumin, 138
Dust Bowl, 107
Dyes, 224
Dynamic speaker, 394

E

Ear, 325
Earth, 62
  age of, 70
  changing crust of, 84
  as a clock, 74
  experiments, 73
  as a magnet, 377
  as a planet, 62
  seasons, 62
  shine, 44
  structure, 66
Earthquake, 69
  waves, 69
Eastman Theater Auditorium, 328
Echo, 327
Eclipse, 42
Ecliptic, 49
Edison, Thomas, 339, 380, 393
Edison lamp, 339
Efficiency of, light sources, 341
  machines, 297
  transformers, 388
Einstein, Albert, 18, 35, 289, 415
Electric clock, 82
  motor, 392
Electrical current, 366, 371
  experiments, 381, 402
  heating, 393
  power, 365, 368
  units, 364
Electricity, 364
  condenser, 370
  experiments, 381, 401
  insulator, 370
  safety precaution, 368
  static, 369
Electrolysis, 208
Electromagnet, 384
Electromagnetic, induction, 387
  spectrum, 198
  waves, 336, 394, 396, 404
Electromagnetism, 378
Electron, 187, 286, 336, 366, 379, 430
Electron gun, 357
  microscope, 185, 349
  volt, 415
Electroplating, 211
Element, 206
Emerald, 114
Emulsification, 265
Emulsions, 269
Energy, 193, 283
  conservation of, 284
  transformation of, 285
Engine,
  Diesel, 318
  internal combustion, 318
  steam, 316
Enzymes, 234
Eosin, 354
Epsom salt, 214
Equations, chemical, 207
Equinoxes, 64
Equivalence of matter and energy, 18
Era, 85
Erg, 415
Ergosterol, 358
Eros, 53
Erosion, 99, 107
Ether, ethyl, 269
Ether, the, 194
Ethyl alcohol, 222
  gasoline, 129
Ethylene, 223
Ethylene glycol, 223, 257
Evaporation, 308
Everest, Mt., 96
Expansion, 305
  coefficient of, 306
Explosives, 215
Eye, 354, 358

F

Fahrenheit thermometer, 304
Faraday, Michael, 208, 223, 384, 387, 391, 395
Farnsworth, Philo, 356
Fats, 231
Feldspar, 117
Fermi, Enrico, 415
Ferrel's Law, 163
Film, color, 343
  motion picture, 358
  photographic, 351
  sound, 358
Filtration, 250
Fission theory, 60
Flax, 273
Fleming, Ambrose, 397
Fluorescence, 112, 340, 359
Fluorine, 192
Fluorite, 359
Foams, 260
Focal length, 347
Fog, 169
Food value, table, 234
Foods, 230

Foot-candle, 342
Force, 287
Formulas, 206
Fossil, 72, 84, 87, 91
  fish, 116
Foucault pendulum, 65
Franklin, Benjamin, 370
Franklin Institute, 14
Fraunhofer, J., 23
Fraunhofer lines, 8, 16, 23
Freon, 222, 310
Frequency, 194
Frequency modulation, 400
Friction, 298
Frost, 169
Fuel values, 311
Fur, 276
Fuses, 367
Fusion, heat of, 307

G

Galaxy, 34
Galileo, 1, 12, 53, 54, 143, 287, 304, 346
Galle, Johann, 55
Galton whistle, 335
Galvanometer, 386
Gamma ray, 197, 200, 412, 414, 430
Garden of the Gods, 107
Garnet, 122
Gas refrigerator, 311
Gases, nature of, 147
Gasoline, 129
  engine, 317
Gastric digestion, 235
Geber, 202
Geiger counter, 418
Gel, 261
Gemini, 49
Gems, 113
Generator, 390
Geologic ages, 85, 90, 144
  table of, 85
German silver, 140
Geyser, 102
Glacial periods, 106
Glaciers, 104
Glass, 133
Glycerin, 223
Gneiss, 90, 108, 122
Gold, 137
Grand Canyon, 86, 90, 103
Granite, 108, 120
Gravitation, 287
  theory of, 289
Grease removal, 269
Greenhouse, 315
Greenwich, 78
Gregorian calendar, 81
Ground water, 100
Gulf Stream, 99, 312
Guncotton, 215
Gunn, Ross, 59
Gunpowder, 215
Gypsum, 117
Gyroscope, 378

H

Hail, 169
Hair hygrometer, 168
Hale, George, 10, 14, 379
Halley's comet, 56
Halo, 38
Hard water, 252
Hardness scale, 111
Harmonics, 327
Heat, 301
  conduction of, 312
  convection, 312
  experiments, 320
  fusion of, 307
  radiation of, 313
  transfer of, 312
  of vaporization, 308
Heliocentric parallax, 33
  system, 12–13
Helium, 16, 146, 155, 200, 411
Helmholtz, Hermann, 18, 344
Hematite, 135
Hemp, 274
Henry, Joseph, 387
Hershel, William, 54
Hertz, Heinrich, 395
High pressure area, 166
Hoar frost, 169
Hormones, 242
Hornblende, 117
Horse latitudes, 163
  power, 293
Hot air furnace, 312
Hour glass, 82
Household chemicals, 214
Humidiguides, 168
Humidity, 166, 179
  measurement, 168
  tables of, 425
Humus, 109
Hurricane, 164
Huygens, Christian, 82
Hydraulic press, 246
Hydrocarbons, 129, 221
Hydrochloric acid, 210
Hydrofluoric acid, 339
Hydrogen, 192
Hydrogen chloride, 210

Hydrogenation, 130, 275
Hydrometer, 247
Hydroquinon, 352
Hydrosphere, 66, 96
  experiments, 110
Hydroxyl ions, 212
Hyperopia, 355
Hypo, 257, 352

I

Iatro-chemistry, 203
Ice, 89, 104, 245, 307
Iceberg, 104
Iceland, 102
Iconoscope, 357
Igneous rock, 119
Illumination, 339–342
Inclined plane, 297
Index of refraction, 345
Indicators, 218
Indigo, 225
Induced currents, 388
Inductance, 397
Infrared, 354
Ink stains, 270
Insolation, 63
Insulators, 370
Insulin, 242
Interference, 194, 336
Internal combustion engine, 318
International Date Line, 80
Intestinal digestion, 235
Ionization, 208, 413
Ionosphere, 11, 208, 399
Ions, 192, 209
Iron, 137, 192
Isomer, 219
Isotopes, 414, 430

J

Jaggers, Dr., 68
Japan current, 99
Jasper, 89
Jeans, James, 58
Joliot, Frederick, 414
Jolly, John, 288
Joule, Prescott, 301
Julian calendar, 81
Jupiter, 53, 143
Jurassic, 94
Jute, 274

K

Keewatin, 106
Kekulé, Frederick, 223
Kepler, Johannes, 49, 76, 287
Kepler's Laws, 76
Kerosene, 129
Kilauea, 67
Kilocycle, 396
Kilowatt hour, 367
Kinetic energy, 284, 396
Kodachrome, 343
Krakatoa, 67
Krypton, 143, 146

L

Land, Edwin, 361
Land breeze, 162
Langmuir, Irving, 191
Laplace, Pierre, 58, 66, 90
Latitude, 78
Lava, 68
Lavoisier, Antoine, 144, 211
Law of areas, 76
  gravitation, 287
  machines, 297
Lawrence, Ernest, 413
Laws of motion, 287
Lead, 137
Leavitt, Henrietta, 33
Leavitt-Shapley Law, 34
Legume, 109
Lens, 346
  contact, 355
Lever, 294
Lever applications, 296
Lift pump, 152
Light, 336
  efficiencies, table of, 341
  experiments, 362
  monochromatic, 336
  polarized, 359
    speed of, 8, 31, 345
  sources, 341
  year, 22, 37
Lightning, 372
Lightning rods, 374
Lignite, 118
Limestone, 116, 118
Limewater, 252
Line spectrum, 15, 196
Linen, 273
Linseed oil, 232
Liquid air, 145
Lithium, 415
Lithosphere, 66
Loadstone, 376
Loam, 109
Longitude, 78
Loud speakers, 394
Low pressure areas, 165

Lowell, Percival, 51, 55
Lowell Observatory, 55
Lucite, 135
Lumen, 339
Lunar eclipses, 43
Lupus, 359
Lye, 212
Lyra, 74

M

Machines, 283, 294
  experiments, 300
Magellanic clouds, 33
Magnesium hydroxide, 213
  sulfate, 214
Magnetic compass, 378
  force, 391
  storms, 11
Magnetism, 376
Magneto, 286
Magnets, 376
Magnification, 183, 348
Major scale, 331
Marble, 116, 123
Marco Polo, 346
Marconi, Guglielmo, 397
Marimba, 333
Mars, 7, 49, 51, 305
Matter, states of, 307
Mauna Loa, 68
Mauve, 224
Maxwell, James Clerk, 394
Mean solar time, 76
Mechanical advantage, 297
  refrigerator, 310
Mechanism of speech, 334
Medicines, 225
Melamine, 280
Mendeléef, Dimitri, 185
Mercury, 43, 50, 138, 153, 340
  arc, 359
  barometer, 153
  metal, 138
  oxide, 204
  planet, 50
Meridian, 74, 76
Mesa, 103
Meson, 417, 430
Mesozoic era, 94
Metals, 135
Metamorphic rocks, 121
Meteor Crater, 40
Meteorites, 57
Meteors, 18, 55
Methacrylates, 280
Methane, 221
Methanol, 222
Metol, 352
Mica, 117
Mica schist, 122
Michelson, Abraham, 31
Micron, 259
Microphone, 364
Microscope, 183, 346, 348
  compound, 349
  electron, 349
  experiments, 363
  resolving power, 350
  simple, 348
Microwave, 400
Midnight sun, 64
Milk of magnesia, 213
Milky Way, 34
Millikan, Robert, 186, 417
Millon's Reagent, 282
Minerals, 111
Minor scale, 332
Mirror, 14, 338
Mississippian period, 93
Molecule, 183
  motion of, 148
Monel metal, 140
Monochromatic light, 336
Monsoons, 162
Month, 41, 74
Moon, 38, 74, 336
  craters, 39
  eclipses, 42
  experiments, 48
  motion, 41
  origin of, 47
  phases of, 41
  temperatures, 41
Mormon Tabernacle, 325
Mosaic, 357
Motors, 392
Moulton, F. R., 58
Mt. Everest, 96
Mt. Palomar, 14
Mt. Wilson Observatory, 11, 14
Music, 331
Musical instruments, 333
Mustard gas, 216
Myopia, 355

N

Naphthalene, 223
Nature of gases, 147
Nebulae, 35
Nebular hypothesis, 58, 90
Neon, 343
Neoprene, 227
Neptune, 54
Neuron, 356

Neutralization, 213
Neutron, 189, 200, 411, 414, 430
New Zealand, 102
Newcomen, Thomas, 316
Newton, Isaac, 2, 15, 183, 194, 200, 287, 336, 395
Niacin, 239
Niagara Falls, 72, 103
Nickel, 140
Nitrocellulose, 278
Nitrogen, 144
Nitrogen fixing bacteria, 109
Nitroglycerin, 215
Nobel, Alfred, 215
Noise, 331
Nonfreeze mixture, 257
North Circumpolar group, 29
Northern Lights, 376
Novae, 23
Nuclear disintegration, 203, 414
Nucleon, 414, 430
Nucleus, 200
Nujol, 129
Nutrition, 230
  experiments, 243
Nylon, 278

O

Obelisk, 82
Obsidian, 120
Ocean currents, 96
  deeps, 330
Oceans, 96
Octane, 221
Oersted, H. C., 378, 384, 392
Ohm, George Simon, 365
Ohm's Law, 365
Oil drop apparatus, 188
Old Faithful geyser, 103
Oleomargarine, 232
Opal, 115
Opium, 225
Opposition, 42
Optical pyrometer, 134
Orbit, 77
Ordovician period, 92
Ores, 135
Organ of Corti, 326
Organic synthesis, 220
Orion, 7, 21
Orion nebula 36
Orthochromatic, 354
Oscillation, 395
Oscillator, 413
Osmosis, 226, 257
Overtones, 327
Oxidation, 204
Oxygen, 144
Ozone, 150

Paleozoic era, 91
Panchromatic, 354
Paracelsius, 203
Paraffin, 119
Parallax, 32
  heliocentric, 33
Parawax, 129
Paricurín, 67
Pearl, 115
Peat, 118
Pelee, Mt., 68
Pendulum, 82
  oscillations of, 82
Pennsylvanian period, 93
Pentane, 129
Peptization, 266
Perfumes, 225
Perihelion, 62
Period, geologic, 85
Periodic Table, 184
Perkin, William, 132, 224
Permalloy, 140
Perpetual motion, 298
Perrin, Jean, 185
Perturbations, 55
Petrified forest, 89
Petroleum, 119, 128
  products, 129
Phenol, 223
Phenolphthalein, 226
Philosopher's Stone, 202
Phosgene, 216
Phosphorescence, 409
Photoelectric cell, 195, 356, 357
Photographic film, 351, 356
Photography, 352
  experiments, 363
Photomicrograph, 349
Photon, 336, 430
Photosphere, 8
Piezoelectric effect, 324
Pisces, 49
Pitch, 324
Pitchblende, 135, 411
Planck, Max, 195
Planetarium, 49
Planetary wind belts, 161
Planetesimal hypothesis, 58, 90
Planets, 49
  experiments, 61
  table of, 50
Plastics, 279, 355
  melamine, 280

Plastics–(*Continued*)
methacrylates, 280
nylon, 278, 280
phenol, 280
polystyrene, 281
urea formaldehyde, 280
vinyl, 281
Platinum, 137
Pleistocene period, 87, 94, 105
Plesiosaurus, 94
Pluto, 55
Plutonic rock, 120
Plutonium, 416, 430
Poison gas, 216
Polaris, 24, 80
Polarized light, 194, 359
Polaroid, 361
Polonium, 411
Polystyrene, 281
Pompeii, 69, 90
Pororoca, 47
Positron, 215, 417, 430
Potassium bromide, 352
hydroxide, 266
Potential difference, 364, 374
energy, 283, 396
Power, 293
Precipitation, 168
Presbyopia, 355
Pressure of air, 150, 246
Prevailing westerlies, 99, 164, 175
Priestley, Joseph, 145, 204
Prism, 15
Prominences, 8
Proterozoic era, 91
Proton, 22, 189, 200, 411, 430
Proxima Centauri, 58
Pterodactyl, 94
Ptolemy, 11, 12
Pumice, 120
Purification of water, 249–251
Pyrex, 133
Pyrite, 117
Pyrometer, 134
Pyroxine, 118

Q

Quadrature, 42
Quality of tone, 326
Quanta, 336
Quantum theory, 195, 405
Quartz, 89, 115, 116, 324
Quartzite, 108, 122

R

Radar, 400
Radiation, 193, 197
experiments, 201
Radical, 207
Radio receivers, 399
tube, 398
waves, 394
Radioactivity, 72, 403, 409
experiments, 418
Radioiodine, 416
Radiometer, 314
Radiosodium, 417
Radium, 18, 72, 135, 411, 414
Radon, 200, 411, 414
Rain, 169
Rainbow, 151, 345
Ramadan, 74
Rancho La Brea, 87
Rayon, 277
Receiving set, 345
Reduction, 204
Reflection, of light, 338
of sound, 325
Refraction, index of, 345
of light, 344
Refrigeration, 310
Refrigerators, 310
Relative humidity, 166
determination of, 168
table of, 425
Relativity, 18
Resistance, electrical, 367
Resolving power, 183, 350
Retina, 356
Reverberations, 327
Revolution, 12
Rheostat, 381
Rhombic crystal, 113
Riboflavin, 239
Rickets, 242
Right ascension, 28
Rock salt, 112
Rockets, 150
Rocks, 111
experiments, 124
identification of, 124
igneous, 119
metamorphic, 121
products of, 128
sedimentary, 118
Roentgen, Konrad, 186, 404
Rotation, 12
Rotor, 391
Rubber, 226
butyl, 227
synthetic, 227
Ruby, 115
Rumford, Count, 301
Rutherford, Ernest, 191, 196, 411, 412

S

Sabine, W. C., 327
Safety glass, 134
  precautions, 368
Sagittarius, 49
Salt, 213
Sand, 107
Sandstone, 118
Sapphire, 114
Sargasso Sea, 99
Satellite, 55
Saturated water vapor table, 426
Saturn, 54, 58
Scale, 331–333
  diatonic, 331
  major, 331
  minor, 332
  tempered, 332
Scheele, William, 204
Schiaparelli, 51
Schist, 122
Seasons, 62
Sedimentary rocks, 118
Seismograph, 69
Serpentine, 117
Shale, 122
Short circuit, 368
  wave, 400
Sidereal time, 74
Silica, 116
Silicates, 116
Siliceous rocks, 118
Silicon dioxide, 116
Silk, 272
Silurian period, 92
Silver bromide, 352
  metal, 137
    colloidal, 261
    sterling, 141
  nitrate, 352
Siphon, 152
Sirius, 22, 23, 30, 288
Slate, 122
Sleet, 170
Smokeless powder, 215
Snow, 170
Soap, 266
Sodium, 16
  bicarbonate, 214
  carbonate, 214
  chloride, 192, 214
  hydroxide, 212
  light, 339
  palmitate, 266
  silicate, 268
  thiosulfate, 352
Soil, 107
Solar constant, 16
  eclipse, 43
  prominences, 9
  radiation, 16
  system, 49, 57–59
  system atom, 191
  time, 76
Sols, 259
Solubility, 255–256
  temperature graph, 256
Solute, 257
Solution, 255
  of ammonia, 255
  concentrated, 257
  conditions affecting, 255
  dilute, 257
  experiments, 264
  saturated, 257
  supersaturated, 257
Solvent, 256
Sosigenes, 256
Sound,
  experiments, 335
  motion pictures, 357
  quality of tone, 326
  speed of, 325
  waves, 324
Specific gravity, 247, 372
  determination of, 247
  table, 247
    heat, 302
      table, 303
Spectra, 23
  types of, 23
Spectroscope, 10, 15, 17, 53, 192
Spectrum, 376
  electric wave, 198
  flash, 16
  line, 196
Spiral nebula, 34
Stain removal, 270
Stainless steel, 140
Stalactite, 101
Stalagmite, 101
Standard time, 77
Staphylococcus aureus, 350
Star, 21
  cluster, 24
  distances, 31
  experiments, 37
  magnitude, 29
  maps, 26, 27, 28, 29, 30, 432
  plotting, 28
  spectra, 23–25
  table, 23
Starch, 230
Static electricity, 369

Stator, 391
Steam engine, 316
turbine, 315
Steel, 137
Stevens and Anderson, 149
Storage cell, 371
Storms, 164
Stratosphere, 149
Streak of minerals, 112
Sugar, 230
Sulfanilamide, 223
Sulfur dioxide, 310
Sulfuric acid, 212
Sun, 7, 336
dial, 336
eclipse, 42
experiments, 20
heat, 16
origin of, 35
rotation of, 9
spectrum of, 15
spots, 10, 379
Surface tension, 266
Suspensions, 262
Swire deep, 96
Syenite, 121
Symbols, chemical, 206
Syncline, 86

T

Talc, 118
Talking movies, 358
Tar, 132
Telephone, 393
Telescope, 13, 346
Television, 356
Temperature, 301
table, 304
Tempered scale, 332
Tetra-ethyl-lead, 129
Textile chart, 282
fibers, 272
identification, 282
Textiles, 272
experiments, 282
Thermions, 380
Thermit, 206
Thermocouple, 24, 305
Thermometer, 303
scale, 304
wet and dry bulb, 168
Thiamine, 238
Thomson, J. J., 186
Thunderstorm, 166, 372
Thyroxine, 242
Tidal theory, 58
Tides, 44
Time belts, 77
mean solar, 76
sidereal, 74
standard, 77
zones, 79
Tone quality, 326
Tornado, 164
Tourmaline, 361
Trade winds, 96, 163, 312
Transformers, 379, 387
Transmutation, 414
Travertine, 101, 118
Triassic period, 89, 94
Trilobite, 92
Trinitrotoluene, 215, 223
Tropic of Cancer, 63
Capricorn, 63
Troposphere, 149
Tungsten, 339
Tuning fork, 323
Tussah silks, 273
Typhoon, 164
Tyrian purple, 225

U

Ultra-microscope, 260
Ultrasonic waves, 150, 324
Ultraviolet, 134, 151, 199, 250, 340, 349, 358, 416
Unconformity, 85
Units, 424
Universe, 35
Uranium, 72, 113, 191, 409
Uranium series, 431
Uranus, 54
Urea, 219
Ursa Major, 21
Ussher, Bishop, 72

V

Vacuum discharge, 187
tube, 397
Valence, 208
Vapor density table, 426
pressure table, 426
Vaporization, heat of, 308
"Vaseline," 129
Vega, 28, 74
Velocity, 286
Velocity of escape, 39
Venus, 30, 50
Vernal equinox, 28, 64, 75
Vesuvius, 68
Vibration, 323
Vinegar, 214
Vinyl, 281

Viscose, 277
Visible spectrum, 336
Vision, 354
Visual purple, 356
Vita-glass, 359
Vitamins, 235
  C, 240
  D, 240, 358
  table of, 236
Vocal cords, 334
Volcano, 66
Volt, 365
Volta, 370
von Guericke, Otto, 143
von Laue, M., 406

W

Warm front, 174
Washing soda, 214
Water, 245
  boiling point of, 309
  composition of, 245
  density of, 245
  electrolysis of, 209
  expansion of, 307
  experiments, 254
  heat of fusion of, 307
  pressure, 245
  purification of, 249–251
  softening, 252
  table, 100
  vapor, 167
Watt, 365, 388
Watt, James, 293, 316
Watt hour, 367
Wave length, 199
Waves,
  compressional, 323
  earthquake, 69
  light, 199
  longitudinal, 322
  radio, 198
  short, 400
  sound, 324
  ultrasonic, 324
  wireless, 397
Weather, 160, 173
  Bureau, 175
  cause of, 161
  experiments, 182
  forecasting, 175
  maps, 175
Weights and measures, 424
Westerlies, 99, 164, 175
Whistling flame, 324
Willemite, 113
Wilson, C.T.R., 187
Wind belts, 161
    erosion, 107
Winds, 160, 162
Wireless waves, 397
Wohler, Friedrich, 219
Wood's Metal, 139
Wool, 275
Work, 292
World calendar, 82
    map, 79

X

Xenon, 146
X-rays, 197, 200, 403
  diffraction, 406
  experiments, 418
  in medicine, 408
  spectra, 406
  spectrometer, 407

Y

Yellowstone gorge, 103
    Park, 101
Young, Thomas, 194, 336, 344

Z

Zeeman effect, 11
Zenith, 28
Zeolite, 252
Zinc sulfide, 359
Zodiacal positions, 49, 75
Zworykin, Vladimir, 277, 356