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PROGRESS IN SCIENCE

SOME OPINIONS OF THE FIRST EDITION

'It has been done well, with a discriminating awareness of the interests of adults. He has never forgotten that he is writing for those only slightly informed of matters scientific. The importance of this interpretation of science to human society must take its place alongside fundamental researches in such subjects as nuclear physics. It is therefore to be hoped that *Progress in Science* will be the precursor to a long series.'

Nature.

'Novel features in content and presentation and should be attractive and instructive to the average layman.

'For a wide field of adult readers interested in science this should prove to be a timely and entertaining book—recommended for Secondary School libraries and particularly useful in connexion with the courses in general science.'

Times Educational Supplement.

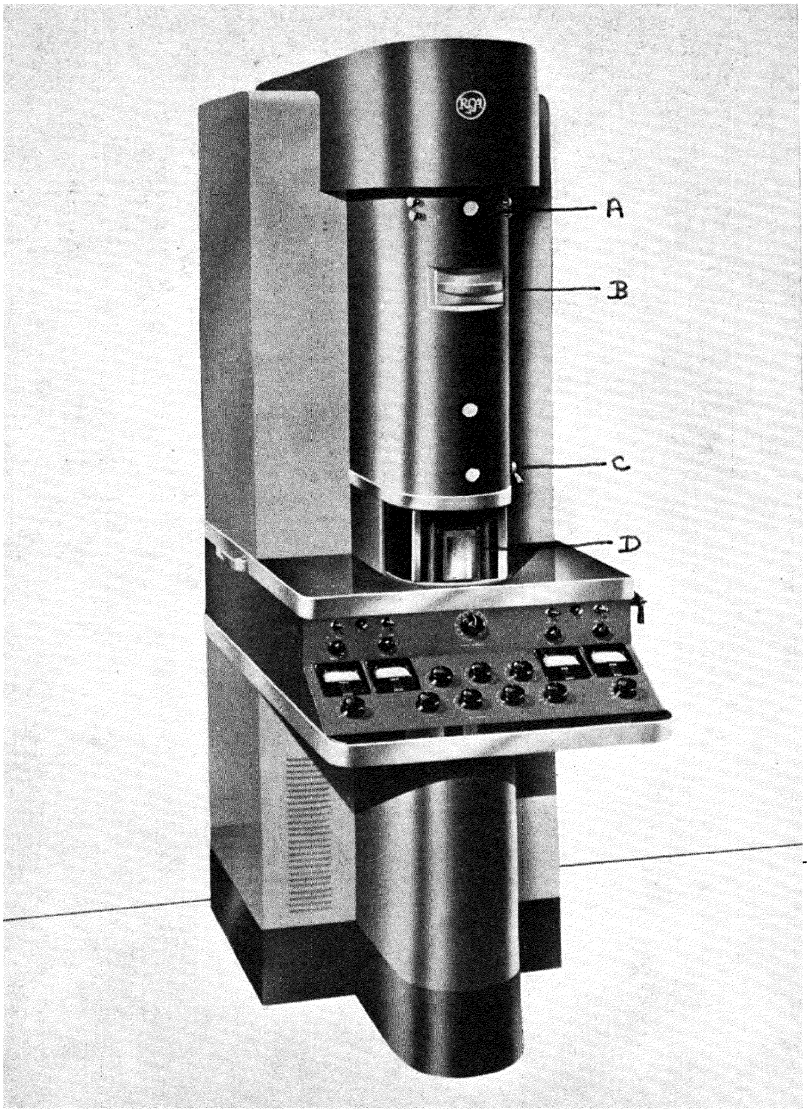


Plate I *Courtesy R.C.A.*

R.C.A. ELECTRON MICROSCOPE UNIVERSAL MODEL

The Electron Gun is at A and the specimen is placed in the chamber B. If diffraction pattern photographs are required the specimen is placed in chamber at C. The viewing window is at D. The magnification can be controlled from the instrument panel. The vacuum pump is below the control panel and the electrical circuits, transformers, etc., are behind the pump.

Facing title page

PROGRESS IN SCIENCE

By W. L. SUMNER

BASIL BLACKWELL
OXFORD
1946

THIS BOOK IS DEDICATED TO THE THOUSANDS OF MEN AND WOMEN IN H.M. FORCES TO WHOM IT HAS BEEN THE AUTHOR'S PRIVILEGE TO LECTURE ON THESE MATTERS DURING THE WAR YEARS AND AFTER

First Edition 1946
Second Edition 1946

Printed in Great Britain for Basil Blackwell & Mott, Limited
by A. R. Mowbray & Co. Limited, London and Oxford

FOREWORD

THIS book, which it is hoped will be the first of a series on scientific discoveries and their applications to life in the post-war world, is adapted from lectures which the author has been privileged to give to men and women serving with H.M. Forces in many parts of the country. It is a book for the layman interested in science rather than for the specialist.

No attempt has been made to produce a complete and connected account of recent thought in science, indeed it is necessary to remind readers that the present chapters deal with some 'technical' aspects of science. A few plums have been picked from the scientific cake, and there is always the danger that one may forget what the cake really is.

Nevertheless, it is becoming not only desirable but a matter on which rests the future of civilization that every one should know something of the methods and results of science, and what can be done to use them to the common good in the solution of the complex problems which now await us.

It is perhaps inevitable that a book on science written at the end of the war, which has seen practically every form of scientific research pressed into the service of defence and offence, should concern itself largely with technical developments. The problems of peace are as pressing as those of the war, and most of our war-time scientific swords can be beaten into the ploughshares of peace. At last the values of science properly considered and scientific training are obtaining some official recognition. Whether we like it or not, we live in a world which has been and will be conditioned, for weal or woe, by the results of scientific research. The power to release atomic energy is not only a sword of Damocles hanging over the entire population

of the world, but if controlled by men of goodwill it could help to produce the cornucopia of plenty.

In writing this book, I am greatly indebted to Mr. H. E. Dale of Boot's Pure Drug Co., Nottingham; the Radio Corporation of America; Dr. Roxbee Cox of Power Jets (Research and Development) Ltd.; A. C. Cossor Ltd.; May & Baker Ltd.; Sir Arthur Sidgreaves of Rolls-Royce Ltd., Derby; the Controller of H.M. Stationery Office; Mr. Peter le Neve Foster of I.C.I.; Dr. P. S. Hudson of the Cambridge Plant Breeding Station; and to my friends and colleagues, Mr. D. H. Thomas and Dr. H. H. Barber. Finally, I have to thank Miss M. D. Hickling for preparing the manuscript for the press.

W. L. S.

UNIVERSITY COLLEGE
NOTTINGHAM

November, 1945

FOREWORD TO SECOND EDITION

THE author is gratified to think that the first edition sold out within a few weeks of the date of publication and that a new edition is required. He is glad to have the opportunity of adding a few corrections and enlarging the chapters on chemotherapy and atomic energy. He has to thank his brother, Mr. T. C. Sumner, for examining and correcting the first edition in minute detail.

W. L. S.

November, 1946

CONTENTS

	PAGE
FOREWORD	v
INTRODUCTION—SCIENCE AND YOU	1
WHAT WE CAN DO WITH ELECTRONS	6
Electrons and their Uses	6
The Electron Microscope	11
Radio-location or Radar	16
Television	27
The Betatron	48
THE RELEASE OF ATOMIC ENERGY	52
JET PROPULSION AND THE GAS TURBINE	89
PLASTICS	105
CHEMOTHERAPY: THE STORY OF SULPHONAMIDES, PENICILLIN AND OTHER NEW DRUGS	121
NEW PLANTS FOR OLD: PLANT GENETICS	143
SCIENCE NOW AND IN THE FUTURE	165

LIST OF PLATES

PLATE		
I.	The Electron Microscope	*Frontispiece*
II.	(Top) Electron Diffraction Pattern	*facing page* 6
	(Bottom) Magnesium Oxide Smoke	6
III.	(Top) The Position Plan Indicator	27
	(Bottom) Range Finder	27
IV.	Cathode Ray Tube	38
V.	Television Receiver	43
VI.	A Cyclotron	54
VII.	The Whittle W2B Engine	95
VIII.	The Rolls Royce 'Derwent' Engine	98
IX.	Experimental Aircraft with Whittle Engine	109
X.	Bakelite and Acrylic Resin Products	116
XI.	(Left) Inoculating the Culture Medium with Penicillium	121
	(Right) Intermediate and Final Stages of Growth of Mould	121
XII.	Harvesting Penicillium	127
XIII.	Freeze Drying of Penicillin	130
XIV.	The Effect of Penicillin on Disease causing Bacteria	136

PROGRESS IN SCIENCE

INTRODUCTION

Science and You

You may not feel that science has any fascination for you. You may think that studies concerning reconstruction, political history, economics and many other topics make a larger claim to your interest. Yet nearly all the other things about which you will be thinking should have a scientific basis, or they will end up in many words and little achievement—mere verbalism, as the Americans would say.

If you do not think that you are very interested in science, science is certainly interested in you. Our lives and our thoughts during the war have been largely determined by the progress of science. We have had a 'very scientific war' and one which has called for the utmost attention to research and the applications of its findings. The modern soldier, sailor and airman has to be a technician controlling and understanding the scientific discoveries of others. Without science our food supply would not have been assured and we should have suffered from plagues and diseases far more deadly than the destruction of war. Our communications, our transport, even our amusements are all the results of the applications of scientific research. The war has brought many special problems which many of the timid said could not be solved. Orders were issued for modern miracles to be forthcoming, and somehow, groups of scientists, working in teams as scientists nearly always work to-day, found the solution. During the war, the problems have seemed unusual and unexpected. Such tasks as the finding of a substance which would keep sharks away from shipwrecked sailors, or the means of making hot palatable soups by

merely adding cold water to powders have been successfully achieved, and these are only two of many hundreds of small but important problems which scientific knowledge and methods have solved.

And now we have the problems of peace, often called by that curious title 'reconstruction'. We are going back to a world which can never be the same as that of 1939, nor do we want it to be the same. New ideas, new knowledge, new techniques and new materials are available for the solution of the problems. Even the time-honoured methods of building houses and other constructions are being supplemented by pre-fabrication. Synthetic substances such as 'plastics', which are the results of chemical research, provide the basis for new forms and new methods. Our ideas concerning travel, food and entertainment will change with scientific progress. Science is immensely dynamic, and when one tries to get a historical picture of what it has done, one sees that it is still accelerating in the speed of its progress. Nothing succeeds like success, and the immense forward march of science has left us bewildered. We may wonder what we can do about it. We shall have to try to understand its methods and what its results imply. The progress of technical discoveries, particularly along the lines of engineering and the related sciences of physics and chemistry, has far outstripped a sense of moral responsibility and a determination to put them to positive social uses. Political remedies are in themselves no cure for social evils. These can only be treated by the vigorous application of scientific method and its results, an awareness of the nature of the trouble and the scientific means of effecting a cure. No one can feel at home in the universe without some appreciation of present-day science. Unless the gifts of science, which we inherit from the illustrious company of scientific workers and discoverers, are used and understood by us, they will be exploited by the unscrupulous to our ultimate disadvantage or even destruction.

You may be asking, 'What after all is science?' Perhaps you recall with varying degrees of pleasure, that in the school laboratory you learnt how electricity travels in wires, how heat is transferred, how acids were produced, how plants feed and many another thing. Perhaps these things did not seem to be related to one another, nor were they related to life. Maybe you thought that science was a thing to be undertaken in laboratories only. Science, and by that we mean organized knowledge, is a much larger business than this. It depends on experiments with careful observations and measurements. There are many disappointments and blind alleys. The observations are recorded in various forms—perhaps in clear simple English, or with the aid of diagrams, graphs or mathematical formulae. The so-called laws of science are only generalizations which are useful to give the scientist a summary of what has gone before, and a stone to stand on until he can jump to the next. He will have to abandon or qualify his 'law' when new phenomena appear which do not fit it. Thus a scientist has to be progressive, to keep an open mind and not to jump too readily to conclusions. When we say that 'the exception proves the rule', we are using the word 'prove' in the old sense of 'to test'. If the exception is really an exception, then the rule is not a rule, but only a generalization which has served its purpose.

We can think of many things which at first sight might not appear to you to yield to scientific treatment, where this method of repeated experiment, observation, discussion, generalization and further experiment can be employed'. Many of our economic problems can be treated in this way. Even so complex a 'structure' as the human mind can be seen to show general patterns of activity, as shown in human behaviour, whether of the individual or of a social unit.

Scientists have come more and more to use mathematics to help them to express their findings; and when a thing can be measured on an agreed scale, it can be talked about

and dealt with in a more convenient manner. Some sciences are not mathematical in the exact sense, and have to rely on other forms of description. Psychologists, economists and those physicists who deal with electrons see that the type of thing they have to describe has often to be dealt with in bulk, and so statistical methods are increasingly useful. This does not mean that you can never be a scientist nor apply scientific method to the problems of life if you are not a mathematician. In many of our difficulties, such as the right use of our time and our money, the simplest arithmetic will suffice. The man who grows tomatoes year by year can be just as good a scientist as the man who plots out the craters of the moon by using expensive telescopes, if he goes about his task in the right way.

The scientist is not a sinister figure if he really is a scientist. He is impelled chiefly by his instinct of curiosity to try to find how things work; sometimes he adds to this a definite desire to relieve humanity from disease, starvation and ignorance. In war-time and for the improvement of commerce, scientists are often tied to particular problems, and there is no reason why their devotion should not equally, or with more determination, be applied to the problems of peace. The scientist does not always know what he may discover. He is neutral, and his discovery may be good or bad according to how it is used. Perhaps we ought to expect a little more guidance from the research worker concerning what should be done with his discovery, but in any case we ought to think of the social repercussions of scientific discoveries and see what can be done about them. It is necessary that our Members of Parliament should know something about the possibilities of science, both for good or evil. It is only through science applied in a spirit conforming to our social ideals that we can have any 'reconstruction' on a permanent basis.

Experimental science as we know it is of recent appearance in the history of mankind. Purely theoretical or

deductive reasoning in our Western civilization held the day until nearly the seventeenth century. This often took forms which to us appear ridiculous. Learned men with all solemnity would debate such questions as 'How many angels can dance on the point of a needle?' and moreover would come to definite conclusions about it. One school of thought said nine and another sixteen! Galileo was one of the pioneers in the introduction of the experimental method. When he was a boy, about the year 1575, the local wise men were discussing how many teeth has a horse, and after a lengthy debate various answers were forthcoming. Galileo, who had a horse tethered outside, suggested that the reasonable way would be to examine the animal's mouth, but he was regarded with horror as a young heretic who could never come to any good. When philosophers, as they were then called, caught the 'knack' of the experimental method, progress was swift; but as regards its applications, it came first in the physical sciences such as engineering, physics and chemistry. The social and economic values of the applications of biology—the very important science of life—came later. We still await most of the benefits which would result from the scientific treatment of many of the problems which we have to face in trying to live from day to day in a world which at once has become much more complex and greater in its problems and smaller in its geographical distances.

WHAT WE CAN DO WITH ELECTRONS

Electrons and their Uses

OBSERVATIONS concerning the passage of electricity through conducting liquids, and later, through rarefied gases in glass tubes, had suggested to scientists during the nineteenth century the possibility that there might be 'atoms of electricity'. The tiny units of electricity, even when they travelled in gases, were always considered to be associated with particles of matter. Towards the end of the century it seemed to many scientists that existing physical theories when suitably developed would suffice to explain the nature of energy and solid matter. Just at this time, however, the English scientist, J. J. Thomson, showed that the 'cathode' rays which were observed when electrical discharges were passed through gases, consisted only of negatively-charged particles, and that the whole mass of the particle was electrical. Here was the beginning of a revolutionary idea, and one which has dominated physics ever since. All matter consists of 'parcels' of electricity. The behaviour of radio-active elements, which constantly give off energy in the form of electrons, X-rays, heat and other particles, provided a clue to the nature of atoms. Lord Rutherford in the early years of the present century conceived the atom as a miniature solar system with a positively-charged centre or nucleus, surrounded by rings of electrons. He was able to test this idea by passing streams of alpha particles (positively-charged helium nuclei given off by radium) through the sheets of metal. The alpha particles were deflected by the powerful charges of the nuclei of the atoms in a predictable manner, and this was good evidence for this theory. The hydrogen atom is, of course, the simplest, and consists of a simple proton (a positively-charged centre or nucleus) and an electron which may be imagined to move in an orbit at a comparatively large

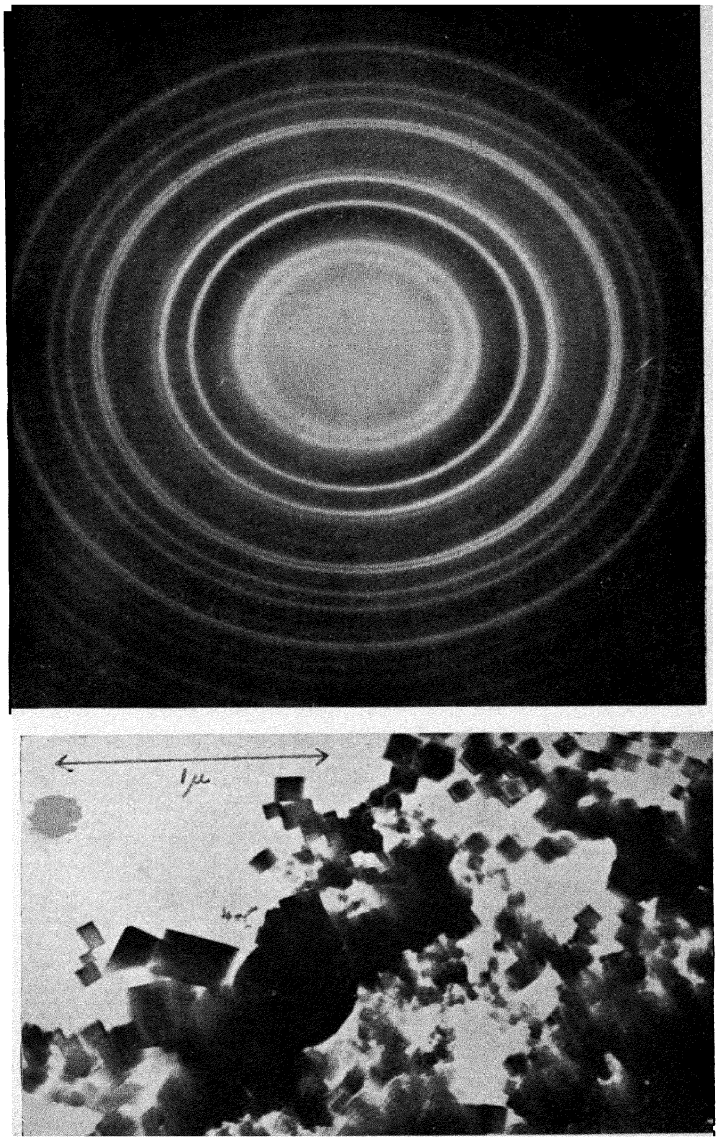


Plate II *Courtesy R.C.A.*

Top. Electron diffraction pattern caused by passing an electron stream through silver foil.

Bottom. Magnesium Oxide Smoke × 50,000 diameters. The line 1μ (one micron) is $\frac{1}{10\,000}$ centimetre or $\frac{1}{25\,000}$ inch long. Some of the cubes have the appearance of being out of focus. The actual focus and resolution are extremely great and these effects are due to the fact that the material is so highly crystalline that reflections of the electrons from the crystal faces take place and produce multiple reflections.

distance from the proton. We may be tempted to think of the proton and electron as hard lumps of positive and negative electricity respectively, and this will suffice for the explanation of certain simple phenomena; but later we shall see that a nucleus may have a complex structure, and that an electron is an elusive thing, sometimes behaving as a particle and sometimes as an organization of waves. No one has ever seen an electron, and if it could be observed it would not help us much, as it could only be seen by using its own energy. Even scientists have great difficulty in conceiving what happens in the world of the very tiny, and it may be that in spite of our knowledge of the energy changes which take place in the atom, we may have to leave its description in terms of mathematical formulae, and not try to make complete models of it in terms of solid things such as arrangements of rods and balls.

However, we are on safe ground when we summarize these matters by saying that:

1. All matter consists of positive nuclei and negative electrons.

2. That atoms are mostly empty space.

3. That powerful electrical fields are associated with the 'inside' of the atom, particularly near the nucleus.

4. That different atoms (for example, those of oxygen, nitrogen, lead and gold) are built up from the same types of electrical 'bricks' and that it should be possible to take atoms to pieces, to change one type of atom into another, or even to build up atoms.

5. That the old laws of the conservation of matter and energy need reconsideration. Matter can be created from energy and energy can appear by the destruction of matter, as in the atomic bomb. Matter is energy in another form. Atoms consist of energy in a very concentrated form and the energy from a little matter would go a long way. Sir James Jeans has calculated that all the energy expended by a strong working man during a long life would only

represent $\frac{1}{60,000}$ of an ounce! At first sight this may sound very discouraging![1]

We shall return to these ideas in later chapters and for the present we propose to discuss the uses to which we may put streams of electrons, which are often spoken of as cathode rays.

In recent years a new branch of science known as electronics has grown up, and in America a new £1,000,000,000 business, which is more than the whole pre-war U.S. motor car industry, has arisen.

We all realize the importance of the thermionic valve in wireless; and many of us know of the use of the cathode ray tube in television, radio location and instruments for finding faults whether in a human heart or a motor car engine.

The use of the term *wireless valve* may have tended to make obscure in our minds the nature of the main types of vacuum tubes, and the uses to which they are put besides that of the true valve action of passing an electric current in one direction only. This will be obvious when we remember that electrons, which are negative electricity, will travel only *away* from a cathode or negatively-charged electrode.

The wireless valve was not invented by one man, and the researches of Sir O. W. Richardson on the emission of electricity from hot bodies were an important milestone on the road to the development of the device. In 1907, Lee de Forest, by introducing a 'grid' into the stream of electrons travelling from the hot cathode to the positively-charged anode, in the evacuated glass container, was able to control the electron current by altering the grid voltage. The valve could not only be used for rectifying a current, but as a small change of grid *voltage* could control a considerable *current* between cathode and anode, the instrument could also be used for amplification. Again, when it is used with electrical circuits containing

[1] See the diagrams on page 56.

condensers and inductances (specially constructed coils of wire) oscillating (vibrating) electric currents could be obtained. At high frequencies these currents would produce wireless radiations, if the valve and its accessories were connected to suitable aerials or other radiating devices. Many improvements have been made to the valve in the last four decades and there are now many types developed for special purposes. We shall meet some of these when we discuss radar or radio-location.

Large valves in water-cooled steel tubes are now used in industry for the control and transformation of heavy electric currents. Alternating current, such as that for which the English 'grid' is designed, is popular because it can be transformed to high voltages for transmission along comparatively thin wires, and then down to lower voltages for domestic and industrial consumption, by static transformers, that is, those which have no moving parts. In America, the demands of war production needed large quantities of aluminium and magnesium which could only be produced by using enormous quantities of direct current. The Westinghouse ignitron 'valve', developed just before the war, solved the difficulty.

The photo-electric cell, a simple device whereby use is made of the fact that electrons are given off by certain metals when light falls on them, is becoming increasingly useful for controlling industrial and other processes.[1] The use of the 'electric eye' for opening doors when they were approached, for turning on lights when it became dark and for finding exposure times in photography under various conditions, was well known before the war. It is in the heart of the 'sound head' of the sound film projector, it will detect flaws on steel strip passing it at 20 feet a second, it can be used for sorting particles of various sizes, it will stop machinery if the unwary approach too closely, it will regulate the temperature of industrial furnaces and even control the cutting to shape of thick sheets of metal

[1] See the Chapter on Television.

by following a curve drawn on a piece of paper. The spectrophotometer made by the G.E.C., which contains optical prisms, photo-electric cells and amplifying valves, will distinguish two million shades of colour, and moreover will record them automatically.

Most of the commercial applications of 'electronics' really depend finally on short wireless waves. Instead of allowing the waves generated by 'valves' to radiate in space, they are fed into a coil of thick copper wire or tubing. The high frequency electrical disturbances within the coil will melt metal placed in a suitable crucible. This principle is applied to the induction furnace, where the heat is generated in the metal itself instead of being applied externally. Electron 'guns' have been devised for spot welding, and many industrial processes such as surface hardening and brazing can be performed by this method.

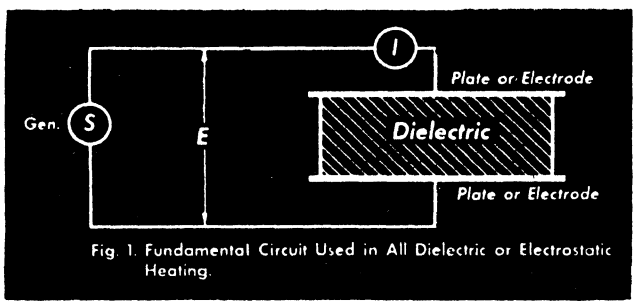


FIG. 1. The 'work' is used as a dielectric between condenser plates. This method is useful for curing and processing plastics, for making special plywood, internal drying, and for treating glass, rubber, textiles and food.

In a similar manner, with electrical vibrations up to a hundred million per second, heat can be generated in non-conducting materials such as wood and plastics. Here the substance to be heated acts as the 'dielectric' between two condenser plates. During the war the process has proved invaluable for making aircraft parts of plywood impregnated with glue or plastics. In the plastics industry it is an advantage to secure curing, or the solidification of the

mouldable substance, by internal heating, just as it is an advantage for paints and enamels to dry from within outwards. An 'electronic' sewing machine, without moving parts, will join quickly the new plastic fabrics and sheets, which are so popular for making articles of clothing and containers. The evaporation of penicillin solutions, the curing of tobacco and the dehydration of foods can all be undertaken, in a manner capable of exact control, by 'electronics'.

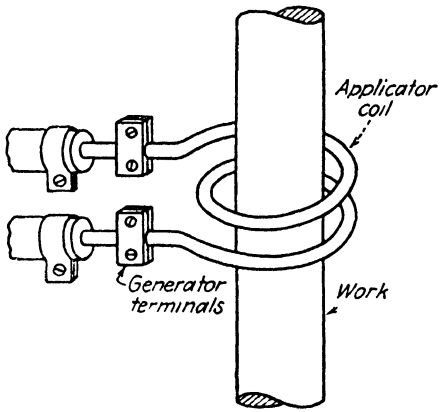


FIG. 2. Induction heating of a metal. The coil serves as the primary of a transformer and the 'work' as a short-circuited secondary. The method may be used for melting and tempering with lower frequencies and surface hardening, soldering and plating with high frequencies.

As we shall see in the following sections, we have travelled far in our control of electrical forces since Thales of Miletus in Greece, about 600 B.C., noticed that when amber was rubbed it attracted small particles to it, and he gave the phenomenon the name *electron*, the Greek word for amber.

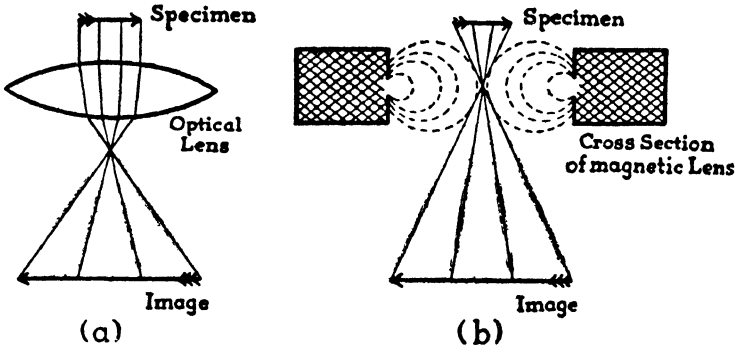
The Electron Microscope

The improvement of the microscope due to the Dutchman Leeuwenhoek in the early seventeenth century (by using two convex glass lenses, one at each end of a short brass tube about an inch diameter), immediately opened a vista of new scientific discovery. With the use of this new scientific tool the eyes could now see objects which were far too small to be observed by the best naked vision. By the mere routine use of the new instrument many major scientific discoveries were made, merely because a new world had suddenly become visible—the world of the small.

Since Leeuwenhoek's time, the optical microscope has continued to improve, but however perfect are the grinding and mounting of the lenses, the power of the instrument in revealing small objects to us is limited. It is only by the use of light that we can see at all, and light seems to behave as though it consisted of waves of short length. If an attempt is made to see an object which is about the same size as a wavelength of light, the light will bend round the object and no clear picture of it will be obtainable. In the past, many attempts have been made to overcome this trouble to some extent by using 'light' of the shortest wavelength possible, or ultra violet light, and by immersing the object in oil or some other transparent liquid which would have the power of reducing the wavelength of light passing through it. The improvement with these methods was quite insufficient for us to be able to see many of the things which we wished to study. The fine crystals and structure of certain metals, the viruses (disease-producing organisms too small to be seen by an ordinary microscope or caught by a filter) and many other important things still eluded us.

A stream of electrons or cathode rays has some of the properties of waves. The structure of an electron does not appear to be simple and it has wave-like qualities. The 'wavelength' is very small and is of the order of about a thousandth of that of the wavelength of yellow light. Moreover, streams of electrons can be bent by 'lenses' which are not made of glass but are merely electrical or magnetic fields. Just as the images which we get from particular glass lenses can be worked out by geometry and more or less simple mathematics, so there are exact calculations for electron optics. This matter is a little more complex, as a stream of electrons is bent in a curve at right angles to the direction of a magnetic field; but the calculations for electron optics are capable of even greater accuracy than those concerning rays of light in glass lenses. An idea of the two systems can be obtained from the

diagrams. With the very finest of optical microscopes no new details of the specimen, which is being examined, appear beyond an enlargement of two thousand diameters, but the electron microscope is not limited by the wavelength of the illuminating beam and can do much better than this, for enlargements of up to a hundred thousand diameters are possible.



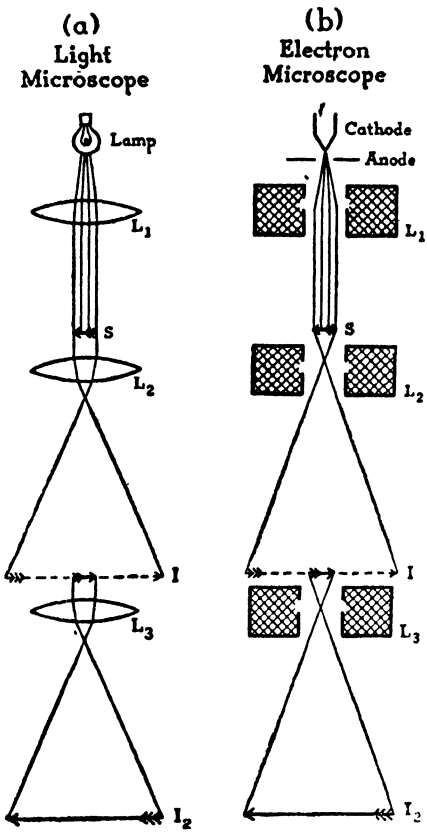
Courtesy R.C.A.

FIG. 3. Here the magnetic coil is shown bringing the electron rays to a focus in a manner analogous to that by which the glass lens focuses the light rays.

In the light microscope (a) in the diagram we may suppose that the source of illumination is a lamp. The light rays from this lamp are formed into a parallel beam and directed on the specimen (S) by the condenser lens (L_1). The image on the specimen then falls on the objective (L_2) which focuses and magnifies it, producing an enlarged image (I_1). A part of this enlarged image is further magnified by the projector lens (L_3). The twice enlarged image (I_2) is that seen by the eye.

In the electron microscope (b) in the diagram the source of illumination is a hot cathode which emits electrons. An anode with a small hole in the centre and positively charged electrically gives these electrons a high speed. A coil of wire in the shape of a hollow circle (L_1) produces a magnetic field which bends the paths of these electrons, forming them into a parallel beam directed on to the

specimen (S). The electron rays pass through the specimen and are affected in a varying degree which depends on the composition of the specimen. Those which pass through are brought to a focus by the field of the coil (L_2) and form an enlarged image (I_1). The electron rays which form a section of this image are in turn magnified by the field of coil (L_3) and caused to form a further enlarged image (I_2). It will be noted that the coils L_1, L_2 and L_3 act like the lenses in the optical microscope and for this reason they are called magnetic lenses.[1] The image (I_2) in the electron microscope is formed by an electron beam which itself is not visible. A fluorescent screen, therefore, is placed so that the beam falling on it produces a visible image. Photographs are made by allowing the electron beam to fall directly on a photographic plate. As the electron beam can only work in a vacuum, the specimen has to be placed in position in the electron microscope, the instrument closed, and the air pumped from the chamber. In the R.C.A. Universal



Courtesy R.C.A.

FIG. 4. The magnetic lenses in the electron microscope are arranged in the same manner and perform the same functions as the optical lenses in the light microscope. The magnetic lenses, however, are not moved as are the optical lenses; the same effect is more easily obtained simply by varying the current flowing in the coils. This varies the intensity of the field acting on the electron rays and is equivalent to producing a continuously variable focal length lens.

[1] We shall see similar devices in the cathode ray tubes of television and radar.

Type EMU microscope, this process only takes about 100 seconds. Magnifications from 100 to 20,000 diameters can be obtained. This means that particles much less than a millionth of an inch in size can be readily seen. There is a relatively large depth of focus and by tilting the specimen stereoscopic photographs can be obtained, which give an impression of its three-dimensional shape. With the electron microscope the electrical engineer at once gives the biologist a most powerful weapon of research. The common cold, for instance, still baffles the physician; the living organisms which cause it are of many varieties and as is the case with a number of diseases, the viruses which cause them are too small to be seen with the ordinary microscope. If you cannot immediately conquer your enemy, a great step towards it is to see him and learn something of his habits! The electron microscope has a great future in the field of bacteriology. Studies of the destruction of germs by the use of penicillin and bacteriophages (the bacteria-destroying organisms) can now be made with the new instrument. See the interesting photographs on Plate XIV.

The fine structure of metals, alloys and their surfaces which is so important from the standpoint of their purity, strength and durability, gives the electron microscope a wide field. The nature of the surfaces to be studied can be investigated by coating them with a thin film of collodion, stripping off this 'replica', and using this film, which bears a true picture of the contours of the surface, in the instrument. The fine structure of natural or artificial fibres, which must be understood in relation to their fitness for various purposes—their strength, durability and other qualities—can also be studied. Even the digestibility of various foods, such as 'homogenized' milk, varies with the structure of the food substance, and here again the instrument proves its worth.

Most interesting of all, from the scientific point of view, are the diffraction patterns which are made by the elec-

trons, when certain objects are placed in the lower chamber of the instrument.

As we have seen, comparatively large objects can cause light to bend round corners. The waves that are in phase reinforce one another, but those that are in opposite phases cancel out one another. Thus, under appropriate circumstances, we should expect to find alternate bands or patterns of light and darkness, depending amongst other things on the wavelength of light. When it was found that streams of electrons showed similar properties, and that electrons appeared to have a wavelength very much smaller than that of light, this was a great discovery for the physicists who were interested in the nature of the ultimate particles of which matter is made. The electron was no longer to be thought of as a formless blob of negative electricity, but as something which had some wave-like properties and some sort of a structure. In the electron microscope diffraction patterns take the form of bright circles, spaced in a manner which bears a direct relation to the arrangement of atoms in a molecule of the substance examined. Thus, new possibilities in the technique of research and production control processes are opened up. It is of incalculable value to the chemist, whose job it is to synthesize compounds from simpler substances, to know something of the architecture of the molecule which he is trying to construct.

Radio-location or Radar

Invisible death rays which were to project enough power to destroy living matter and to stop aircraft or motor engines, over long distances, have been a favourite theme for novelists for many years. When war clouds again gathered over Europe more than ten years ago, and it became evident that the defence of our country from air attack was then a matter of extreme difficulty, scientists were asked whether they could, in fact, send powerful beams of electrical radiation which would bring down or

destroy enemy aircraft. The answer was that such an idea was not then practicable, nor was it likely to be so for many years, if ever. But research workers were developing a much more useful plan and one which would be just as useful in peace as in war; and in the days when hostilities had ceased, would save life and make travel by sea and air much safer.

In 1935, Robert Alexander (now Sir Robert) Watson-Watt was experimenting in an old R.A.F. truck near Daventry, while an aeroplane was flying on a set course, to and fro above his instruments. But even before this, Sir E. V. Appleton had been using wireless beams for exploring the upper atmosphere round the earth, and had made some valuable discoveries by finding how they were reflected at various heights. Wireless technicians of several nations, a few years after the last war, had investigated the reflection and interruption of wireless waves by solid objects, and even Heinrich Hertz, who had discovered the waves in 1888, had found that they behaved like very long light waves, in many ways.

Research in America continued under the direction of Dr. J. H. Dellinger of the radio division of the National Bureau of Standards, and by 1934 the American navy had rudimentary radio-location apparatus in a number of ships and shore stations. Radio could penetrate fog, snow, smoke screens, and report the positions of ships on the sea, and aircraft in the air. Watson-Watt was appointed Director of Communications Development to the British Air Ministry in 1938, and two years later Scientific Adviser in Telecommunications. The work of his group went on in secret, and when in 1940 the German Luftwaffe attacked this country in large numbers, their direction, speed, altitude and position were known before they crossed the coast, and our comparatively few fighter pilots dealt with them with great effect. The aircraft and personnel which would have been required for an adequate patrolling of our coasts and home waters were simply not

available at the time. Radar told our fighter pilots just where they would be required. With its aid an elaborate scheme for the protection of this country was devised, in which searchlights, anti-aircraft guns and fighter planes were all employed in a co-ordinated way. The 'laying' of the guns and the adjusting of the fuses to take into account the speed and range of the aircraft and other factors were all automatically effected by radar. Most people living in England through the blitz period will have seen the short aerials of the radiolocation transmitting and reception apparatus, often associated with some 'acres' of wire netting, arranged in a true horizontal plane to act as an 'earth'. The detailed principles of radar, and the extent of our application of it, were kept as secret as possible, but unfortunately some of our best equipment was allowed to fall into German hands at the time of the collapse of France. The Germans developed a similar system, but their equipment was nearly always inferior to ours, though at the time of our large scale bombing offensives the enemy radio-location devices were extremely effective. The well-remembered Commando raid at Bruneval had as its objective the removal of a radio-location station which the Germans had set up, to give them an 'electro-magnetic eye', which would reveal movements of our aircraft or ships in the Channel.

The name radar is obtained from the phrase 'radio detection and ranging', which would be more properly called 'radio direction finding and ranging'. Radar has a greater range than the eye, even under the best conditions of visibility; it can see in the dark and is not greatly disturbed by rain, snow, fog or smoke. Clouds, smoke screen and the glare of the sun do not hide an object from the searching beam of radar.

Here is an imaginary report of the type of incident which happened many times during the recent war.[1]

[1] Quoted from *Radar: A Report on Science and War*, H.M.S.O.

'No IFF, evaluation—enemy; could be task force reported to have sortied from Tokio Bay, consisting of one BB, one CL and three cans.[1] At this point CIC (combat information centre) would be feeding information to the gunnery department. The targets bearings and range, course and speed are fed into computers as the huge main battery directors swing swiftly into position. Gun crews stand ready to load powder bags and shells.

'The two forces continue to close. New ranges and range rates automatically reposition the mighty guns. Finally the radar indicates that the enemy is within range. Word is given to "Commence firing". The master salvo key is closed and with a roar nine 16 in. shells go hurtling through the night. So sensitive is the radar that the operator can "watch" the shells move across the screen toward the target "p p". Then he sees indication of their splashes and can quickly read off how much correction must be made. Again the guns boom forth and this time the salvo appears to land squarely on the leading ship. Sure enough; as the operator watches, the "pip" slowly fades from the screen. The ship has been discovered, identified, tracked, fired upon, and sunk without a man seeing it visually.'

The principle of radar is simple. As long ago as 1888 Hertz showed that wireless waves had many of the properties of light and it was soon evident that the difference between these two forms of radiation was one of wavelength. Long waves bend round corners and cannot be directed in the form of a beam. Short waves are essential for the invisible feelers of radar. Radar demands a technique for the measurement of small intervals of time. A pulse of radio waves travelling from the radar aerial and partly reflected from an object a thousand yards away will travel the complete journey, to and fro, of two thousand yards in $\frac{6}{1,000,000}$ of a second, but we have to judge the distance of the object to within five or ten yards, and this

[1] Battleship, light cruiser, three destroyers.

requires an instrument which will measure time to an accuracy of at least one thirtieth of a millionth of a second! Only the stream of electrons operated by a 'time base' can leave their trace at the end of a cathode ray tube fast enough to achieve this.

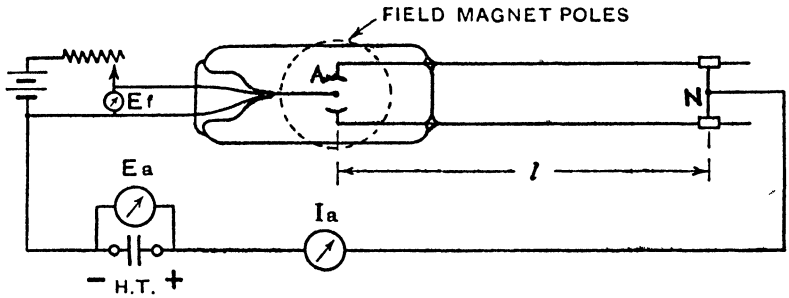
Thus, the cathode ray tube comes to our aid with its electron beam which can be regarded as a pointer without appreciable weight and inertia. It can be made to move backwards and forwards in the cathode ray tube by means of external rapidly alternating currents. A horizontal line made by the quickly moving electron beam appears on the fluorescent screen at the end of the tube. As the rapidity of the oscillations of the beam is known by the frequency of the alternating current, divisions of the line on the screen can be taken to represent very small but accurately defined periods of time. This is known as the 'time base', and the alternating electric currents are generated by valve oscillations which can be controlled by crystals so cut that they 'vibrate' at a high frequency which is predetermined and invariable. Wireless waves travel at 186,000 miles a second and we have to measure them accurately to the time equivalent of a few yards!

We have already seen, when discussing the electron microscope, that all energy which travels in wave-like form tends to bend round corners at the edges of an obstacle which it encounters. This applies to sound waves as well as to electro-magnetic radiations such as wireless waves and light. The shorter the wavelength, the less is this bending or diffraction effect. When a locomotive is blowing off steam, many sounds of high pitch and short wavelength are generated. These can be screened from the ear by putting the hand between it and the source of the sound, and the hissing noises will be cut off, leaving only the notes of lower pitch. The low pedal notes of an organ will bend and come through a church door, to be heard outside after the higher notes have become inaudible. A similar effect appears in beams of wireless, where those of

short waves can be directed and reflected without the broadening and spreading which long waves would undergo. As a probe for 'feeling in the dark', and finding something about the size and even the shape of distant objects, it is clear that only short wireless waves will be suitable. At once difficulties crop up. A wavelength of a metre means 300,000,000 complete vibrations a second, but in radio-location waves of the order of a few centimetres are necessary. Oscillations of this great frequency present difficulties. The electrical 'resistance' to these high frequency currents, known as impedance, is considerable. The design of valves to produce sufficiently powerful oscillations at these frequencies is a matter of the utmost importance. The Germans neglected the development of this type of valve and here English workers were pre-eminent. The magnetron valve, which was invented before the war, was greatly improved subsequently; and the perfected valve which would handle 'centimetric' radiations was a jealously guarded secret. The decision to fit such valves to the radar apparatus used in planes flying over enemy country was a difficult one to make, and devices were fitted which were intended to destroy the apparatus if a forced landing had to be made. The valves, however, were of a very sturdy construction, and were quite small. The designs of the latest types of magnetron valves are still kept secret. They were developed by a group of scientists working at Birmingham University.

The parts of a magnetron valve are of small but critical dimensions. It will be noted that the various electrodes and conductors are kept apart as far as possible in order to avoid unwanted capacity effects. The valve is placed between the poles of a powerful magnet and the electrons from the filament spiral round and round in the space between the cathode and the split anode, energizing first one part of the anode and then the other, thus giving rise to very rapid oscillations in the external circuit. Slow moving electrons

cannot therefore act as a 'brake' on the oscillating system. The simple and older form of magnetron shown below is



TYPICAL CIRCUIT FOR MAGNETRON OSCILLATOR

FIG. 5 *Courtesy G.E.C.*

analogous in its action to a 'closed' organ pipe. The parallel wires of length l are known as a Lecher Wire System and l is approximately a quarter of the length of the wave produced. N is the node which corresponds to the closed end of the organ pipe, and the energy of the rapidly oscillating electron stream is fed into the parallel wires at the split anode A. This corresponds to the mouth of the organ pipe where the energy is received from an oscillating sheet of wind and communicated to the air column in the body of the pipe. The new magnetrons, the designs of which are still kept secret, depend for their action on the electron 'resonance' in a cavity electrode. New alloys, containing vanadium, have been used to produce permanent magnets which give powerful fields and are admirable for use with magnetron valves. The properties of such alloys have been investigated by L. F. Bates of Nottingham and others.

In its undeveloped form the magnetron valve was known throughout the world before the war, but after 1939 German research on radio valves was far behind that of this country.

We are now in a position to understand how radar works. By means of a suitable magnetron valve circuit, short

bursts of radio waves of low wavelength are generated, for a millionth of a second or so, and then turned off sharply. The power, which on the average may be as much as a kilowatt, may momentarily run into hundreds of kilowatts at peak. During the interval between bursts of energy, the receiver must be connected to the aerial so that it can catch the feeble echo waves; and during the bursts the receiver must be isolated from the transmitter or it would be burnt out by the powerful energy discharges. The design of the aerial or antenna used in transmitting radar beams is a matter of great importance. The direction of objects from the transmitting point can only be determined if the radiation is concentrated into a narrow beam. The antenna must have directional properties. The aerial must also have a high efficiency so that none of the energy leaks off into directions other than that of the main beam, and it must be capable of being rotated so that the beam will scan in all directions. In the case of aerials in use on ships and aircraft, the 'aerial' must be stabilized in order to neutralize the movements of the ship or aircraft. Sometimes the aerial is made directional by building it up from a series of fairly thick rods, fed at the centre with energy, and each having a length equal to half that of the short wave used. Or in a way similar to the action of the searchlight, the energy may be directed by a large parabolic mirror. It is easier to obtain a concentrated beam with a comparatively large aerial system than with a small one.

In order to accomplish an 'all round' scanning of space the aerial must itself be rotated, but where only a narrow sector has to be covered, as in the case of guns which need their data accurately and quickly, a rapid electrical scanning, which does not require movement of the aerial, can be used.

Very short high frequency currents do not travel well in ordinary wires. Electrical 'resistance' caused by induction increases with frequency. This is known as impedance. Also, the current tends to travel on the surface of the

conductor and thus, although coaxial cables will suffice for ordinary wavelengths, very short waves are best conducted from the oscillators to aerial by 'wave guides' or in pairs of thick parallel wires suitably spaced. The task of 'wiring up' is popularly referred to as 'plumbing', when coaxial 'pipes' are employed.[1]

Almost all radio-location devices employ a super-heterodyne receiver. This uses the principle of 'beats', which finds a musical analogy when two notes of slightly different frequencies are sounded together. The frequency of the 'beats' is the difference of the frequencies of the two generating wave systems. Accordingly, a 'local' oscillator produces a radio frequency not far removed from that of the incoming radio echo, and when the two are combined the 'beats' are amplified by valves. The receiver has to be capable of dealing with frequencies which are even higher than those employed in television. For this reason crystal detectors have again come into use owing to their fast response. Much research has been devoted to the method of making the crystals, and determining their optimum size. Short aerials connected directly to crystals of carefully determined composition, shape and size can be regarded as highly sensitive tuned units showing highly selective or resonant response to incoming waves. In addition, as we have already indicated, the receiver must be electrically closed from the transmitter during the tiny periods when the latter is sending out its short but very powerful bursts of energy.

The time taken for the double journey of the radio waves to and from the object, which is being scanned, is measured by the position of a V-shaped break in the horizontal line of the cathode ray on the fluorescent screen. On a suitable scale the distance of the 'pip' can give a direct measure of the range. This simple cathode ray tube device is known as an A-scope. The most spectacular type of radar indicator is the 'position plan indicator' or the

[1] See page 41.

PPI tube. In this, the cathode ray beam starts from the centre of the tube and moves radially outwards in the same direction as that of the 'aerial' which is transmitting the scanning beam. The 'aerial' system rotates at a constant speed, and the radial line of the time base rotates in synchronism with it. The returning radio echo, after amplification, is made to intensify the brilliance of a spot on the time-base line, for an instant. As the aerial system rotates at the rather slow speed of from one to twenty revolutions per minute, a special fluorescent screen has been developed, so that the brilliant spots persist for a number of seconds after the electron stream has passed. Thus, instead of a number of isolated brilliant points of light on the cathode ray screen, a complete 'map' can be seen of what is below the aircraft carrying the equipment, and moreover, this is not affected by darkness, cloud or other conditions affecting visibility. The intensity of the reflected ray differs according to the nature of the object from which it is reflected.

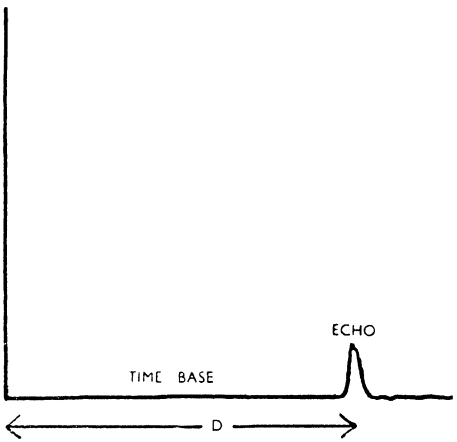


Fig. 6. The distance D of the v-shaped break caused by the returning echo wave along the time base is a measure of double the distance of the object from the transmitter and receiver in terms of a time interval. As the radiation travels at 186,000 miles per second the time base represents a very small fraction of a second.

A particularly interesting technique which was developed in this country early in the war was known as G.C.I.[1] In this, enemy aircraft were detected by ground radar, and night fighters were directed to a suitable course and position behind the enemy plane. The fighter's radar then took over, and the position and range of the enemy could be seen as a

[1] Ground controlled interception.

'blob' on the screen of its cathode ray equipment. The direction of fire power and the destruction of the enemy then became practically automatic. The development of this technique called for the utmost skill and good team work.

There are many different forms of radar, but most of them use the principle which we have described. In wartime, radar was a weapon of defence against enemy aircraft, and in the case of pilotless craft, the flying bomb or V1 it worked admirably. Many gunners preferred to exclude all other means of gun-laying, and the destruction of V1s went on in cloudy and misty weather to such an extent that comparatively very few reached their target. On one Sunday in August, 1944, 105 flying bombs crossed the English coast but only three of them arrived, so efficient was the radar-controlled gun fire. The protection against long range rockets was again to be sought in radar. Radar was also a weapon of aerial offence, enabling bombing planes to carry out their missions, find their targets and return to their bases in weather which a few years previously would have been considered unfit for flying. Radar shortened the war by its aid in the destruction of the enemy's war potential.

Radar was largely responsible for our ultimate defeat of the U-boat menace, the seriousness of which in 1942 and 1943 can hardly be overestimated. Apparatus for the detection of surface vessels is known as ASV. Owing to our development of centimetric radar the German technicians were mystified as to the nature of the radiation which we were employing to feel for and track down their surfaced U-boats. Although they had developed a receiver for revealing the presence of the longer exploring radar waves, our ability to make use of the shorter wavelengths baffled them completely, and at the end of the year 1944 they were driven to such devices as the Schnorkel tube, which enabled them to run the internal combustion engine of the submarine while it was still submerged.

Radar allowed the positions of ships in a convoy to be noted, whatever the condition of darkness and fog. By a

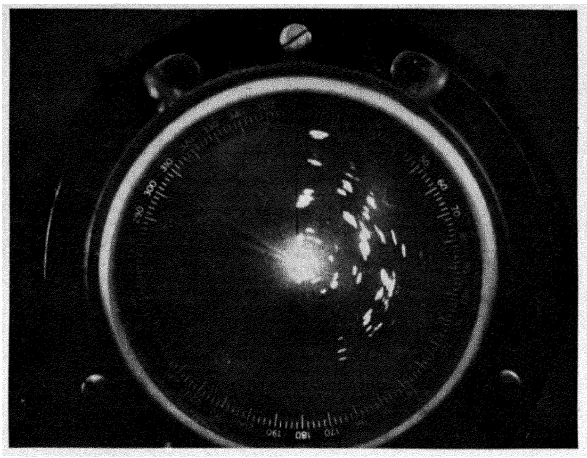


Plate III

The P.P.I. (position plan indicator). A mass of shipping, buoys, etc., is seen below the aircraft which carries the apparatus, between bearings 0–170°.

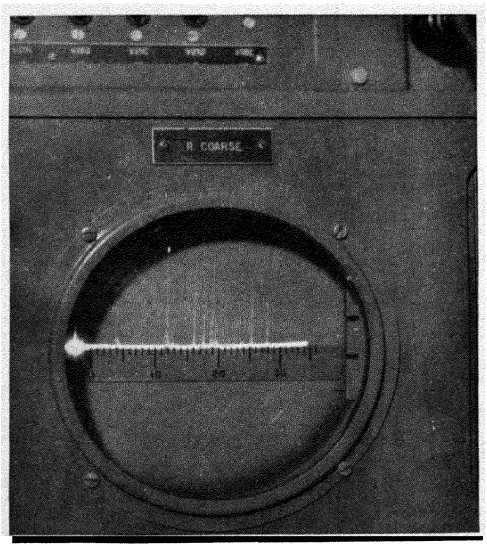


Plate III

A pulse of radio waves is transmitted from the radar aerial into space. It strikes a target such as a plane or ship and some of it is reflected. This reflected pulse or echo is caught by the Radar and is presented on a Cathode Ray Tube in the form of a break in a line of light—the time base. The distance along the time base at which the target break appears is a measure of the range of the target. The reflections from several targets are seen here.

simple radar device known as IFF (identification of friend or foe) any friendly aircraft or warship could at once identify itself. Thus, radar proved an admirable weapon of offence, not only in the destruction of U-boats, but in searching out and destroying the surface craft of the enemy. Equally, by enabling navigators to see at night, radar has permitted ships to approach strange harbours and coasts in the darkness, so that shore batteries and other installations could be destroyed by point blank gun fire.

Many of the war-time radar devices can be developed for air and sea navigation in peace time. Radar beams, originating from strategic points, will cover the air and ocean routes of the world. Radar carried by ships will detect obstacles, other vessels or icebergs, and make navigation safe in conditions of bad visibility. The air navigator will know exactly where he is at any time, and what is his height, not only above sea level but also above the ground below. The radar operator at shore or ground stations will follow continuously the position of ships at sea or planes in the air. A new era of safety, and not only of speed, for those who travel by sea and air, is with us.

Television

The problem of transmitting a moving picture by wire or wireless is very different from that of sending sound. In the case of the latter, for ordinary purposes, it is sufficient to think of the sound as a single complex wave motion, which can be represented on a graph in the form of a wavy line plotted against time. In this case, only one thing varies with time. Thus, the sound may be made to vary a single electric current in a wave-like manner, and this can be modulated on a train of high-frequency waves for wireless transmission.

The problem of television is much more complex. Every tiny part of a moving picture may be constantly changing and it is therefore necessary to find some means of breaking up the picture into very small parts, according

to some definite plan. As is to be expected, it is easier to transmit still pictures than those that are moving. In the cinema, in order to produce the impression of continuous motion, twenty-four separate pictures are projected on the screen each second. The screen is completely dark while one 'frame' of the film is being withdrawn, and the next one substituted for it. Moreover, even while a particular frame is stationary in the gate of the projector, a shutter cuts off the light once or twice, and this simple procedure reduces flicker. The fact that impressions are retained in the eye and the mind, for about one-tenth of a second, however fleeting the external cause of the impression may be, is known as 'persistence of vision', and makes the cinema and the television of moving objects possible. In order to secure complete freedom from flicker, it is necessary to have more than ten pictures each second; in the case of the talking film, it is twenty-four. We shall see later how the impression of continuity of movement is obtained in television. The essentials of any system for sending television are:

1. A means of splitting up a picture into small squares or 'dots', in some regular and convenient manner.

2. A method of 'scanning', or traversing the whole of the dot system of the picture, a certain number of times each second. In view of the phenomenon of persistence of vision, twenty times a second will be reasonable for televizing ordinary moving objects.

3. A means of making the light from each part of the 'picture' control electric currents.

4. A suitable transmitter which will be capable of sending out signals of *high* frequency. We shall see the reasons for this later.

In 1873, a telegraph operator named May noticed that when light fell on electrical resistances made of selenium, more current was passed. Exposure to light had rendered the semi-metallic element selenium a better conductor of electricity. This was a photo-electric effect. Although the selenium was slow in its action, and its change in resistance

lagged behind the variations in illumination, the principle was seen to be a valuable one and attempts to control illumination electrically were made with varying degrees of success. Even as long ago as 1880, two well-known scientists, Ayrton and Perry, made proposals for the transmission of pictures by using this photo-electric property of selenium. An image of the scene to be televised was projected on a screen, which was composed of small separate squares of selenium. Each square was connected by two wires, via an electric battery, to the corresponding part of the 'receiver', also broken up into squares, each of which was an aperture with a shutter in front of a source of light. The idea was that when light fell on a particular square of the transmitter, the selenium passed more current, and accordingly an electro-magnet at the receiving end would open the shutter, and illuminate the corresponding square.

In order to obviate the necessity of having thousands of wires between the transmitter and the receiver, various devices were used to split up the picture into small elements, and to transmit them in rapid succession. The method of covering the picture is known as 'scanning', and if the process is done rapidly enough the mind obtains the impression of a complete picture. One of the best-known ways of splitting up a picture by mechanical means was patented by Nipkow in 1884. The method of working will be evident from the diagram.

A circular disc of large diameter has a series of small holes arranged in the form of a single turn of a spiral. No clear definition of the picture was possible with this crude arrangement, but it was used for a number of years as the basis of a television method. Nipkow's device was hardly a practical one, but he employed a clever means of varying or modulating the light in the receiver. He tried to take advantage of the property of flint glass, whereby polarized light, that is light which may be regarded as vibrating in a particular plane, in passing through the glass, has its

plane of polarization rotated by a magnetic field. There was no valve amplification in those days, and the feeble

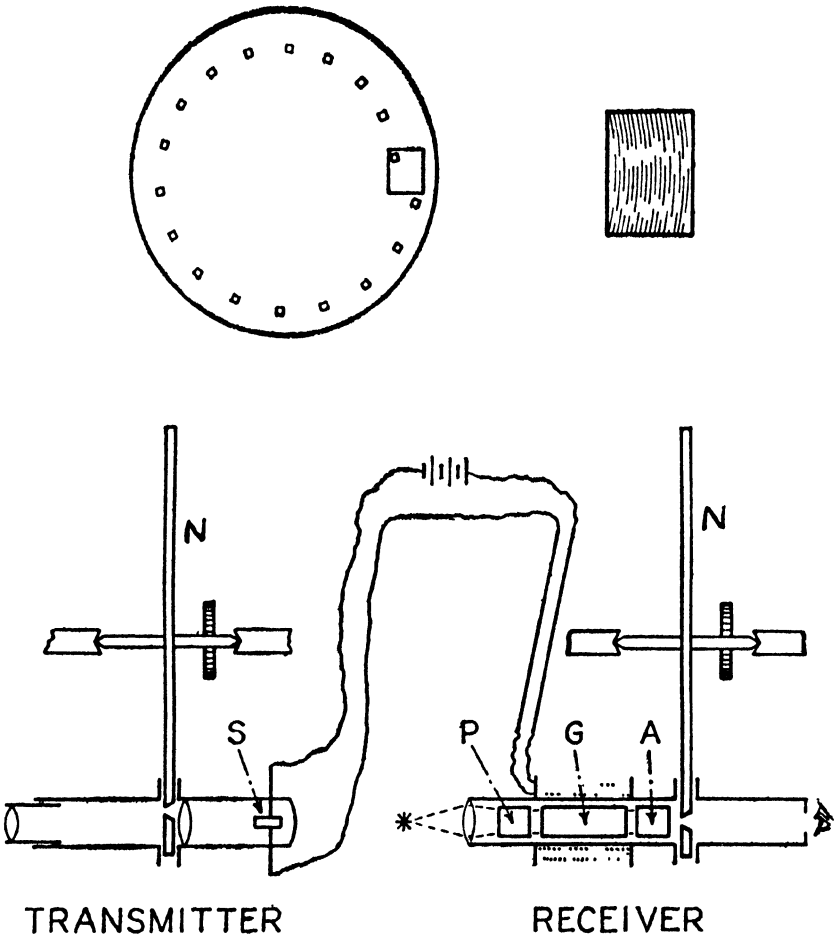


FIG. 7. Nipkow's disc for splitting up a picture. Two discs are used at N, S is a Selenium cell, P a polarizing prism. G is made of flint glass and A is the analysing prism. The date of this patent was 1884.

currents passed by the selenium cells were quite incapable of accomplishing any positive results in the receiver. Nevertheless, in principle, this was the system which was used by J. L. Baird for some years.

Another system of scanning, used by Atkinson in 1882,

and independently rediscovered seven years later by Weiller, was the mirror drum. A drum was fitted with a number of mirrors, each one of which was placed at an angle slightly different from that of the last. As the drum revolved the whole surface of the image was scanned in a series of lines and the light was reflected to a selenium cell. Some hundreds of schemes for television and the transmission of pictures by wire, appeared in patent specifications from 1877 to 1895. Before the end of the century it was seen that owing to the time lag in the photo-electric action of selenium it had no future in television schemes, where the very rapid variations in light intensity of the light from the scanning device made no impression on it. Accordingly, interest in the matter waned and did not appear to return until about 1907. In this year, a patent was granted to Boris Rosing for the use of a rudimentary form of the cathode ray oscillograph as a receiver. An evacuated tube of special pattern had been used by J. J. Thomson in 1897 for measuring the ratio of the charge and mass of an electron, which was a fundamental piece of research on the electrical nature of matter. This cathode ray tube was later improved by Braun and bore his name. Rosing used mirror drums for scanning the image, and the varying currents from the photo-electric cell were transmitted to the receiver by wire and here they charged two condenser plates in the cathode ray tube. The beam of electrons was bent according to the fluctuating charges of the plates, and this was made to cause a variation in the number of electrons which passed through a hole in a plate in the tube. The electron beam was then caused to traverse a fluorescent screen at the end of the tube. This was done by electro-magnets.

In 1908, in a letter to *Nature*, and again three years later, Campbell Swinton, the first Englishman to bring X-rays to practical use in this country, proposed a system which, although it was not workable at the time, anticipated in a remarkable manner the cathode ray receiver and the

emitron camera transmitter. The idea was to have a mosaic of photo-electric 'dots' in a special form of cathode ray tube. The back of this screen, on which an image was focussed by means of a lens, was scanned by a beam of cathode rays, whose movements were governed by alternating currents in two electro-magnets. The movements of the beams of electrons on the receiver were synchronized by electro-magnets energized by alternating current from the same generators which supplied the transmitter. The photo-electric currents for controlling the intensity of the receiver beam were transmitted in a separate wire.

Thus, ingenious ideas for television had outrun the technical developments necessary for their practical realization, for without sensitive and quickly operating photo-electric cells, amplifying valves, well-designed cathode ray tubes, and efficient short-wave wireless technique, no satisfactory high definition television could result.

We will first consider improvements in photo-electric cells. As we have already seen, selenium is slow in its photo-electric action, and in addition it is most sensitive to the red and infra-red end of the spectrum. In 1888, Hertz showed that the voltage required to produce a discharge across a spark-gap when light fell on it was less than that which was necessary when the spark gap was not illuminated, and incidentally in the course of these investigations he discovered wireless waves. Immediately afterwards, Hallwachs made complete researches on this matter and found that an insulated zinc plate could lose a negative charge, but not a positive charge, when it was illuminated by the ultra-violet light from an electric arc or burning magnesium ribbon. The effect is instantaneous and is due to the emission of electrons under the influence of the light. It was found that bright surfaces of sodium and potassium enclosed in evacuated glass cells exhibit this effect. Thus, a photo-electric cell was readily constructed by connecting the metallic surface to an electrode

and inserting another wire to act as an anode. Current, in the form of streams of electrons passing from the sodium or potassium surface to the anode, would pass if the external leads were joined to an electric cell, when light fell on the plate.

Many improvements in detail were made, and an extremely sensitive photo-electric cell was produced by using as the cathode, a plate of oxidized silver, coated with a very thin layer of caesium, probably only one atom thick. The glass container can either be evacuated as perfectly as possible, in which case it will respond exceedingly quickly to variations in the light intensity, or a small quantity of hydrogen may be introduced into the container, in which case there may be a slight time lag, but a more copious stream of electrons will result, owing to the collisions between the electrons emitted from the cathode, and gas molecules. There are types of photo-electric cell which will generate a small electric current when light falls on them. A layer of cuprous oxide on copper is covered by a thin electrode, transparent to light. These cells have too low an internal resistance, and too large an electrical capacity, to be of value in high-frequency work requiring valve amplification. However, they are admirable for working such instruments as photometers, in particular, the exposure meters used in photography,where they are combined with a sensitive voltmeter. The small output of the photo-electric cell must be magnified millions of times when it is used in television or the talking-film projector. As valve amplification, except in the final stages, always introduces noises, an electron-multiplier may be combined with the photo-electric cell. The electrons given off by the caesium-coated cathode are made to strike another plate of the same type, when many more electrons are emitted. These are guided to another plate and so on. The electron paths are accurately determined by external magnetic and electrical fields and from the end plate a considerable emission of electrons

results. A ten-stage multiplier in a single glass tube gives a magnification of five million, and finds many applications in talking-film apparatus and certain types of television cameras.

In the earlier forms of television receivers, much ingenuity was shown in methods of controlling light; that is, in making the feeble electric currents at the receiving end of the system vary the intensity of a source of illumination. Advantage was taken of the fact that light, which had been polarized by passing it through prisms of certain natural crystals cut in a particular way, would have its plane of polarization rotated through an angle when it was passed through certain liquids, such as carbon bi-sulphide, which were subjected to an electrical stress. Such a device is known as a Kerr cell. Another method which gave better results, when images were to be projected on a screen, depended on the properties of a series of high-frequency waves set up in a transparent liquid by means of a piezo-electric crystal. Such crystals are of wide use in wireless and other electrical technique. A crystal of quartz, for instance, cut in a particular way, will vibrate at a definite rate, when subjected to an electrical stress from an alternating electric current of the correct frequency. Such a device can be used for generating extremely rapid mechanical or supersonic waves which are useful in echo sounding. Again, the piezo-electric crystal can be used for calibrating and controlling the high electrical frequencies used in radio transmission. The perfecting of the cathode ray tube with the modification of it known as the Emitron camera, has revolutionized television technique; and as regards reception on small screens for home use, has done away with mechanical devices for scanning, such as rotating discs. Where the image has to be projected on a screen in a large cinema, the matter is rather more difficult.

It will now be convenient to discuss briefly the development of the cathode ray tube. The name *cathode ray* was given by Plucker, in 1859, to the electrical discharge from

the cathode (negative pole) when a high voltage electric current is passed through a glass tube, from which practically all the air has been withdrawn.

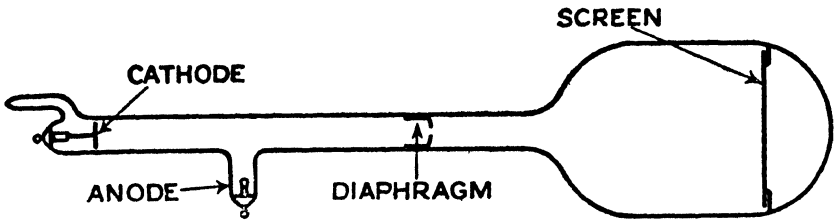


FIG. 8. A form of cathode ray tube due to Braun, made nearly half a century ago.

As we have already noted, the Braun tube was adapted from J. J. Thomson's tube for measuring the ratio of the charge and mass of an electron. The central portion of the stream of electrons from the cathode continues through the hole in the diaphragm and a comparatively large and ill-defined luminous spot is seen on the fluorescent screen. An external magnetic or electric field could be used for deflecting the electron beam. In 1905, Wehnelt improved the Braun tube, by adding a cathode of platinum strip coated with oxides, which when it was heated to redness by electricity, emitted electrons vigorously. A brighter spot on the screen was obtained by this means, even when a lower voltage was applied to the anode. Even so, the mutual repulsion of the similar charges of the negative electrons tended to make the electron beam diverge.

Later, Wehnelt surrounded the cathode with a cylinder which was negatively charged, and this had the effect of concentrating the electron beam into a narrow stream. Nevertheless, the focusing of the electron spot on the screen left much to be desired. In 1921, Van der Bijl and Johnson discovered that improved definition resulted by leaving a little residual gas in the tube and controlling the density of the electron stream by altering the current in, and thus the temperature of, the cathode.

The mechanism was as follows: the fast moving electrons, by collision with atoms of the residual gas, produce

positively-charged atomic particles. These are heavier, and move more slowly. Thus, a positive central core in the middle of the beam remains to attract the electrons to it, concentrating them into a thin jet.

No real progress could be made as far as television was concerned until the exact control of electro-static fields permitted the focusing of the electron beam, in a manner analogous to that obtaining when light is concentrated by an arrangement of lenses. As we have seen when discussing the electron microscope, electron 'lenses' in the form of electro-static or magnetic fields can be made to concentrate the beam. The science of 'electron optics' has thus become very important. Two or three 'lenses' are usually sufficient in a television tube. These may be regarded as anodes as they are positively charged. The first is charged at a voltage of a few hundred, and in order to give the electrons the necessary speed towards the screen the second anode (or electron lens) has a voltage of upwards of one thousand, and a third between three and six thousand volts. In a piece of optical apparatus, such as the compound lens of a magic lantern, we have to use a number of separate glass lenses in order to avoid aberration. The third electron lens is also used to avoid spherical aberration. Wehnelt's cylinder is now called the grid and its voltage controls the number of electrons which reach the screen. The 'vision' signal is, therefore, applied to it, and hence it controls the brightness of the spot on the screen. For deflecting the beam, so that it scans the screen twenty-five times a second, the output voltages of two time-base generators at 10,125 and 50 cycles per second respectively are applied to the beam by two sets of plates. One pair is at right angles to the other pair and they are placed beyond the third anode so that the electron beam passes between them.

Some form of electron camera is used as the 'eye' of television and in general two types of these are available. The first or 'storage' type is called the Emitron camera,

and was developed from the suggestions of Campbell Swinton, which we have mentioned already. The second is known as the image-dissector type and was patented by Dieckmann and Hell in Germany in 1925. It has been developed and perfected by Baird. Both cameras are closely related to the cathode ray tube, and depend on the principles of the precise control of electron beams by appropriate magnetic and electrical fields.

How the Emitron camera works can be seen from the diagram. Electrons are produced by electrically heating the cathode D and they are accelerated and concentrated in the electron 'gun' E and F in a manner similar to that used in the ordinary cathode ray tube, so that they are focused into a small spot on the mosaic screen M. F is really a silver coating on the inside of the tube and is joined to an appropriate HT source at G. As the electron

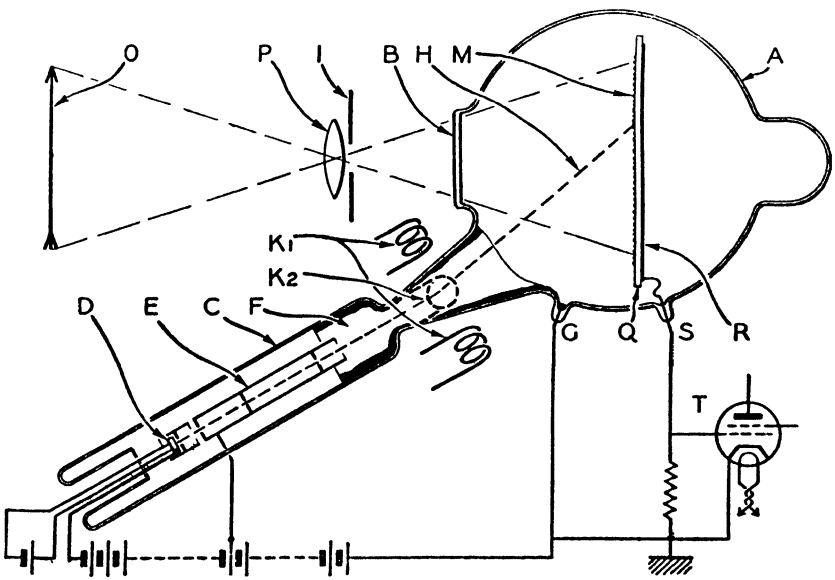


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FIG. 9. An Emitron camera.
The brightness of the image may be controlled by the diaphragm I.

beam passes through the narrow portion of the neck of the tube it is subject to the effects of two mutually perpen-

dicular magnetic fields produced by the two pairs of coils K1 and K2. These are supplied with alternating currents of special wave form and frequency, from a pulse generator actuated by valves, and cause the electron beam to be deflected and to scan the surface of the mosaic screen in a series of parallel lines.

A lens at P forms an image of the scene O to be transmitted on the screen M, and for this purpose a flat plate B of optically worked glass is incorporated in the glass envelope of the tube. The screen is made of a thin sheet of insulating material Q, such as mica, covered on one side with a conducting metal coating R, known as the 'Signal Plate'. To this, electrical contact is made by a wire sealed into the glass envelope at S. On the side of the mica sheet Q, which faces the scene to be televised, a mosaic M is formed of a very large number of tiny globules of silver deposited in such a way that each globule is separate and insulated from its neighbours. After this, the surface is treated so that each globule is covered with a photo-electric surface. When light falls on the surface of the mosaic screen, each coated globule gives off electrons in proportion to the amount of light falling on it. Also, each tiny particle of the mosaic, separated from the metal signal plate by a dielectric of mica, acts as a condenser with it.

Imagine now that an image of a scene has been focused on the screen. The particular mosaic elements which are well illuminated will produce a large number of electrons, the elements on which no light falls will liberate no electrons, and those which are not brightly illuminated will produce an immediate number of electrons. Corresponding positive charges will be left on the globules of the mosaic.

As the electron beam scans the surface of the mosaic element it restores sufficient electricity to each element to bring its charge to zero. Owing to electro-static induction in the condenser produced by each globule, the mica and the signal plate, the discharge is communicated to the signal plate, whence it is transmitted to the first valve of

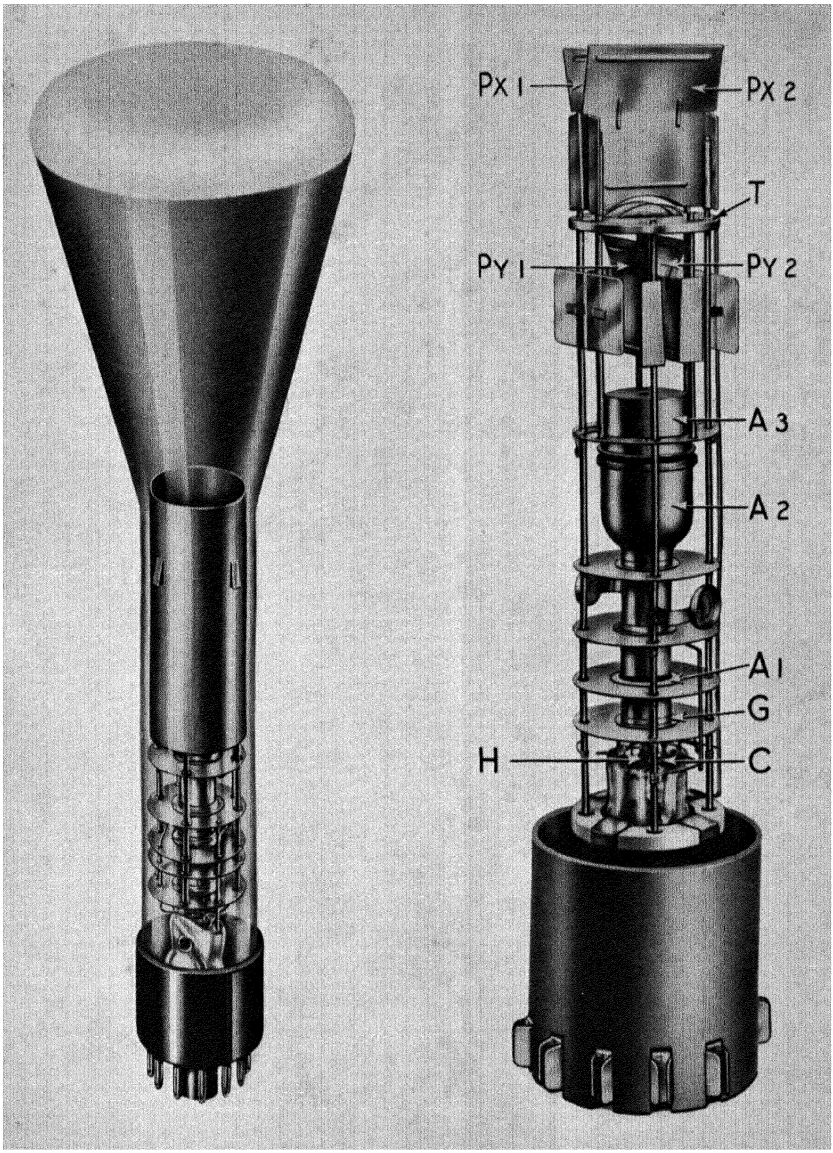

Plate IV *Courtesy Cossor Ltd.*

Left—A recent type of Cathode Ray Tube.

Right—Internal assembly of a recent type of Cathode Ray Tube. H = Heater; C = Cathode; G = Grid; A_1, A_2 and A_3 = anodes charged positively at increasing voltages to accelerate and focus electron beam. PY_1 and PY_2, PX_1 and PX_2 pairs of deflecting plates at right angles, to move electron beam. The circular fluorescent screen is the part of the glass envelope at the end of tube.

the amplifier (T). Thus, as the scanning beam covers the mosaic, a series of electrical impulses, which vary with the image brightness along each scanned line, are sent to the amplifier. The train of impulses which goes to the amplifier, when the whole image has been covered line by line, is called 'the picture signal'. The electron beam covers the mosaic twenty times each second and remains on each globule for less than a millionth of a second; but the light of the image remains on each element between whiles, and consequently the charge builds itself up, until with the return of the electron beam it is discharged. This explains why this type of device is called a *storage* tube. It can readily be seen that the Emitron camera has an 'electric memory'. If an image is allowed to fall on the mosaic, a picture in terms of electron density will be built up and will remain for some seconds, unless it is disturbed by a scanning beam, by which means it can then be reproduced. This property has been used in certain methods of film transmission in which the image is made to produce its effects on the mosaic, and is scanned while one frame of the film gives place to the next.

The Baird Electron camera is a development of the image-dissector tube. An image of the scene to be televised is focused upon a large flat plate which is coated with photo-electric material. Electrons are given off at any point in proportion to the amount of light which is falling there. Thus, an 'electron image' corresponding perfectly with the 'light image' is produced just in front of the photo-electric surface. By the use of a combination of electrical and magnetic fields, the electron image is brought to a focus in a plane parallel to that of the photo-electric plate or cathode, and some distance from it. The electron image substitutes electron density for light intensity. The focusing of the electron image is made possible by what we know of electron optics; and this is an important general principle, as we have seen when discussing the electron microscope. The scanning of the electron image is accomplished

by moving it, as a whole, across a fixed scanning aperture, by using two magnetic fields, perpendicular to the focusing

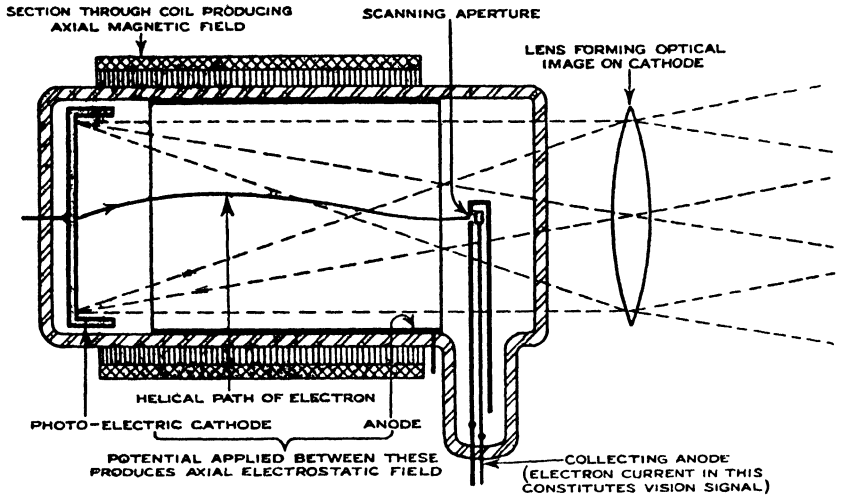

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FIG. 10. An electron camera of the image dissector type.

field. A collecting anode behind the scanning aperture picks up the electrons from each spot on the image, and from it they pass to an electron multiplier which gives an amplification of about two thousand. From this the camera current goes to further valve amplifiers.

The English standard for television is 405 lines across the picture, and twenty-five pictures are built up a second. 'Interlaced' scanning is used, and this gives many improvements in overcoming flicker, particularly when fairly rapid moving objects are televised. In this system the picture is scanned fifty times per second but only the 'odd' lines, 1, 3, 5, 7 and so on are covered on one sweep, and the even lines 2, 4, 6, 8 on the next. This double operation is repeated twenty-five times each second. It is obvious that in view of the number of the tiny elements into which the picture is divided, and the fact that each is covered twenty-five times each second, all the circuits of transmitter and receiver must be capable of responding to very high fre-

quencies, in fact to two and a half million cycles per second. The standard which will suffice for the transmission and reception of audible sounds is not nearly good enough for television. For transmitting sound by 'land line', ordinary telephone circuits will give fairly satisfactory results, but television requires a special technique. In order to serve the whole country with television, a considerable number of relay stations will be required at such places as Birmingham, Manchester or some other suitable place in Lancashire. If it were necessary to transmit 'television' by land line from a studio at the Alexandra Palace to a relay station at Birmingham, it would be essential to use coaxial cable.[1] In this a central wire is enclosed in a cylindrical metal tube with a gas or other dielectric, such as the remarkable synthetic plastic substance polystyrene,[2] between them. If the correct dimensions are preserved, the condenser action of the wire and tube offsets the induction effects along the wire, and high frequencies can be dealt with. As we have already seen when discussing radiolocation, research into the problems there presented by high-frequency electric pulses, should also bear fruit in simplifying many television problems.

In America, there were nine commercial television stations at the time this book was written, with a weekly service of fifteen hours each. There are at least forty applications before the U.S. authorities for post-war television transmitters. The American standard, which it is still proposed to continue for some years, is 525 lines with thirty complete scannings, that is sixty interlacings, per second. This system uses a part of a side band (the vestigial side band) of the carrier-wave transmitting the picture, and frequency modulation for the associated sound. Larger screen types of television are being tried. A small cathode ray tube receiver, giving a very high intensity illumination is used, and an image of the enclosed end of the cathode ray tube is thrown on a screen by a

[1] Such a cable was already in existence before the war.

[2] See page 112.

lens. This is also being developed experimentally in this country, and research on fluorescent screens, which was made necessary for developments in radar, has proved useful in this matter. The French television transmitter employs 450 lines, and this will probably not be modified for some years.

Experiments have been made with colour television by Baird in England, Goldmark in U.S.A. and others. The number of lines is considerably reduced and definition falls off. A two-colour system whereby two translucent screens, one fluorescing red to orange, and the other green to blue, were placed together so that each was activated by a cathode ray stream, one on each side, has been tried by Baird. Puckle, an English expert, promises satisfactory colour television by 1952.

The English transmitter is at the Alexandra Palace which has the advantage of being near London and on high ground. One of the towers was strengthened in order to take the weight of an aerial of special design.

When ordinary speech frequencies are transmitted by wireless, in order to secure proper radiation and tuning, a higher frequency carrier-wave is modified by combining it with the wave of lower frequency. This is the process of modulation.

Suppose our transmitter is producing a wavelength of 300 metres. This represents a frequency of 1,000,000 cycles per second; that is, a megacycle. If now this wave is modulated by sound waves having a frequency up to 10,000 per second, the frequency of the 'side bands' will be from 1,000,000 — 10,000 cycles to 1,000,000 + 10,000 cycles, that is, from 990,000 cycles to 1,010,000 cycles; or in wavelengths, between 297 and 303 metres. Thus, the wavelengths of various stations must be so chosen that there is no overlapping of the side bands. The frequencies of the television currents are higher than those of the ordinary carrier waves of medium wavelength broadcast stations. Thus, for television it is necessary to employ a carrier wave

Plate V *Courtesy A. C. Cossor Ltd.*

A Modern Television Receiver for Home Use. The image appears at the end of a large cathode ray tube.

Facing page 43

of much higher frequency, and therefore of smaller wavelength. In England, when all matters were considered, a wavelength of 6·67 metres was decided upon. This limits the range of the transmitter, although the refraction or bending effects tend to produce a reasonable signal strength behind hills. Data obtained from radar research should result in the improvement of design of the output part of television. In this country, the sound associated with television is sent out on a wavelength at 7·23 metres, and the transmitter has a frequency response from 30 to 10,000 cycles, which is practically distortionless. The reproduction quality is therefore remarkably high.

We can now trace briefly the stages in a television transmitter between the electron camera and the transmitting aerial.

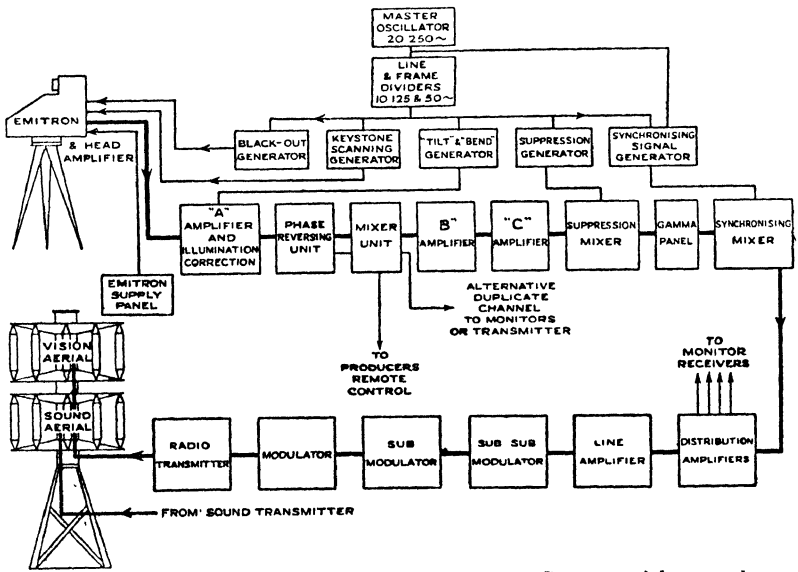

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FIG. 11. Diagram showing the arrangement of the television transmitter at Alexandra Palace.

The feeble currents generated by the television camera are first amplified in a four-stage unit built into the camera itself, and then are passed to the 'A' amplifier where certain

modifications and corrections can be made where necessary. The general illumination of the picture, the contrast between light and shadow, etc., can be adjusted and it is even possible to reverse the phase of the signals, so that when it is desired black becomes white, and negative cinema films can be transmitted as positives. Here also is the mixer unit, so that several cameras can be controlled from one panel and one picture faded into another. The producer can achieve this by remote control from his desk, and by the use of a 'monitor' cathode ray tube can see exactly what he is doing. The devices of the cinema for fading or the super-imposing of pictures can thus be obtained. The television current then passes to a four-stage amplifier, known as the B amplifier, where various unwanted signals are removed, such as those caused by the 'fly-back' of the electron beam at the end of each line and at the complete scanning of the picture or frame. As amplification proceeds, a 'synchronization signal' is mixed with the television pulses so that the receiver shall be able to keep perfect pace with the transmitter. In order that the scanning beam shall cover the signal plate at just the right speed, it is controlled by the currents from impulse generators. A master oscillator, which is electrically locked to the 50 cycle mains, generates a rectangular wave form with a frequency of 20,250 cycles. From this is derived the line frequency of 10,125 cycles and the frame frequency of 50 cycles. Thus, the picture is scanned by moving the electron beam to and fro 10,125 times a second and in a direction at right angles to this fifty times a second. Various other generators are supplied from the master oscillator. These are known as 'black out', 'tilt and bend', 'keystone' and 'suppression' generators respectively. In brief, their function is to determine the shape of the rectangle of the picture, and to suppress the television current in the 'fly back' period between the line and picture (frame) scanning periods. The picture current is then modulated by the direct current or 'D.C. method'. The diagram will make

plain what happens. The current, now varying with the picture signals and interrupted by synchronizing pulses, is kept in position; that is to say, it is not allowed to swing from positive to negative about a zero line, as in alternating current. D.C. working permits perfect control of the overall

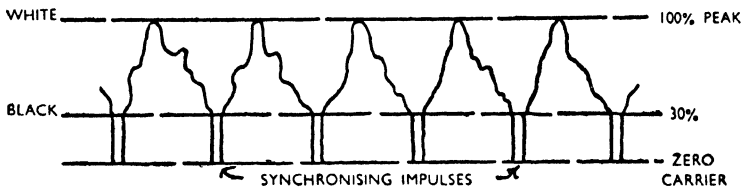


FIG 12. Direct current modulation.

brightness and contrast of the picture, the peak of amplification can be secured without the risk of distortion or blur, and definite levels may be fixed to correspond with the extremes of black or white in the picture.

Finally, high-power water-cooled valves giving a peak output of 17 kilowatts represent the last stage of modulation amplifier, and then the high frequency current is fed to the aerial. At present, the only such aerial in England is on the south-east tower of the Alexandra Palace, which is about six miles north of Charing Cross and on high ground between Muswell Hill and Wood Green. On the upper portion of the mast, which is about 200 feet above the ground and over 600 feet above sea level is the vision aerial system, with eight vertical sets of antenna. It is so arranged that reflectors ensure efficient radiation and prevent any appreciable losses vertically, which, as in the case of radar, would have a disturbing effect if the radiation were reflected from the ionized layers of the upper atmosphere. It will be remembered that our knowledge of these layers is due to the experiments of Appleton, in which short wireless waves were reflected from these upper regions. The lower part of the aerial structure carries the short-wave antennae for the sound associated with the television.

The action of a television receiver is very easy to under-

stand if we have grasped the working of the cathode ray tube. Let us begin with the aerial. An H-shaped aerial, with a thick wire 'lead-in' from the centre of the cross-piece, is a common sight, and usually denotes that there is a short-wave radio receiver somewhere beneath it. This type of aerial is useful for television reception. Generally, a vertical wire of rather less than half the wavelength is the essential feature of the aerial. If it were possible to erect an aerial in free space, a half wavelength aerial would be excellent, but owing to the capacity (that is, the condenser effect between the aerial and the ground) the aerial has to be shortened somewhat. Just as an open organ pipe resounds to note of wavelength about twice its own length, so the half-length aerial has a useful resonance effect. A metal parabolic reflector facing the transmitter, with the vertical receiver aerial placed at its focus, would make a very efficient form of receiver. Usually it is sufficient to limit the reflector to a single rod or wire parallel to the first, rather longer than it, and at a distance of a quarter of a wavelength behind it. With high-frequency currents, which are easily lost or attenuated between the aerial and the receiver, it is necessary to regard the 'lead-in' as part of the aerial. A concentric cable or two parallel wires are used as a feeder. The electrical resistance to high frequencies or impedance of the feeders has to be matched to that of the aerial, in order to avoid energy losses.

The feeble incoming signal has first to be amplified. This can be done in one of two ways. The vision and sound currents may be amplified together through seven or eight valves and after the first few stages of amplification the sound carrier-wave is filtered off and separately amplified. Amplification of signals at very high frequencies is no easy matter. At such frequencies the electrical resistances of conductors to wave-like currents increase enormously, whereas condensers, conductors in proximity and parts of valves which act like condensers, pass considerable current and their equivalent 'resistance' falls enormously. 'Feed

back' takes place and this upsets conditions at the grid of the valve. Again, free electrons, near the grid of the valve, absorb energy when their time of passage between the cathode and anode is of the order of that of the high frequency oscillation. These difficulties are even more marked in radar, and there they have been overcome by the use of the magnetron valve and special circuit design. In television receiving apparatus the magnetron has not normally been necessary, but good circuit design together with the use of special small valves has proved sufficient.

The alternative method of amplification is to use the super-heterodyne principle. Here a local oscillator (that is, one in the receiving set) produces a frequency fairly near to the incoming frequency, and the heterodyning or 'beating' of lower frequency can then be amplified in a more convenient manner. For example, suppose that the incoming signal has a frequency of 45 megacycles[1] per second and that the local oscillator has a frequency of 42 megacycles per second, and the 'side bands' due to the modulation of the picture frequencies give a range of from 46·5 to 43·5 megacycles per second in the incoming signal. The 'beats' or 'heterodyning' will contain frequencies from 1·5 to 4·5 megacycles per second. Both sound and vision signals can be heterodyned by the same local oscillator, and are then separated. The matter is simplified by the fact that the wavelength of the sound and the vision signals respectively are fixed, and therefore the receiver has to deal only with fixed or narrow ranges of frequency.

After rectification the vision signal contains the synchronizing impulses which make certain that the scanning circuits of both transmitter and receiver keep pace with one another. The vision and synchronization can be separated either before or after amplification, by suitable filter circuits. As the brightness of the televised scene usually changes slowly, it is necessary to amplify uniformly down to zero frequency; that is to say, the direct current

[1] A megacycle is a million electrical oscillations or vibrations.

part of the signal after 'detection' must be passed. As we have already seen, the time-base generator circuits contain frequencies which, when filtered out, will give separate frequencies for controlling the 'frame' and 'line' motion of the cathode ray beam. The vision signal is so applied to the cathode ray tube that it can control the intensity of the electron beam and hence the brightness of the fluorescent spot on the screen. So far, we have dealt only with reproduced pictures which could be contained by the end of the cathode ray tube. Ingenious arrangements of rotating mirror drums with high intensity mercury-lamps were used up to the time of the war; and the poor definition given by the earlier arrangements was overcome by the Scophony system which was able to employ the full 405 line picture. Many ingenious ways of mounting small mirrors and prisms are used for converting a modulated line of light, travelling in a fixed direction, into one or more beams which rapidly scan a screen.

Much research has taken place during the war on the perfection of cathode ray tubes and fluorescent material, for all but the largest screens. New light-sensitive materials coated on or flowing over a fabric mesh screen, with projection from the rear, give excellent results. High intensity cathode tubes are used and wide aperture plastic lenses magnify the bright picture formed at the end of the television tube, and cast an enlarged image of it on the screen. It is probable that television projectors with moving parts will be superseded when post-war methods get into their stride. The domestic television receiver has contained no mechanically moving parts since the introduction of high definition pictures.

•

The Betatron

When the radiations of radium were first carefully examined, they were found to consist of three distinct types: atoms of helium charged positively, electrons or particles of negative electricity and X-rays. These were

called alpha, beta and gamma rays respectively. Thus, the betatron is a machine for making beta rays (that is, a stream of electrons) move very quickly. What the cyclotron does for heavier particles, such as heavy hydrogen and helium nuclei, the betatron does for electrons. Although both machines produce the enormous speeds which they give to their respective particles by a whirling process, the principles of their operation are different. As we shall see, the cyclotron operates by giving the nuclei carefully timed 'kicks' as they travel in spirals, whereas there is a continuous push all the way round, in the case of electrons in the betatron. A cyclotron occupies much laboratory space and the complete equipment of a small model may weigh nearly 100 tons. The betatron is small in comparison; it weighs no more than $3\frac{1}{2}$ tons and requires only a fifth of the 150 kilowatts of the cyclotron to work it.

If a stream of electrons is sent through a tube from which the air has been evacuated, the speed attained by the electrons is dependent on the voltage which causes their acceleration. Further, if the stream of electrons is allowed to strike a target made of a heavy metal, X-rays are given off. Although this target imposes certain characteristics on the X-rays, the length of their pulses—we might popularly describe it as their wavelength—depends on the speed of the electrons, and therefore on the voltage producing this speed. The X-rays will be shorter in wavelength as the voltages and electron speeds become greater, and up to certain limits the X-rays will become more penetrating. By the direct method of applying voltages, we cannot hope to obtain *steady* streams of electrons equivalent to more than about 1,500,000 to 2,000,000 volts; but the betatron, by whirling round the electrons inside a circular tube, will produce the equivalent of 100 million volts. X-rays of entirely new penetrating power and energy can be produced, and it is probable that a stream of electrons coming from the machine at high speed will prove useful in the treatment of malignant

growths within the body, without causing any bad effect on other tissues. It has been suggested that electrons at a speed representing 25 to 30 million volts would be useful for medical work.

The idea of the 'betatron' was not a new one, and as early as 1921, many physicists, including those at Cambridge, had seen possibilities in the idea, but had given it up through lack of equipment and the fact that other atomic research had absorbed their energies. The first machine was designed and built by a young American, Professor Kerst of Illinois, and was finally completed on July 15, 1940, when it worked successfully from the start.

The study of atoms and electrons for a number of years has advanced from what has aptly been called 'the tobacco tin' stage, and is now in the realms of heavy electrical engineering. After taking his research degree in physics, Kerst spent a year in industry. In spite of discouragements from his employers who said the 'betatron' idea would be impossible to realize in practice, the young physicist was not dismayed, but left his industrial work and joined the teaching staff of the University of Illinois, where Professor Kruger gave him much help. Kerst's first machine consisted of a 3½-ton electric magnet, the core of which was made from 17,500 laminations of silicon steel. The faces of the magnet poles were about 20 inches in diameter, and between them was a circular glass tube 19 inches across, 4 inches wide and 2 inches deep. Electrons are released from a filament in 'bursts' of 180 per second by means of a pulsating voltage on an 'injector' associated with the cathode. The current in the coils of the electro-magnet is so arranged that it is zero at the moment that the electrons are released at each 'gush'. The electrons are forced to travel in a fixed orbit, which is so arranged that they do not strike the injector, by the powerful magnetic field. They reach a speed approaching that of light, and have an energy equivalent to 20 million volts. Some of the electrons pass through the walls of the tube owing to their

great speed, but at the peak of the magnetic cycle in the field coils, they leave their orbit, strike a target, and produce X-rays equivalent to hitherto attained voltages. The effect of the electrons obtained from Kerst's first machine is equivalent to 4 lb. of radium—more than twenty times the world's entire supply which was extracted at a cost of between three and four million pounds. The G.E.C. have built a much larger betatron capable of an output of 100 million volts which was successfully operated in October, 1945, in America.

Apart from its medical and industrial uses in producing X-rays and streams of electron of hitherto unknown quality, the betatron has already proved useful in investigations concerning atomic energy. Very accurate measurements of the electron voltages required to smash the nuclei of the atoms of various elements can be made. For instance, it was found that 11 million volts would suffice for copper, but 19 million were required for carbon. Again, it was found that when voltages increased above 3 million, the penetrating power of X-rays became less. This is in accordance with theory, which predicts that at about one million volts X-rays begin to change into matter. The conversion of energy into matter increases with increase of voltage, and this explains why beyond a certain voltage, X-rays become less penetrating, even though their energy is greater. This has been referred to in the newspapers as 'the atomic bomb in reverse'. It is probable that the new betatron will be useful in producing rays equivalent to cosmic rays, the mystery of which is not yet completely solved. These complex radiations, representing energies of thousands of millions of volts, reach us from outer space and may be produced by the destruction, or equally the construction, of matter at extreme distances from our solar system.

THE RELEASE OF ATOMIC ENERGY

(Atomic Energy and the Cyclotron)

WHEN we were discussing the electron in the previous section, we saw that it might be useful to think of an atom as a miniature solar system with a positively charged centre or nucleus, surrounded by a system of electrons. As we think of the atoms arranged in order of their atomic weight starting with hydrogen and finishing with uranium, we find that the nucleus becomes more complex in structure, more massive and, speaking generally, contains more energy. From the time of the Greek, Democritus (born in Thrace in 460 B.C.), until the end of the nineteenth century, ideas concerning atoms underwent certain changes, notably through the work in chemistry of the Manchester schoolmaster Dalton in the early years of the last century. But always atoms had been considered to be unchangeable, fundamental solid units of matter and to have a permanent existence.

A few scientists had suggested that all the different elements may have been built from one primal form of matter. In 1817 Meinecke called this imaginary substance *urstoff* and in 1857 Hinrichs postulated *pantogen* as this fundamental substance. William Crookes called it *protyle* and described it as 'matter generalized, stripped of its distinctions, the same from whatever source derived, it is matter in potency rather than in act; intangible, inaccessible to sense perception, probably indifferent to the solicitations of gravity'. The fact that so many atomic weights were approximately whole numbers seemed additional evidence for this idea. In the year after the battle of Waterloo, W. Prout had suggested that all atoms were built up from atoms of hydrogen.

One of the first hints that all was not well with the old comfortable theory of the solidity of atoms was the discovery in 1896, by Henri Becquerel, that certain minerals showed

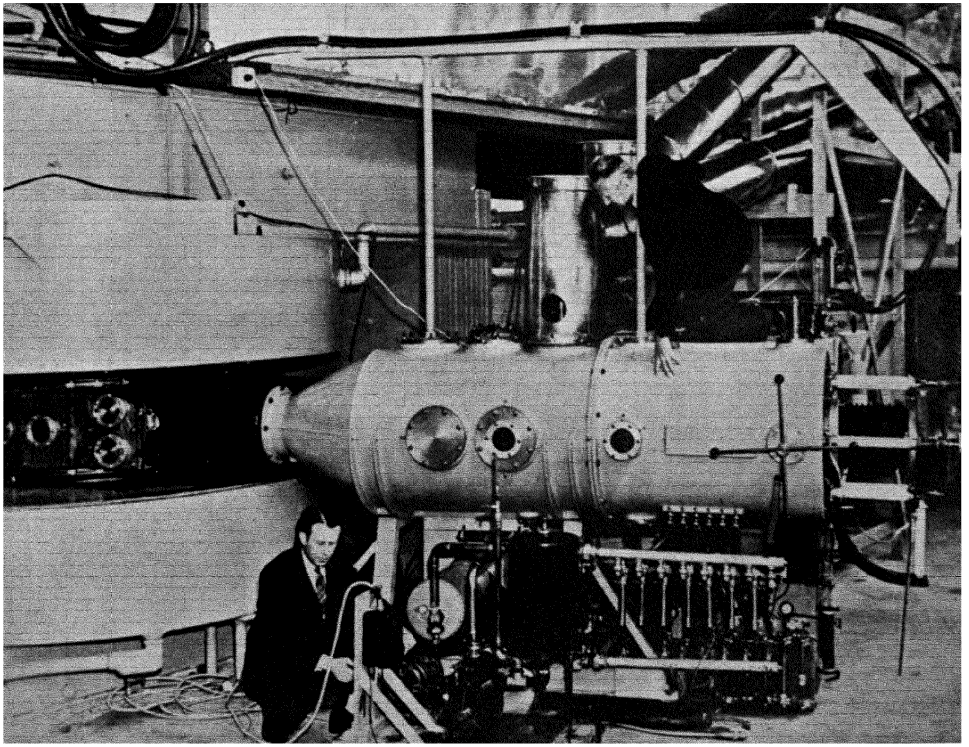
radio-active properties. He found that compounds containing uranium continuously gave off radiations which would pass through boxes and envelopes opaque to light, and would fog photographic plates contained therein. Becquerel was merely repeating in a more systematic way some experiments conducted thirty years before by Niepce de St. Victor to see if substances which were fluorescent, that is shone in the dark under certain conditions, also emit invisible radiations. Becquerel was also following Röntgen's discovery of X-rays in 1895, by finding if substances which become fluorescent under the influence of invisible rays, would also themselves emit such rays. He discovered that the uranium ores emitted their radiations spontaneously and continuously even when they had not been exposed to light or other rays. In the last years of the nineteenth century, Pierre and Marie Curie made a thorough examination of various minerals containing uranium, and found that some of these ores were more radio-active than uranium itself. They correctly inferred that 'the strong activity of the pitchblende from Joachimstahl in Bohemia is due to the presence of small quantities of a substance wonderfully radio-active, and different from any other simple body known'. With little which we should now call apparatus, negligible facilities for scientific research, and much hard physical work, infinite patience, and finally by a lengthy chemical process, a tiny quantity of radium chloride was extracted. Radium was seen to be a new element, related to the metal barium from which it was with difficulty separated; it occurred in those minerals which also contained uranium, but in a proportion many thousand times less. Radium constantly gave off energy in the form of electrons and helium nuclei moving at high speeds, X-rays, and as might be expected, light and heat. Its radio-activity was not modified by combining it chemically, nor by heating or cooling it. Thus, the radio-active effects clearly came from within the atom. There seemed to be nothing explosive about the

release of the energy which could not be modified in its unhurried and unperturbed pace. Radium was an exceedingly rare substance and expensive to prepare, but here was an element whose atoms were constantly disintegrating while giving off large quantities of energy. Many of the degradation products of radium were also radio-active, and it appeared that after many years of radiation the metal lead would be the end product. Almost immediately after the discovery of the metal radium, it was seen that it gave off energy far in excess of that of a chemical reaction, as, for example, the combustion of an equal amount of gunpowder. An early conservative estimate showed that radium gave off a quarter of a million times as much heat as a similar weight of coal when this was burnt chemically. When examinations of various radio-active substances, their emanations and other products had been more thoroughly conducted, it appeared that uranium, the element with the greatest atomic weight, was the parent of radium and that the former would spontaneously pass into the latter via an intermediate form of uranium. This process would take some thousands of million years. Radium itself produces a number of degradation products, of which radium emanation (radon) decays to half its activity in about a year, and its radiation is thus more powerful. The final substance was the metal lead. The metals thorium and actinium also showed analogous 'genealogical tables'. Moreover, natural radio-activity seemed to be confined to the last few elements in the chemical table of ascending order of atomic weights.

As we have already observed when discussing electrons, Rutherford used the quickly moving heavier particles, called alpha particles, given off by radium to explore the interiors of other atoms. It is obvious that the intense electrical field surrounding the nucleus of an atom acts as a powerful 'coastal defence' and the positively charged alpha particle will tend to be repelled or diverted from its course. The alpha particle is 7,200 times as massive as

Plate VI

A large American cyclotron in the University of California. The cylinder in the foreground is the target chamber and the large horizontal electro-magnet poles can be seen on the left. A preliminary test showed that deuterons spun between these poles produced an energy equivalent to 19 million volts. Professor E. O. Lawrence is below and Dr. D. Cooksey, his assistant, is above.



Courtesy E. O. Lawrence

an electron, but in view of its positive charge it is not surprising that it is not usually particularly effective as a missile with which to penetrate and break asunder an atomic nucleus. Nevertheless, through his researches at the beginning of the century, Rutherford was able to construct a working model of the atom in the form of a miniature solar system with a positive nucleus at the centre surrounded by electrons arranged in orbits, and this was most useful in subsequent researches. Niels Bohr, a Danish mathematical physicist, successfully extended Rutherford's idea of the atom (which occupied space but was mostly empty in itself), to show that its physical and chemical properties, including the spectrum of the light emitted when substances containing it were heated, were due to the rings of electrons.[1] The mass of the atom was due to the nucleus. This is in keeping with what we shall learn about isotopes, where we find forms of elements with the same chemical properties but with different atomic weights. It was soon seen that the spontaneous radiations from radium did not involve a complete splitting of the nucleus. Only a tiny part of its mass was given off in the form of energy.

The use of the fast-moving particles of radium and other radio-active substances, though applied with the utmost ingenuity by Rutherford and his collaborators, had many limitations. One cannot take a fortress with a collection of small arms, however varied it is! Nevertheless, in 1919, while still at work in Manchester, Rutherford succeeded in disintegrating atoms of nitrogen, to provide fast moving hydrogen nuclei, by the use of swiftly moving alpha particles from radium, and concluded, to use his own words, 'The results on the whole suggest that if the alpha particle or other similar projectiles of still greater energy were available for experiment, we might expect to break down the nucleus structure of many of the lighter elements'. During the following five years, Rutherford and Chadwick succeeded in disintegrating most elements from boron to

[1] Speaking generally.

potassium. Research workers soon turned to the possibility of producing high voltages which could be used to acceler-

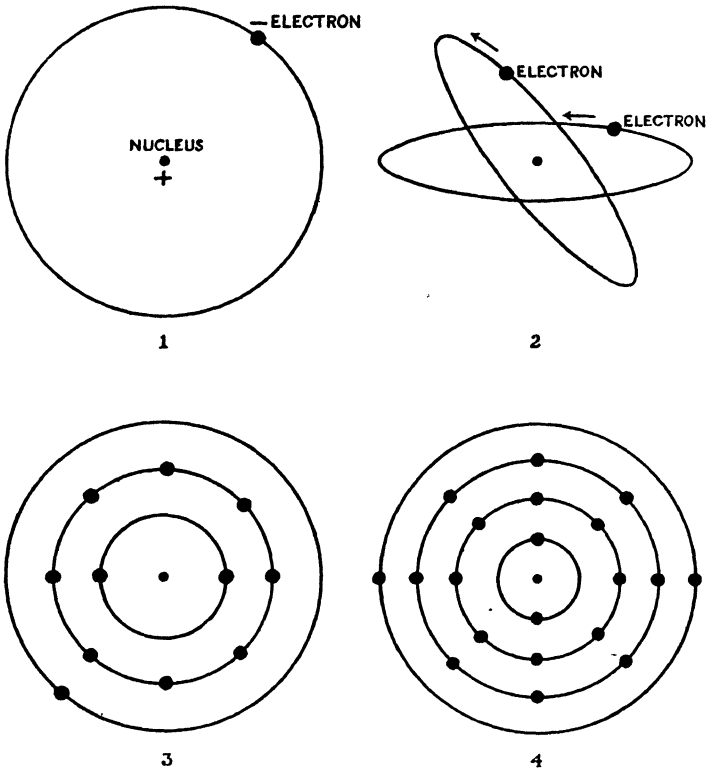


FIG. 13. Diagram illustrating (1) Electron and proton in hydrogen atom. (2) Helium atom. (3) Atom of sodium. (4) Atom of calcium. The valency electrons which govern the combining properties of the atoms (3) and (4) are in the outer rings. The central nuclei of the heavier atom may have a complex structure and it is from the nuclei of heavy atoms that energy is released in fission processes. Diagrams of atoms give no idea of relative sizes and distances, and yield only a limited idea of their structure. Atoms are not flat as depicted in (3) and (4) above and electrons are not spheres of negative electricity.

ate particles such as helium or hydrogen nuclei (alpha particles and protons respectively) to such a speed that they would penetrate other atoms placed on a suitable target. This is not as simple as it might appear at first sight. The

resources of heavy electrical engineering have to be called into play to provide voltages up to two million, and in view of the smallness of the target, no little patience and ingenuity are necessary to ensure that a suitably thin but powerful stream of particles really hits the target at the precise point required. Moreover, the acceleration can only be made in evacuated glass tubes, which require breaking into, or taking to pieces every time an adjustment is to be made. Not only is it necessary to secure vacuum pumps which will quickly withdraw the air from the system of tubes, but also some substance which has a low volatility and will seal all joints has to be obtained. Plasticine was found to be fairly satisfactory for this purpose, but research on this matter had already been undertaken in connection with the electric lamp industry which has grown enormously in the last decade or two. The oils and greases which evaporate with extreme slowness, developed by Dr. C. R. Burch, were found to be indispensable for sealing the joints in the glass tubes which are used in atomic research.

Dr. Cockcroft and Dr. Walton, working in the Cavendish laboratory at Cambridge in 1930, first accomplished the disintegration of atoms by using a machine. With a voltage of less than a million, protons were driven down a six foot tube and made to strike a target placed at the bottom at an angle of 45° to the direction of the stream of particles. What happened to the atoms of the target was seen on a fluorescent screen, and needed experience for its correct interpretation. Cockcroft and Walton found, to their surprise, that if the target were made of the light metal lithium, some of its atoms disintegrated with protons driven by voltages as low as an eighth of a million, and helium nuclei were given off. The penetrating power of these helium nuclei was such that it represented an energy of eight million volts. The accelerated proton appeared to have acted as a detonator releasing the energy of the atom!

The 'equation' for what had happened might be expressed as follows.

lithium nucleus + proton = 2 helium nuclei + energy

$$\begin{matrix}7 \text{ protons} \\ 4 \text{ electrons}\end{matrix} + 1 \text{ proton} = \begin{matrix}4 \text{ protons} \\ 2 \text{ electrons}\end{matrix} + \begin{matrix}4 \text{ protons} \\ 2 \text{ electrons}\end{matrix} + \text{energy}$$

or in terms of masses:

Lithium + Proton = 2 × Helium + equivalent mass of energy released.

$7 \cdot 0104 + 1 \cdot 0072 = 2 \times 4 \cdot 0011 + \cdot 0154$

It will be observed that a helium nucleus contains two electrons as well as four protons; and thus in a helium atom, which would be neutral electrically, we should expect to find two electrons in the external orbits. (It is now more convenient to think of a nucleus in terms of protons and neutrons. The helium nucleus thus consists of two protons and two neutrons. Its mass is 4 and its electrical charge 2. A nucleus of heavy hydrogen consists of a proton and a neutron.)

By placing fluorescent screens at equal distances from the lithium target, it appeared to Cockcroft and Walton that the helium nuclei were emitted in pairs moving at great speed in opposite directions.

A piece of apparatus which has been most valuable for revealing the behaviour of sub-atomic particles and for obtaining photographs of them, is C. T. R. Wilson's 'cloud chamber'. This has been used since J. J. Thomson's experiments concerning the electrical constitution of matter and when improved in 1912 it put a most useful tool into the hands of the experimenter. The characteristic tracks of all sorts of charged particles could now be photographed. Rutherford called it 'an instrument which to my mind is the most original and wonderful in scientific history'. The principle is a simple one. As has been known for many decades, when air saturated with water vapour is suddenly expanded—as can be shown in the receiver of an air pump—a cloud or fog is produced for a short time. Electrically charged particles, such as electrons, act as nuclei for the

condensation of the water-vapour into small drops, and thus under suitable illumination the path of the particle is clearly visible and can be photographed. Developments of this device have been used by Blackett for making 'cosmic-rays' automatically take photographs of the ionization which they produce in passing through the apparatus.

A relatively simple method of producing high voltages for accelerating atomic particles and moreover, one which could be easily controlled and adjusted, was that due to Robert van de Graaff. The principle is a simple one and recalls an experiment of Faraday's made more than a century ago. A hollow sphere of brass or other conducting material has no electric field within, even though it is carrying a powerful charge on its external surface. In Van de Graaff's machine a hollow metallic sphere is mounted at the top of a hollow insulating pillar or column, within which travels a continuous belt from a pulley wheel, driven by a small electric motor at the bottom of the column, to a pulley inside the sphere. An electric charge is 'sprayed' on the belt at the bottom with a comb-like metal device and collected at the top within the sphere. The charge gathers on the external coating of the sphere until a voltage of several million may be built up. It is even possible to use the inside of the sphere as a 'laboratory' when the outside is fully charged! A dry atmosphere is necessary for the effective working of this apparatus but it has been found possible to enclose it in a large chamber filled with a dry gas under pressure in order to assist insulation. The Van de Graaff machines function much better in their native America than in the damp climate of England. Thus, a relatively small voltage fed to the base of the apparatus is multiplied by taking advantage of an old principle of electrostatics.

It was obvious that higher voltages and more intense streams of particles were required for the effective exploration of the atomic nucleus than could be obtained by directly accelerating the particles in a straight line. The

possibility of causing the particles to travel in circles in the field of a powerful electro-magnet, and giving them a

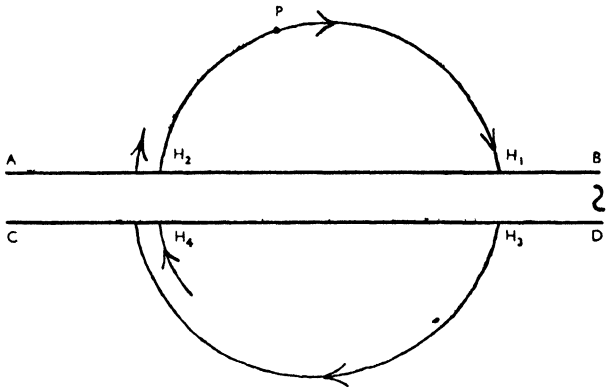


FIG. 14

'push' on each rotation at just the right instant, so that they built up enormous speeds cumulatively, had been thought of by the Cambridge physicists, but had been abandoned owing to the considerable technical difficulties and the use of other methods. Professor E. O. Lawrence of Berkeley University, California, succeeded in overcoming the difficulties and he constructed an 'atomic electric motor', which was called the cyclotron. The paths of the charged particles whirling round at great speeds, and constrained to move in spirals by the powerful fields of the electro-magnet, were carefully worked out. Great patience and many trials were necessary to ensure that the concentrated stream of particles finally hit the target at the precise spot required. The principle of the cyclotron will be evident from the following description.

The charged particle P moves in a circular track (slightly spiralled so that it will eventually hit the target) under the influence of a powerful magnetic field. AB and CD are two plates with suitable holes at the H_1, H_2, H_3, H_4. These are connected to an alternating current supply of high frequency—in effect, a powerful wireless transmitter—so that when the particle passes from H_4 to H_2

it receives a push, and coming round to pass in the opposite direction from H_1 to H_3 it again receives a push, the

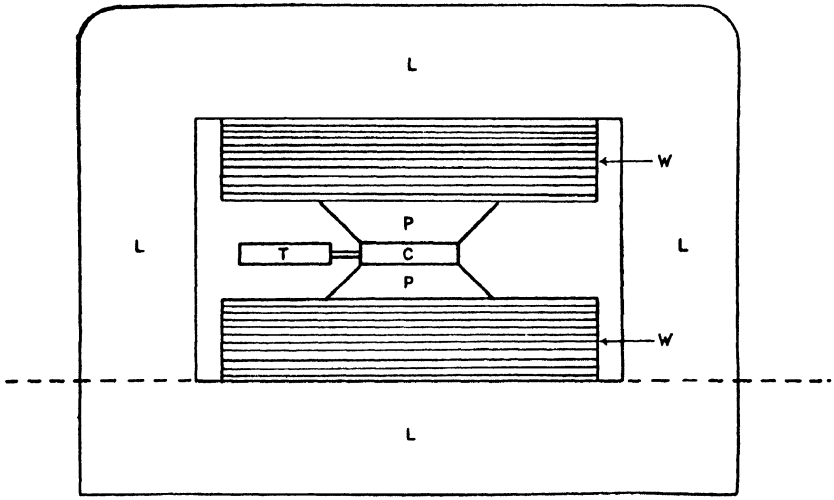


FIG. 15. This is a diagram of the magnet of a large cyclotron which is more than 20 feet high above the floor level. Two large windings W on the laminated iron former L produce an intense magnetic field between the pole pieces P. The particles are spiralled in the flat circular tank C and are accelerated twice in each revolution by 'kicks' received from semi-circular charged metal chambers. Accessories include a target chamber T to receive the particles as they are finally diverted from the outer spiral by an electrically charged deflector plate. A vacuum pump for exhausting the tank and a 'wireless station' for generating the high frequency accelerating current are also necessary. A large direct current energizes the field coils and water cooling is applied.

alternating current having reversed itself in the interval. The cyclotron uses a principle developed mathematically by the late Sir Joseph Larmor, who died in recent years near Belfast. When a charged particle is forced to move in a powerful magnetic field, and it is caused to increase its speed, it will spiral outwards with a constant angular velocity; that is to say, although it is accelerating in speed in a spiral path, each revolution of constantly increasing radius takes a similar period of time. The charged particles start near the centre of the field, and are ejected through a 'window'.

In actual practice, instead of using two charged plates the particles are made to spiral inside two semicircular chambers, appropriately known as 'dees', connected to the high frequency generator. These are placed inside the flat circular cyclotron tank which lies horizontally between the poles of the large magnet. At the end of their journey the particles are deflected through the 'window' by an electrically charged plate.

Cyclotrons were built in England at Cambridge and Liverpool, and even the Japanese pursued atomic research to some effect with other models at Tokyo. The possibility of using atomic energy for making bombs of enormous explosive power was an incentive to atomic research during the war. Again, an apparatus wherewith a submarine could be driven without oxygen for internal combustion engines, or refuelling for months or years at a time, would give it great range of operation and it would prove very difficult to detect or destroy.

A cyclotron with a total weight of 4,900 tons, and capable of producing streams of particles of 100 to 300 million electron volts, has been built on the hills near Berkeley, California, and has already yielded remarkable results in releasing atomic energy, building up atomic nuclei and transmuting one element into another. It is interesting to think that in the same American state, the 100 inch Mount Wilson telescope and the gigantic 200 inch instrument at Mount Palomar will be probing even further into the vast distances of the universe, and dealing with problems which are complementary to those of the atomic researches, in spite of the vast distances and sizes which occupy the astronomers who witness matter in its evolution and decay.

Even with his first cyclotron, Lawrence, by using hydrogen and heavy hydrogen nuclei (protons and deuterons), obtained streams of these particles equivalent to the alpha particles from more than 35 lb. of radium. Before returning to a discussion of some of the results from

this modern alchemy, whereby atoms of one element are turned into those of another and energy is released or absorbed, we propose to consider certain other particles which appear to be fundamental in the ultimate structure of matter.

While Lawrence was solving the problems associated with the construction of a successful cyclotron, research of no less significance was being pursued in America to detect and isolate the isotope of hydrogen. When we began to know more about the constitution of the atom in relation to its physical and chemical properties it became evident that atoms could exist which were identical chemically with other atoms yet were different from them in mass. The substances obtained from the disintegration of radio-active material showed this clearly. For atoms of different mass but similar as regards their chemical properties the name 'isotope', meaning 'occupying the same place', in the table of chemical elements, was used. In the year 1910, J. J. Thomson, working at Cambridge, brought a stream of atomic particles travelling in a tube which was practically exhausted of gas, into electric and magnetic fields and thus was able to separate the particles according to their masses and electric charges. When using tubes which contained the gas neon he found that there were two sorts of neon atoms: one with a mass of 20 units and another with a mass of 22. It seemed reasonable to suppose that ordinary neon, which had an atomic weight of 20·2, was a mixture of these two types.

Thomson's colleague, F. W. Aston, improved the apparatus and obtained 'mass spectra' of a large number of elements. He showed, for instance, that chlorine with an atomic weight of 35·46 consisted of a mixture of 'isotopes' of 35 and 37. Thus, one of the main stumbling-blocks to the acceptance of Prout's hypothesis was removed. By 1935, at least 250 isotopes were known, apart from those unstable radio-active types whose name is legion. By using a Wilson cloud-chamber, Blackett had shown that an atom

of nitrogen, from which a proton had been thrust out by collision with a helium nucleus, would sometimes combine with the latter, thereby transmuting itself into an isotope of oxygen with mass 17. An isotope of mass 18 was also found by Giauque and Johnston. If we take the atomic weight of oxygen to be 16, the atomic masses of all other known elements are nearly whole numbers. It seemed reasonable to look for an isotope of hydrogen, particularly in view of the fact that its atomic weight was slightly different from that which theories of the 'mass equivalent' of energy seemed to suggest.

The Americans, Birge and Menzel, showed that if we could assume that one in every 4,500 atoms of hydrogen had a mass double that of ordinary hydrogen, the discrepancy would be explained. In the case of this isotope, the heavy hydrogen molecule should be less mobile than the common type. In the case of liquid hydrogen, that with atoms of mass 1 should evaporate more quickly than that with atoms of mass 2. In 1932, Brickwedde allowed a large amount of liquid hydrogen to boil away until only a small residue remained. The gaseous hydrogen from this latter was examined by Urey and Murphy, who found faint lines on the photographic plates of their spectroscope, which indicated the presence of the isotope.

When water is electrolyzed, hydrogen and oxygen are given off and it is to be expected that any atoms of heavy hydrogen will tend to stay behind in the cell. Accordingly, water purified from old battery and electrolytic cells was found to have a slightly greater specific gravity than ordinary water; and Urey, Brickwedde and Murphy showed that this was due to an excess of heavy water.

By electrolysis, G. N. Lewis, a distinguished American physical chemist, was able to prepare pure heavy water in the University of California. He showed that one atom of heavy hydrogen was present to about 6,500 of the normal type, and more than six litres of ordinary water will yield less than a cubic centimetre of the heavy variety. It is

obvious that the consumption of low voltage electric current in the production of heavy water is enormous. When its possible use in the explosive release of atomic energy became apparent, the Germans had certain advantages. In occupying Norway they were able to use the products of Norsk-Hydro, a great electrical industry where much electrical power is available by using the natural water supplies from the mountain streams and rivers, thus saving coal for other purposes. Heavy water was practically a by-product of the Norwegian electrolytic industries.

The Germans succeeded in transporting several tons of the rare and precious liquid to their own research laboratories and it became necessary both by air attack and airborne saboteurs for the Allies to destroy the German supply, both in its manufacture and transport. This was done in 1942 and the following year, and notable feats of great heroism were achieved.

Heavy water has a density about 11 per cent greater than that of ordinary water, it freezes at 3·8° C., and boils at 101·42° C. Seeds do not germinate and small fish and other living creatures soon die in it. As hydrogen occurs in combination in all plants and animals, and in nearly all 'organic' substances, an immense field of investigation was at once opened to the biologist and chemist by the possibility of substituting heavy hydrogen for ordinary hydrogen in many thousands of substances. The American investigators who had been responsible for the researches on 'heavy hydrogen' suggested that it should be called '*deuterium*' and its nucleus '*deuton*', or '*deuteron*', and although Rutherford suggested '*diplogen*' and '*diplon*' respectively, the former terms are those usually in use at the present.

There is, of course, no shortage of heavy water in the world and some thousands of tons of it go under London Bridge every day. The problem of extracting 'D_2O' in quantity is merely one of obtaining a sufficiently large electrolytic plant and adequate supplies of electricity. When a sufficiently high concentration of heavy water has

been obtained by electrolysis the final stages of the removal of ordinary water may be accomplished by special distillation methods.

The heavy hydrogen nucleus was at once used by Lawrence in his cyclotron, and although some unexpected results of great utility were forthcoming, it was found, as was expected, that the '*deuteron*', with double the mass of a proton, was often more effective in experiments on atomic disintegration. We shall return to these matters again shortly, but first we must consider briefly yet another type of atomic particle.

About the time of the end of the first Great War, Rutherford and his pupil Chadwick had been studying what happens when the particles thrown off at great speeds by radio-active substances strike the nuclei of other atoms. Both the alpha particles (helium nuclei) and beta particles (electrons) from various substances were used, and Rutherford succeeded in knocking pieces from the nuclei of such atoms as those of aluminium, in 1919. The alpha particles were 7,200 times as heavy as electrons and in spite of their positive charges, which were violently repelled by those of the nuclei, they were used for the first artificial disintegrations of atomic nuclei. In 1930 the Germans, Bothe and Becker, found that the metal beryllium (of atomic weight 9, and sometimes called glucinium because of the sweetish taste of some of its compounds) emitted exceedingly penetrating radiations when bombarded with fast moving alpha particles from polonium, a radio-active degradation product of radium. These beryllium rays in their turn would knock protons of great energy from such substances as paraffin. As the laws concerning the interchange of energy between particles and waves were already known, it appeared to Madame Curie-Joliot (Madame Curie's daughter) and to her husband Professor Joliot that here was a case where the law of interaction between waves and particles no longer applied. Dr. Chadwick (later Sir James Chadwick) gave his attention to the

matter, and remembered a remarkable prediction made by Rutherford in 1920 in the Royal Society's Bakerian lecture: 'The idea of the possible existence of an atom of mass one which has zero nucleus charge . . . is by no means impossible. On present views the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached at a distance, and the spectrum of hydrogen is ascribed to movements of this distant electron. Under some conditions, however, it may be possible for an electron to combine much more closely with the hydrogen nucleus, and in consequence it should be able to move freely through matter. Its presence would probably be difficult to detect by the spectroscope, and it may be impossible to contain it in a sealed vessel. On the other hand, it should enter readily the structure of atoms, and may either unite with the nucleus or be disintegrated by its intense field, resulting possibly in the escape of a charged hydrogen atom or an electron or both.'

Twelve years after this, in 1932, Chadwick was able to show that the beryllium rays were streams of neutrons or particles having the mass of protons but with no electric charge. A neutron may be regarded as a proton in close conjunction with an electron, or as a hydrogen atom in an abnormally low state of energy. It has been suggested that it may be a proton with an electron at its centre, but it must be remembered that the further we explore the smallest particles which we find in physics, the less useful is it for us to try to explain their behaviour in terms of models.

Chadwick's very modest account of the importance of his researches has not been borne out by subsequent developments. 'Positive results in the search for the neutron would add considerably to the existing knowledge on the subject of the constitution of matter and as such would be of great interest to science, but to humanity in general the ultimate success or otherwise of the experiments being carried out in this direction would make no differ-

ence.' It is safe to say that Chadwick's experiments made a contribution of prime importance to the discovery of a principle which marks the beginning of a new epoch in the history of man and one which spells his control over terrifying forces, or his use of them to destroy himself. The size of a neutron was seen to be very small compared with that of a hydrogen atom. The 'diameter' of an atom is $\frac{1}{10\,000,000}''$ but a neutron is a hundred thousand times less in diameter than this. Thus, 10^{15} or 1000 billion neutrons could occupy the space taken up by one atom. Obviously, then, a neutron represents very dense material. Although neutrons would stream through the walls of any vessel in which an attempt was made to contain them, a pint of neutrons would weigh half a billion tons. A quickly moving neutron may travel a considerable distance without colliding with electrons, it will readily pass through the 'empty' spaces within atoms and will enter and disrupt an atomic nucleus which comes into its path. Such collisions will be rare owing to the small size of the neutron, but the chance that a neutron will come into contact with an electron is four million times less than the possibility of it striking a nucleus. As a neutron has no electric charge, it can reach and penetrate a nucleus.

Using heavy hydrogen nuclei as projectiles, Lawrence bombarded various elements with streams of particles moved by the powerful forces of his cyclotron. In the case of gold and platinum he found that these metals were not transmuted when the deuterons were accelerated at 1,500,000 volts, but that the heavy hydrogen nuclei were disintegrated, giving a proton and a neutron and producing $7\frac{1}{2}$ million electron volts of energy. The cyclotron could be used for producing streams of neutrons much more powerful than those obtained from natural sources. By bombarding lithium with deuterons of only 21,000 volts of energy, it was transmuted into beryllium with an emission of 22·5 million electron volts. Only one in every hundred million deuterons hit a lithium nucleus and thus there was

still a debit on the energy supplied. Nevertheless the possibility of a trigger which should release atomic forces was obvious, from these and other experiments. Many transmutations of one element into another were performed by suitable bombardments in the cyclotron. A radio-active isotope of sodium of mass 24 was produced, which by the spontaneous emissions of electrons changed into magnesium; bismuth changes into a substance identical with the natural element radium E, and in the years before the second Great War, more than 250 new radio-active substances had been produced. The use of some of these, which have short decay periods, has been suggested for treating various internal malignant growths in the human body.

The study of nuclear physics occupied scientists in all parts of the world during the years preceding the second Great War. Fermi and his colleagues in Rome started in 1934 a thorough investigation of the behaviour of all atomic nuclei when bombarded with neutrons. Uranium, the last element of the atomic series with atomic number 92, thus seemed to yield a radio-active isotope of number 93. Hahn and Fraulein Meitner, both working in Germany, by bombarding uranium isotopes with neutrons thought they had produced 'transuranic' elements with atomic numbers 93, 94, 95 and 96. It has been suggested that when the earth broke away from the sun, such radio-active isotopes of known elements and the 'eka' elements were present, but owing to their instability they disappeared as the earth became cooler, leaving uranium and thorium, which continuously produce tiny quantities of other radio-active substances, as the only survivors. It was difficult on theoretical grounds to account for these further new atoms whose nuclei seemed to be more massive than those of the heaviest known elements. In January, 1939, Hahn and Strassman of Berlin published a paper, in which they gave an account of the chemical nature of the new isotopes, and showed that one at least was an isotope of barium with an atomic number only about half that of uranium. At once Frisch and Meitner showed

that this discovery meant that the uranium nucleus had broken into two parts of about equal mass, forming atoms of barium and krypton. This was a new type of nuclear reaction and was accompanied by the release of great energy. The name 'nuclear fission' was proposed for this phenomenon, which was immediately investigated by physicists in many parts of the world. Early in 1939, Joliot and his colleagues in Paris showed that when the nucleus of uranium splits in the fission process a number of neutrons is produced. It was at once recognized that here was a reasonable basis for the release of nuclear energy. Not only did uranium nuclei cleave asunder with great energy-release, when bombarded with neutrons, but further neutrons were produced by the fission process, and under suitable conditions a chain reaction would result and become self-sustaining. In the former experiments on the bombardment of atoms with neutrons, only one in some billions of neutrons was effective, and energy changes in a particular atom would not 'touch off' an adjacent atom.

In 1939 Professor Bohr, whose 'model' of the atom had been so useful in the theoretical and practical researches on the electrical nature of matter, paid a visit to the United States, and during the same year, in collaboration with Professor J. A. Wheeler of Princeton University, published a theory explaining further the structure of the nuclei of the heavy atoms and the fission process. It appeared to follow from this theory that the various isotopes of uranium would require different circumstances for successful fission, a prediction which was entirely fulfilled. Uranium consists of 99·3 per cent of atoms of mass 238 and 0·7 per cent of atoms of mass 235. There is also a trace of 0·008 per cent of an isotope of mass 234. The first two, which are most important in schemes for releasing atomic energy, may be referred to as U 238 and U 235 respectively. Niels Bohr has always shown great ingenuity in devising models of atoms which have proved fruitful in helping us to explain the phenomena of radiation. It may be that no satisfactory

picture of the inside of the atom will ever be made and that it will remain buried in the mathematical formulae of statistics, wave and quantum mechanics; but Bohr's conception of a heavy nucleus was certainly most helpful in explaining the fission of uranium with neutrons. He compared a heavy nucleus to a large drop of water which would become unstable when only slightly deformed and would break up into smaller drops.[1]

In March 1940, Booth, Dunning and Grosse of Columbia University, New York, and Nier of Minnesota, confirmed the prediction, which follows from Bohr's new theory, that U 238 would undergo fission when bombarded with high-speed neutrons, whereas U 235 would require neutrons of low velocity. It was seen that a chain reaction in a mass of uranium would produce enormous amounts of energy, but much calculation and experimental work had yet to be done. The shape and size of the uranium would be critical, for it was necessary to conserve as many neutrons as possible in order that they would produce further fission effects. Moreover, only neutrons of a certain speed range would produce the effect. Investigations were made to find a suitable substance for slowing down the neutrons without capturing too many of them. Heavy water seemed to be a suitable material for this. The separation of U 235 from the more common uranium is a matter of some difficulty. From our definition of an isotope, it can be seen that no chemical process will suffice. In the case of the isotope of hydrogen, the heavy atom has a mass which is twice that of the common type. Thus, the difference of mobilities of the atoms or ions of the two types, to be expected when the hydrogen is in liquid form, or as an ion in aqueous solution, can readily be put to good account for separating the isotopes. This is not so in the case of U 235 and U 238, for the difference in mass of the atoms is only about 1 ¼ per cent.

[1] The development of the Bohr-Wheeler theory in mathematical terms will be found in the *Physical Review*, No. 56, pp. 426–450.

It is clearly impossible to separate the isotope U 235 from uranium by any chemical means for they are chemically identical. Four physical devices were tried therefore. Each was difficult and slow and some needed many stages in the process in order to obtain a progressive enrichment of the isotope. Two methods depended on diffusion; the first aimed at a separation of the isotopes by taking advantage of the differences in rates at which the isotopic fractions in uranium hexafluoride vapour diffuse through a porous barrier under appropriate temperature conditions. (It has been known for some years that an almost perfect separation of chlorine gas into its isotopes of weight 35 and 37 can be accomplished in one stage by this means. The lighter isotope tends to rise within an inner porous tube.)

The second method, known as thermal diffusion, used the principle of the partial separation which takes place when the liquid uranium hexafluoride is subjected to heat convection. The principle of the milk separator (the centrifuge) was that of the third method. When milk is spun on the revolving disc of the separator the lighter cream is not thrown as far by the centrifugal forces as the heavier watery content of the milk. Similarly, a rapid spinning of a uranium salt in gaseous form would be expected to leave the U 235 nearer the centre. Only very partial separation would take place at any one stage, and considerable industrial effort would be required to achieve anything approaching the perfect separation of even a small quantity of U 235. Nevertheless, these methods could be used for obtaining samples of uranium richer in U 235 than is the natural metal.

The method finally decided upon was that of the electromagnetic separator. Uranium is vaporised electrically and charged so that the outer electrons are stripped from the atoms. A beam of these ions is then projected into a chamber between the poles of a large magnet. The streams of ions are bent into almost circular paths but those of the

U 235 are separated as they have a circular path of smaller radius than those of U 238. Thus, they may be collected at a suitable point. The matter is attended by many difficulties, not the least of which is that of preventing all the ions separating owing to their mutual repulsion. Fortunately, Lawrence had a giant magnet designed to be used with a large cyclotron at Berkeley, California. This was readily adaptable and moreover could accommodate the apparatus containing a number of streams of ions. This colossus had magnetic poles of over eighteen feet in diameter and a pole gap of six feet.

It will not need much imagination on the part of the reader to see the difficulties in developing a laboratory apparatus which will do its work with a few atoms, to a factory process capable of producing stones of U 235. Developments in the technology of 'electronics'—a word which is used broadly and not always accurately—made this possible, but it is not surprising that the total cost of the plant used to produce the atomic bomb was £500,000,000.

Uranium is by no means a rare metal and throughout the earth's crust it is as common as copper. Pitchblende from Joachimstahl in Bohemia is comparatively poor in its yield of uranium. Whereas it contains 50 per cent of uranium oxides, the deposits at Lukwengule in the Uluguru Mountains of East Africa contain nearly 90 per cent of a mixture of the uranium oxides UO_2 and UO_3; that is, 70 per cent of metallic uranium. Colorado, Connecticut and Cornwall are all known for their varying yields of uranium and one of the richest sources in the world is found in the Canadian mica mines. There are some unworked deposits in the Ural Mountains in Russia, and Poland is not deficient in supplies of this mineral. The extraction of the ordinary metal uranium presents no great difficulties. ·7 per cent of this, or 15·7 lb. per ton, is U 235, which produces the chain fission effect. Some thousands of tons of ordinary uranium can be produced each year,

and the energy which could be released when the fissile isotope is separated from this is colossal and stuns the imagination.

The mineral pitchblende was imagined to be an ore of zinc, iron or tungsten, until in 1789 Klaproth showed that it contained a 'half metallic substance' which seemed to have no relation to these three metals. Peligot proved that Klaproth's 'element' (which had been called 'Uranium' in honour of Herschel's discovery of the planet Uranus in 1781) was really uranium oxide, but succeeded in isolating the metal in 1842. Formerly, small quantities of uranium were used for colouring glass and pottery glazes, for making tough steel alloys, in photography and for making gas mantles.

For a number of years the technique of the best laboratory mass spectrograph was not good enough to reveal the presence of isotopes in uranium. The industrial development of the laboratory instrument to separate the isotope on a large scale is indeed a triumph.

At the beginning of 1940, Professor Peierls and Dr. Frisch of Birmingham and Professor Sir James Chadwick of Liverpool pointed out the possibility of producing an explosion thousands of times the power that could be obtained from any chemical reaction, and this by the conversion of only a few per cent of the nuclear mass of uranium into energy.

Ordinary uranium was not considered to be suitable material for such a purpose, for even if a chain reaction could be produced in it, a great quantity of the metal would be necessary. On the other hand, calculations showed that the amount of U 235 for making an 'atomic bomb' would be somewhere between two pounds and two hundredweights. Any quantity of U 235 less than the critical amount (that is, of such a size and shape that its surface area in relation to its volume permits a sufficient escape of neutrons) is quite safe. No process of chemical explosion, heat, light or electricity will detonate it, but if

two pieces of U 235 were brought together to form an amount exceeding the critical size, a violent explosion would result. This must take place very rapidly otherwise the neutrons will escape when the mass disintegrates, and the action will cease. Temperatures of many million degrees and pressures of many atmospheres are produced, and the expansion is marked by violent shock waves. Not all the uranium will be affected, and of those atoms which undergo fission only a few per cent of the energy represented by their mass will be released; but if only one pound of U 235 is 'split' by the action of neutrons, energy equivalent to 8,000 tons of T.N.T. is forthcoming!

We may summarize the fission of U 235 as follows:

$$\text{neutron} \rightarrow \text{U } 235 = \text{Ba } 137 + \text{Kr } 83 + \left\{\begin{array}{l} \cdot \text{ 2 neutrons which produce fissions in further nuclei.} \\ + \text{ 200,000,000 electron volts energy.} \end{array}\right.$$

The nucleus of U 235, when split by the neutron, gives Barium of atomic weight 137 and Krypton of atomic weight 83. The difference $(235 - 137 - 83)$, or about 6 per cent of the mass of the U 235, is accounted for by the enormous amount of energy released. This is purely theoretical and in actual practice only a tiny fraction of one per cent of the U 235 is converted into energy, and this is equivalent to 8,000 tons of T.N.T.

At this juncture it may be interesting to say a little about the mathematical equivalent of matter and energy. As we have seen, atoms consist of nothing but electric charges in one form or another. When any of the mass of an atom is converted into energy this ultimately gives intense heat and high temperatures, where there is a chain fission effect. Light, X-rays, other radiations and streams of particles would also be given off.

Eighty years ago, James Clerk Maxwell derived mathematical equations of electro-magnetic waves travelling at

the speed of light. He was able to obtain an equation for the energy of light waves. In 1905, by developing this, Einstein was able to show that when a mass of M units is converted into energy, an amount of this equal to MC^2, where C is the speed of light, is produced. One gram (that is, about $\frac{1}{28}$th of an ounce of matter) gives 9×10^{20} ergs of energy, and this is independent of the kind of matter which is converted into energy. This amazing piece of mathematics and scientific intuition had to wait more than a quarter of a century for its practical proof, which was given by the experiments of Cockcroft and Walton which we have mentioned. In other words, the destruction of one gram of matter would yield twenty-five million kilowatt hours, which is the total year's electricity supply for a fair-sized town. Readers will recall that one kilowatt hour (one unit of electricity) will light a 60 watt lamp for sixteen hours, or will supply a small electric fire for about one hour. A similar quantity of matter is equivalent to the energy which would raise one hundred million tons weight to a height of over three hundred feet. A few cubic yards of uranium would serve the entire national needs in power, heating and lighting for years.

In order to make an atomic bomb it is not only necessary to disintegrate individual atoms by an initial bombardment with neutrons of suitable speed, but to ensure that there is a chain effect, that is to say, the explosion is handed on from one atom to another. As we have already noted, Chadwick of Liverpool, Peierls and Frisch of Birmingham, showed that if pure uranium isotope of atomic weight 235 (U 235) were available, there seemed to be a probability of 'producing an atomic bomb by release of energy in a mass of fissile material of suitable dimensions at a rate which would yield violent explosive results'. American and German workers arrived at the same conclusions at about the same time, and it is fortunate for us that our enemies could not put into the field of research, which went on as a neck and neck race, the immense industrial

resources and the great body of scientists which were mustered by Anglo-American collaboration, for one must admit that individual German atomic physicists were not deficient in any way. In order to make the atomic explosive chain-reaction self-sustaining, a number of conditions have to be fulfilled. These may be summarized as follows: firstly, the system as a whole must be of such a size and design that the neutrons produced by the disintegration of individual atoms shall not escape and thus be unable to split other atoms; secondly, the system must not contain too much material which would absorb neutrons, and thus prevent them from taking part in splitting other atoms; and thirdly, it is essential that only slow neutrons should be used, otherwise they would escape before the whole mass had exploded.

Even when the extraordinary difficulties of making sufficient U 235 or plutonium[1] had been overcome there yet remained the problems of atomic bomb manufacture. A number of pieces of the fissile material have to be brought together suddenly in order that a piece greater than the critical size shall result. Precautions have to be taken that no partial building up of neutrons takes place, which would result in a feeble and premature explosion. Moreover, a dense 'tamper' or case for the fissile material, which shall reflect and conserve the neutrons, has to be devised, for as soon as the bomb begins to fly apart the neutrons escape and fission ceases. It was calculated that if the pieces were shot together by a gun-like device in the relation of missile to target this would bring them into conjunction at about the right speed. Beyond this no further information is available but we must add that the atomic bomb as we have heard and read about it is exceedingly inefficient as a scientific machine.

It cannot be supposed that the present methods of releasing atomic energy in bombs are unique, for eight methods are known and others are possible. The metal thorium which is much more common than uranium and

[1] See page 82.

is a by-product in the titanium oxide (paint) industry offers a range of radio active and fissile products. Moreover, there are possibilities that in the future we may be able to obtain energy not only from the disintegration of heavy nuclei but also from the building up of lighter atoms. If we could make a gram of helium by bringing together neutrons and protons a fifth of a million kilowatt hours of energy would be released! Nor is it likely that the devices used, which were not found by chance, but by mathematical investigation and experimental research, could not be found by any group of atomic research workers in a year or two if adequate facilities are forthcoming. Even the Japanese have produced some competent atomic physicists. The sudden release of enormous quantities of energy by atomic disintegration will produce temperatures higher than those ever produced by artificial means, and the resulting incandescence will contain radiations of small wavelength and great chemical power. Not only will shock waves of terrible destructive force be produced, but the searing effect of the energy appearing as heat in the form of the intense agitation of atoms and molecules will cause the vaporization or burning of everything in its path. The actual qualities of the light emitted and the X-rays produced might lead to blindness, secondary poisoning effects and cause degenerative changes in human bodies which were not protected from the flash. Chemical changes, electrical effects such as ionization and some temporary radio activity of many substances in the immediate vicinity of the explosion would be in evidence after it had taken place.

The atomic bomb is an awful weapon and is capable of much greater development than that of the two bombs released over Japan. The whole technique of war is revolutionized, and man must learn to solve his problems without having recourse to armed conflict, or perish from the earth. Many timid people may ask whether it is possible that some over-venturesome scientist may succeed

in releasing atomic energy which will 'touch off' all the atomic energy of the earth. Astronomers have sometimes observed distant dark stars suddenly burst forth with explosive brilliance. Was this due to the action of some atomic researcher who went too far? We think not! The most common atoms, which are to be found in the earth as a whole, could only be disintegrated with the greatest difficulty and even then they would show no chain effect of one handing on its explosion to the next. Radio-active material capable of producing a chain fission effect is found in a very attenuated form in other substances in the earth. Besides which, it is probable that in the history of the making of the earth, it has been subjected somewhere in its bulk to forces which are greater than those which are now in evidence, and which failed to alter the general atomic constitution. The researches which resulted in the release of atomic energy were the work of the greatest body of eminent scientists ever brought together in the world's history. Discoveries which had been made in the spirit of scientific inquiry, and for no utilitarian motives, such as the production of heavy water, neutrons and the isotopes of uranium, were all combined together in a remarkable way. The problems of peace offer opportunities no less important.

The development of the atomic bomb must be considered to be a triumph of theoretical and practical research, and the culmination of investigations made in many parts of the world. In war-time the speed of progress was particularly remarkable in view of the conversion of so many research and production facilities to military purposes, and the pre-occupation of the allied physicists and technicians with other problems of defence and offence. Some controversy has arisen in the matter of the ethical aspects of the use of the atomic bomb. Scientists pursue their researches as a quest for the truth, and the great majority of them also work for the good of humanity. War is not a desirable feature of human activity, and there is no such

thing as a 'gentlemanly' war. All war is inhuman. When Archimedes used various machines of his own invention during the siege of Syracuse (212 B.C.) the enraged Romans inveighed against him for using mechanical discoveries to alter the technique of war. A similar, though less valorous lamentation, can be read in Shakespeare's *King Henry IV* when Hotspur says:

> It was a great pity, so it was,
> This villainous saltpetre should be digged
> Out of the bowels of the harmless earth,
> Which many a good tall fellow had destroyed
> So cowardly; and but for these vile guns
> He would himself have been a soldier.

Apparently war was no longer a business fit for gentlemen at the end of the fourteenth century, and before the Battle of Agincourt. The 'atomic bomb' hangs over the nations like the sword of Damocles, for its secret cannot long be withheld and humans have to learn to live together and settle their differences without recourse to war. The gifts which science has given to man are such that their proper use would, by diligent application, produce a world of plenty.

The layman will be forcibly struck by certain general aspects of the research which resulted in the large-scale release of atomic energy. Many independent investigations which seemed to have no more than academic value at the time, when subsequently brought together and combined, were seen to have the utmost practical use. Teams of scientists, with adequate financial and material resources, with enlightened direction and co-ordination, could solve many, if not all, of the problems of mankind. Disease, poverty of mind and body would largely vanish. In the matter of the release of atomic energy, even the most sanguine hopes of the allied scientists were realized sooner than was expected. The vigour, variety and resource of modern science stand in happy contrast to so many other phases of contemporary life, where so much in civil

administration is characterized by moribund ideas and feeble initiative. If our secular affairs were imbued with the same scientific spirit, what a resurgence of thought and action, made more necessary after the frustrations and waste of recent wars, would result.

The first small experimental atom bomb was exploded from the top of a specially constructed tower near Almogordo, in the desert of New Mexico, on July 16, 1945. Observations were made from a distance of about six miles, behind strong concrete bulwarks. The effect was exactly as was predicted—the steel of the tower was vaporized, a flash of extreme brilliance, rich in short radiations with interesting thermal, ionization and chemical effects and air waves on a large scale, resulted.

Two atomic bombs of different types, small in size in comparison with those filled with chemical explosive, were dropped on Hiroshima and Nagasaki in Japan, during August, 1945, with devastating effect. The bombs were released from U.S. Super Fortresses at a height of 29,000 feet and descended comparatively slowly, exploding at about two thousand feet. This gave the maximum blast effect and limited the chemical effects from the gamma rays and radio-activity.

It is pleasant to be able to turn from the atomic bomb and discuss the progress which has been made in methods for the release of atomic energy in the form of heat which can be used as a source of industrial power.

The problem of bringing atomic energy under such control that it can be regulated to a steady stream, or turned off altogether, is one which is now the subject of much research. Heavy water, carbon and cadmium (a metal in the zinc group) have been used for slowing down the reaction; and in a few years or even less, the commercial use of the energy, locked up when the atoms were made by cosmic forces, may be possible. Here at last man will be independent of the sun for sources of heat, mechanical power and electricity. Formerly, all our coal, petroleum,

tidal and water energies found their origin from the sun in some way or other.

When the experiments on the bombardment of uranium (U 238) by neutrons of various velocities were being undertaken, it was found, as was expected from Bohr's theory of heavy nuclei, that neutrons of a certain critical velocity were absorbed by U 238 without causing fission. This is known as a 'resonance' effect. The energy of the 'neutron' may be considered to be collected by the nucleus of the uranium in a manner analogous to that of a child's swing, which is given a push at just the right instant and with a similar force each time. The new nucleus of mass 239 emits two electrons, one at a time, and first produces an isotope of number 93 which has been called neptunium, and then an isotope of number 94 called plutonium (PU 239). In brief, when U 238 has captured a neutron, PU 239 is produced. It was also found that another heavy element, thorium, of atomic number 90, will also undergo fission when bombarded with very fast neutrons, and that the extremely rare radio-active element protactinium of atomic number 91, requires neutrons of intermediate velocity. PU 239, on the other hand, will undergo fission with slow speed neutrons. Neptunium and plutonium, which are 'synthetic' elements of atomic number greater than that of uranium, are called 'transuranium' elements, and just as uranium was named after the planet discovered by Herschel so they have appropriately taken their names from planets whose orbits are beyond that of Uranus.

Long distance railway trains powered by atomic energy are said to be a development of the near future in the U.S.A. Suitable masses of U 235 or plutonium mixed with carbon in the form of graphite, and controlled by the introduction of metals which absorb neutrons, can be made to glow white hot for weeks or months. One pound of uranium is equivalent to 1,500 tons of coal. Again, the difficulty is that of adapting this energetic heat producer

to simple and convenient commercial use, but it is a problem which is fast being solved.

Many methods were devised for establishing a slow chain reaction in masses of U 238. Heavy water, helium, various light metals, carbon, paraffin made from carbon and heavy hydrogen had all been suggested as suitable 'moderators' for slowing down the neutrons. Beryllium, if a sufficient quantity could be obtained, was thought to be a possible substance for the enclosure of the reacting materials.

It was seen that pure graphite was sufficient for the purpose of slowing down the neutron speeds and that heavy water was not necessary. Atomic 'piles' were built in the United States at Clinton and Hanford and one will soon come into operation at Didcot in England.[1] Although many difficulties had to be surmounted and pure materials had to be obtained the action is really quite simple. The pile is usually a large cubic lattice of graphite into which rods of uranium are placed. In order to prevent corrosion by the cooling water the uranium is sealed into aluminium cans (which process proved to be of extraordinary difficulty). The vigour of the action is controlled by sliding in and out rods of cadmium which absorbs neutrons. The pile has to be of such size and shape that more neutrons are produced within it than are lost by radiation. Enormous quantities of water are needed to keep down the temperature of the pile and the water has to be allowed to remain in large reservoirs until it is free from all radio-activity, after it has left the pile. The vast amounts of heat generated should be used for driving machinery and generating electricity but at present most of it is lost. There is no reason why the heat from atomic energy should not produce electricity which is as cheap or cheaper than that from coal or hydroelectric power.

In order to start the operation of a pile it is only necessary

[1] As far as can be determined the first atomic pile ever set up was made to work by Fermi in the autumn of 1942. It was set up on the floor of a squash court under the West Stands of Stagg Field in U.S.A. It was a graphite sphere containing about six tons of uranium lumps.

to withdraw the controlling cadmium bars to the correct amount. No source of neutrons is necessary as there are enough stray radiations or cosmic rays to start the action. Neutrons are formed by the disintegration of the U 235, these are moderated by the graphite and some are captured by nuclei of U 238 to give plutonium. Many other radio-active substances are formed and some of these decay very rapidly when the pile is shut down. It is possible to put other substances into the pile and they are then subject to intense neutron bombardment and may show interesting transmutations and artificial radio-activity. Before the U 235 in the uranium rods is exhausted the pile is closed down and the rods removed for chemical separation. The uranium is dissolved by a chemical process and in a series of tanks the plutonium is separated from it by chemical means. All this has to be done by remote control in order to protect the scientists from dangerous radiations. Small electroscopes no larger than a fountain-pen and pieces of photographic film enclosed in light-proof cases and worn by the operators will give evidence of exposure to dangerous radiation. Plutonium is not dangerously radio-active in itself in small quantities.

The efficiency which would result if we were able to utilize more directly in heat engines the very high temperatures resulting from nuclear fission is denied to us. The radiations from a uranium pile are harmful to living matter and although it is fairly easy to screen the gamma rays, the apparatus must be operated by remote control and be surrounded by walls of concrete ten feet thick which will absorb the neutrons and thus prevent damage to the cells of workers employed near the apparatus. The chief problems to be solved concern the development of materials for containing the 'pile'. Much research in refractory substances and in metallurgy for the materials used in constructing the apparatus remains to be undertaken.

We have already mentioned the production of radio-active isotopes of various elements by bombarding them or

their salts with the powerful streams of particles coming from the cyclotron. Such substances can also be made in the uranium pile if other atoms are incorporated with the fissile material. Quick and effective methods of separating the radio-active substances have now been developed.

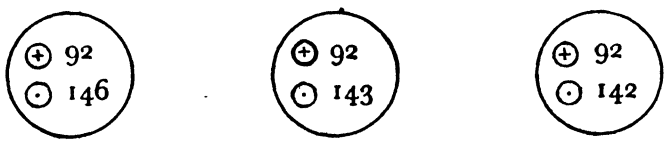
Radio-active isotopes will probably find many uses in medicine. Even in the smallest quantities radium cannot be taken internally owing to the cumulative action of its radiations which ultimately destroy the activity of the body in replacing its damaged or worn-out cells. On the other hand the artificial radio-active substances expend their energies in a shorter time. For instance, the activity of radio-active phosphorus diminishes to half its intensity in a fortnight. Compounds containing such phosphorus have shown remarkable results when used in the treatment of leukaemia, which is a form of pernicious anaemia due to an overproduction of white cells. The radio-active phosphorus is absorbed into the bones which are the chief places where these 'rogue' cells are produced.

Radio-active isotopes have opened up an entirely new field of research known as 'tracer' chemistry. All living things constantly build into themselves atoms from the food on which they live. This process goes on when the organism has only to maintain itself and not merely during growth. Living things catch up for a short period the atoms of which they are composed. The process of chemical change which goes on in the various parts and organs of plants and animals is known as metabolism. The changes differ in growth, maturity, decay and disease. It is of incalculable help to the physiologist, who studies the way in which elements are absorbed into the various parts of a living organism, to be able to trace the passage of the atoms by means of the radio-active 'label' attached to them. Radio-active isotopes which can now be prepared for nearly all elements are detectable in very much smaller quantities than are susceptible to the most delicate chemical tests. An instrument called the Geiger-Muller

counter is sensitive enough to detect a single ionizing particle given off when a radio-active atom disintegrates. In this device a charged particle coming from such an atom passes into a tube containing two electrodes which are kept at a critical voltage difference. The gas inside the tube is at a low pressure and the invading particle produces ions which on being attracted to an electrode produce a momentary tiny current which passes between the electrodes. (These may take the form of a wire at the centre of a short copper tube.) The current can be amplified by valves and made to register a 'click' in a loud speaker or to actuate a mechanical recording counter.

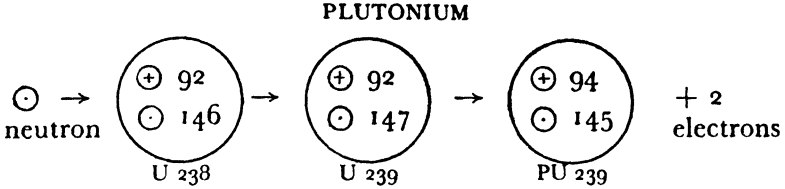
Thus, scientists can trace how elements such as iodine are absorbed by the thyroid gland, calcium and phosphorus by the teeth and bones, sodium by the blood cells and the constituents of various fertilizers by plants. Foods containing small quantities of the radio-active element are given to the plant or animal and the arrival of radio-active atoms at a particular place in the organism is noted by the Geiger-Muller counter. The conditions of health and disease and some indications of the determining factors may be found thereby. As the radio-active isotope of carbon of atomic mass 14 produces very feeble radiations another isotope, C 13, may be used in preference to it. This is now separated from carbon 12 fairly easily and is sold commercially in America by the pound. As this is not radio-active, other and less convenient physical means have to be used to detect it.

URANIUM ISOTOPES



These are the nuclei of the isotopes of uranium. Each contains the same number of protons ⊕ 92 and thus has

92 electrons in the orbits external to the nucleus. Each has the same chemical properties. Their differences are due to the neutrons ⊙ in their respective nuclei. The energy binding the protons and neutrons together is released when the nucleus splits.



A neutron at the correct speed is captured by the U 238 nucleus and turned into U 239 which is short-lived. Two of its neutrons give up electrons, thus turning into protons and giving the 'synthetic' element plutonium.

Researches into the electrical constitution of matter, how it was originally built up and how it may be broken down, go on in the laboratory where experiments are made with the smallest of all particles, and simultaneously in the observatory where enormous telescopes, calling for the resources of heavy engineering, are used for observing the nature of matter at distances of millions of light years.[1]

A great deal of knowledge is accumulating concerning the penetrating radiations known as cosmic rays, which come from outer space and not from the sun or the stars. They have energies of upwards of six thousand million electron volts. In researches on these rays, Anderson discovered positive particles with the mass of an electron. These had been predicted by the English mathematical physicist Dirac, and were regarded by him as 'holes' in negatively charged space. They were called 'positrons'. In 1938, Anderson and Neddermeyer discovered particles with masses greater than electrons and less than protons. These existed in both negative and positive states.

[1] A 'light year' is the distance travelled by light in a year. As electro-magnetic radiations travel through free space at a speed of 186,000 miles per second this is well beyond the 'threshold of Stun' as far as the human imagination is concerned!

Even the nuclei of the lighter elements have not a simple structure; those of the heavier elements up to uranium are very complex. It is significant that the elements which are naturally radio-active have heavy and very complex nuclei.

The electrical building stones of which all matter is composed may be summed up as follows:

Name of particle.	*Mass in Electron units.*	*Electric charge.*
Electron or Beta Particle	1	$-e$
Positron	1	$+e$
Mesotron	200	$\pm e$
Proton (Hydrogen nucleus)	1800	$+e$
Neutron	1800	0
Deuton, Deuteron (Diplon)	3600	$+e$
Alpha Particle (Helium nucleus)	7200	$+2e$

The electron, proton, and neutron are of prime importance. A photon is a unit of energy in the form of radiation. If an electron and a positron combine and annihilate one another two photons of electro-magnetic energy travelling in opposite directions replace them. The 'size' of the photon depends on the frequency of the radiation.

JET PROPULSION AND THE GAS TURBINE

HAS it ever occurred to you that the familiar motor car engine is mainly a device for converting the chemical energy of petrol into the mechanical energy of motion—and the petrol engine with its moving parts and accessory apparatus is a fairly complex structure? The obvious question presents itself to the mind, 'Is it possible in a more direct and convenient way to turn the energy in a fuel into the energy of motion?' The idea of jet propulsion is by no means a new one. It is found in nature. The principle was perfected millions of years before man appeared on the earth by a group of animals known as the Cephalopods, the best-known of which are octopus and cuttlefish. These take in water through a comparatively wide orifice and then expel it forcibly through a narrow siphon tube. As the stream is directed forwards, these creatures travel backwards when using this powerful method of locomotion. Moreover, they have perfect control of direction. The dragonfly in its immature stages also uses jet propulsion when skimming over the water.

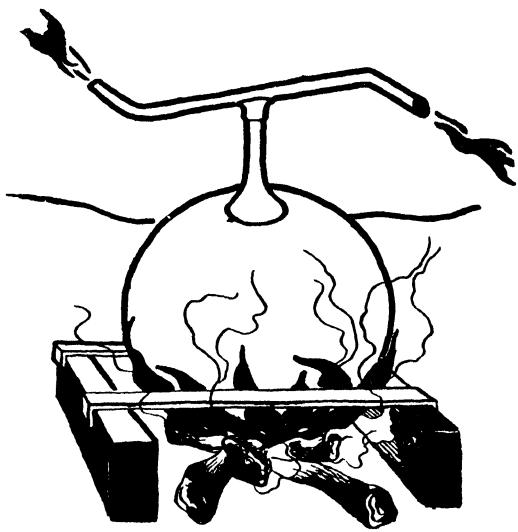


FIG. 16. Hero's turbine or reaction engine.

If we turn to man-made devices we find that the first steam engine also worked on this principle. In early times Hero of Alexandria made the first recorded steam turbine.[1]

[1] The date of this cannot be fixed. Apparently Hero lived sometime between 150 B.C. and A.D. 200.

How it worked will be seen from the sketch. The water in the metal shell was boiled over a fire and the steam forced its way up the vertical tube, along the cross piece which was jointed so that it could revolve easily, and out into the air through two nozzles pointing in opposite directions, one at each end of the cross-piece. It had previously been thought in error, that the turbine works because the steam, rushing from the nozzles, pushes on the air. A moment's thought will show this to be erroneous. Any gas (including of course, the air and steam) consists of molecules all moving about at considerable speeds in their own way, and it is quite impossible that the jets of steam from Hero's turbine, the gases issuing from a jet propulsion engine or a rocket could push on molecules of air, and be themselves pushed back, communicating this thrust to the jet or nozzle. Jet propulsion is a simple example of Newton's Third Law of Motion, formulated precisely by him more than two hundred and sixty years ago: '*Action and Reaction are equal and opposite.*' The effect is not from the air that is pushed on by the steam or the stream of gas, but from the reaction at the jet or nozzle itself. In other words, a stream of gas, no matter how fast it travels or how compressed it is, can never transmit a thrust back along itself as though it were a solid rod.

All reaction engines work because of the thrust at the jet. In the older forms of locomotion the *action* was utilized and the corresponding *reaction* was not used. In jet propulsion the reaction is utilized and the *action* is thrown away. In turbines where jets of gas from fixed nozzles are made to impinge on moving blades, it is the action which is used and the reaction at the jet is left as a thrust which, because it does not move, is not converted into energy. Unless the oxygen of the air is used for producing a jet of gas by combustion, the air is actually a hindrance to aeroplanes or aerial projectiles because it offers great resistance at high speeds. At the speeds of upwards of three thousand miles an hour attained by the V2 rockets, the missiles were

sometimes seen to be red hot owing to their friction with the lower strata of air; and special precautions had to be taken to reduce the effect of this as much as possible. (This is what happens with shooting-stars. A piece of ironstone, sometimes no bigger than a marble, coming into our atmosphere at a great speed, is rendered incandescent by the enormous friction and the heat so generated causes it to turn into dust-like particles. A shooting-star or small meteorite is the result. Thus, our atmosphere acts as a shield against small missiles, which would otherwise be falling on it constantly, although it does not offer protection against larger meteorites.)

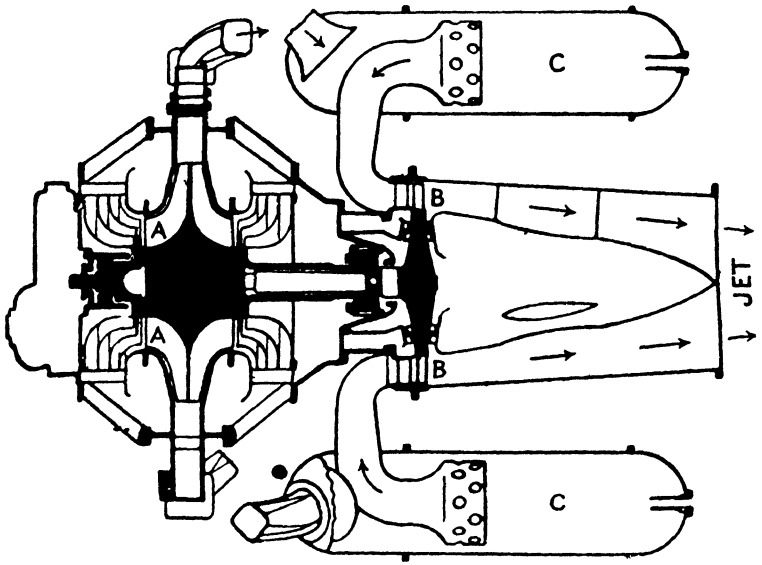
It can easily be seen that jet propulsion offers advantages and possibilities which are not afforded by internal combustion engines driving an airscrew or propeller on aircraft. However powerful we were to make our internal combustion engines and however fast we could rotate the airscrew, there would still be a limiting speed to our aircraft. Even though we could eliminate all the many factors which tend to retard an aircraft at high speed, a propeller can only push or drag the machine forward at a speed less than that at which we can get air to stream away from the propeller. The theoretical upper limit to this is the average speed of the motion of the molecules of the air, which is about equal to that of sound, 1,100 feet per second or 760 miles an hour. The actual speeds obtained by propeller traction when the aeroplane is flying on a level course are very much less than this. This shows the limitations of *action*. In the case of gases forced from a jet, these upper limits to the *reaction* speed do not exist. A jet-propelled aircraft seems to dawdle when it is flying with the fastest of planes fitted with ordinary piston engines. Thus, it follows that jet-propelled aircraft would fly better at great heights, provided that sufficient oxygen is forthcoming to maintain fuel combustion. The force of friction which resists motion through the air, increases at speeds of over 100 miles per hour out of all proportion to

the increase of speed. Or expressed in another way: friction is proportional to $(\text{speed})^x$ where x is the index of a power which rapidly increases from unity, as higher speeds are attained. A rocket, consuming the oxygen of its own propellent, travels best when it is in rarified air, or above the 'skin' of air which surrounds the earth. In jet-propulsion aircraft there will be an optimum height of operation at any particular speed. This will effect a compromise between the reduction of friction due to the increasing rarefaction of the air with height, and the reduction of the oxygen available for combustion. The simple construction of the V1 engine units would not be suitable for use at a great height, for without an air compressor, which is usually called a supercharger, there would not be enough oxygen to cause proper combustion of the fuel with which it is supplied. The question of the 'lifting power' of the air, acting on the wings and body of the plane, is not a primary matter of concern in stratosphere flying; but it will be obvious that special wing areas and shapes will have to be contrived for this purpose.

The simple principle of the jet-propulsion engine as used in aircraft will be seen from the diagram. We will suppose the engine to be travelling from right to left. The motion of the aircraft will assist the streaming of the air into the wide duct at the front of the engine, where it is compressed by a light, rapidly moving fan known as the supercharger. The compressed air passes into a combustion chamber where it causes atomized jets of liquid fuel, forced in under pressure, to burn with almost explosive violence. This release of heat causes great expansion of the gaseous products of combustion. A small amount of this energy is used for rotating the turbine which drives the rotating supercharger, but most of it is retained by the stream of gases which issue from the jet at the rear of the engine, thus producing a considerable thrust, and tending to impel it forward.

The simplicity of the reaction engine and the possibilities

of the great speed which it offered attracted aircraft designers before the war. The Germans evolved and used



Courtesy Power Jets Ltd.

FIG. 17. Section of Experimental Whittle engine. Air is taken in on the extreme left and compressed by the fan A, thence it passes to the combustion chambers C and the expanded gases pass through the blades of the outer ring of the turbine B before they go to the jet.

many types, but paid little attention to the durability of the engine. This did not matter in the simple and cheap V1 engine, the life of which would be half an hour or less, but in the case of aircraft which have to be kept serviceable durability is a necessity. The delay in the production of British jet-propelled aircraft was due to a lack of co-ordination between engine and aircraft designers, owing to the conditions of secrecy imposed on the former, and the characteristic British search for extreme durability and reliability.

The problem of making a jet-propulsion engine was partly a metallurgical one. Alloys had to be found which would endure high temperatures and the constant impinging of hot corrosive gases without much ill effect. More-

over, where the engine contained rotating turbines the blades must not be unduly thick and they must run hot without friction and without the development of brittleness and fatigue in the metal. The shape of the various ducts, the size of the combustion chambers, and the shape and dimensions of the jet are matters of prime importance. Even the V1 was a very clever essay in airflow design. There were no rotating parts in this jet-propulsion unit. The V1 had to be launched into the air from a sloping ramp by rockets or some other device, for the engine would only begin to work when it was passing through the air at a speed for which it was designed. It is a very simple machine, but much calculation went into the problem of the sizes of the front opening, the shape of the taper of the body, and the size of the orifice or jet at the rear.

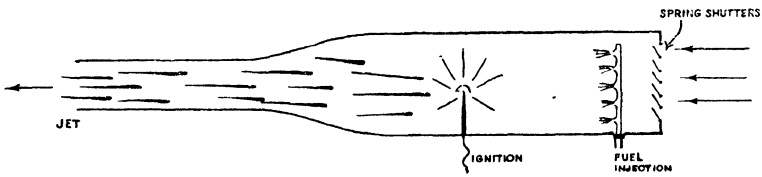


FIG. 18. Diagram of V1 engine.

The air, which was compressed to a certain extent in the tapering tube by the rapid forward motion of the engine, is sprayed with liquid fuel and the mixture is exploded electrically. The force of the explosion closes the shutters behind the front opening, a jet of flame and hot gas is forced through the rear orifice, and the thrust here pushes the engine forward. When the pressure falls somewhat, the force of the air, assisted by a spring device at the front, opens the shutters and the process is repeated. In a way, the action is analogous to that of a two-stroke engine and the noise produced is also somewhat similar. The V1 engine is noisy, will only go at one speed, its life is short, it is uneconomical in fuel consumption, and it needs the correct air speed before it will function. This air stream engine was a triumph of cheap construction in view of the

Plate VII

The Whittle W2B engine. The starting and lubrication mechanism and the air intake are shown at the front and the combustion chambers round the body of the engine. The jet, which is not shown, is at the rear.

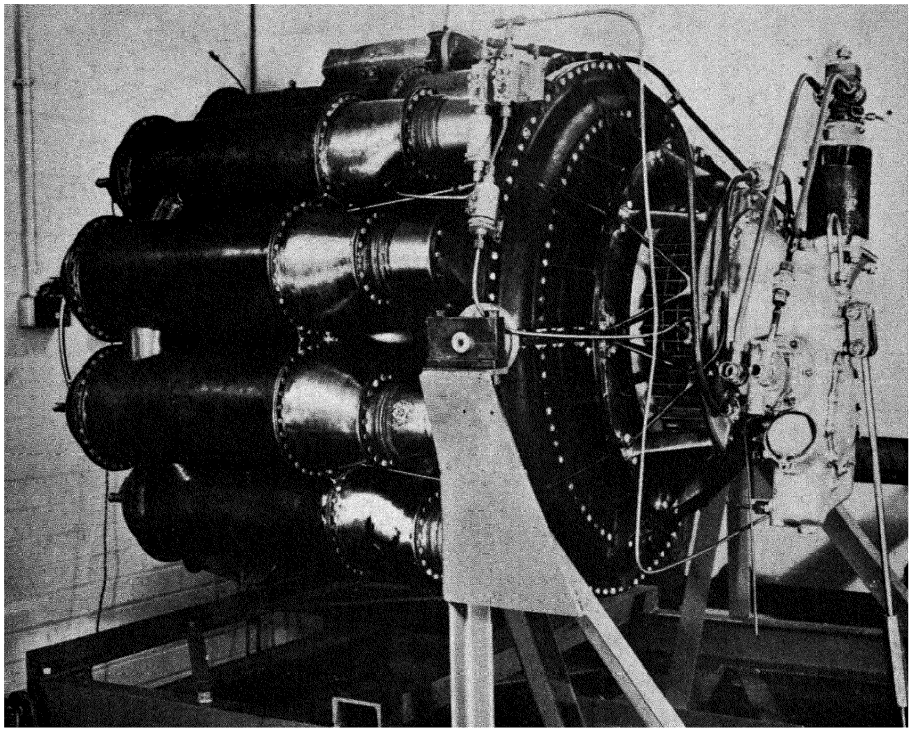


Plate VII

Courtesy Power Jets Ltd.

Facing page 95

purpose for which it is designed, but something much better is required for aircraft. It is even possible to design a continuous duct or airflow engine known as the blow-lamp motor. This would not need rotating fans or shutters at the front. It would only work on a light aeroplane. Air is continuously caught and compressed to a certain extent by the forward motion of the engine. Liquid fuel burns at a nozzle in the middle of the duct and a constant stream of expanded air leaves a jet at the rear of the device. A painter's blow-lamp, placed on a small wooden boat or raft on a still pond, will propel it at a speed which may be quite surprising.

Rocket propulsion only differs from jet propulsion in that the propellent includes a supply of oxygen and the rocket is therefore independent of the oxygen of the air. In fact, the rocket travels much better above the earth's atmosphere. The earliest rockets were made with a special kind of gunpowder, or gunpowder soaked in oil. The fairly rapid burning of the charcoal, sulphur and other combustibles in the oxygen supplied by the saltpetre gave hot gases which, on leaving the orifice at the base of the rocket, produce an upward thrust. Many new propellents were constantly being tried, from cordite to a mixture of petrol and liquid air.

Since the time that liquid oxygen became a common industrial commodity, and one which was readily transportable in large 'thermos' tanks on motor lorries or railway trucks, the use of this substance as the supporter of combustion in rockets soon suggested itself. It has been used with benzene, light paraffin, liquid acetylene, liquid hydrogen and alcohol. Most of the V2 weapons used alcohol and liquid oxygen, stored in separate tanks in the body of the missile. Pumps controlled the supply of these liquids to the combustion chamber and the alcohol circulated through its double walled casing, thereby keeping it cool on the outside and also ensuring that the liquid arrived at the nozzles hot and under pressure. A rocket is

sometimes called a self-contained or chemical-fuel motor. The following table shows the *theoretical* maximum jet velocities of various chemical fuel motors.

	Feet per second.	*Miles per hour.*
Ordinary gunpowder	6,800	4,600
Petrol and air	7,000	4,800
Cordite	9,600	6,500
Light Paraffin and Liquid Oxygen	13,300	9,000
Paraffin and Liquid Oxygen	14,300	9,600
Petrol and Liquid Oxygen	14,450	9,700
Benzene and Liquid Oxygen	14,850	10,000
Acetylene and Liquid Oxygen	15,900	10,800
Liquid Hydrogen and Liquid Oxygen	17,000	11,600

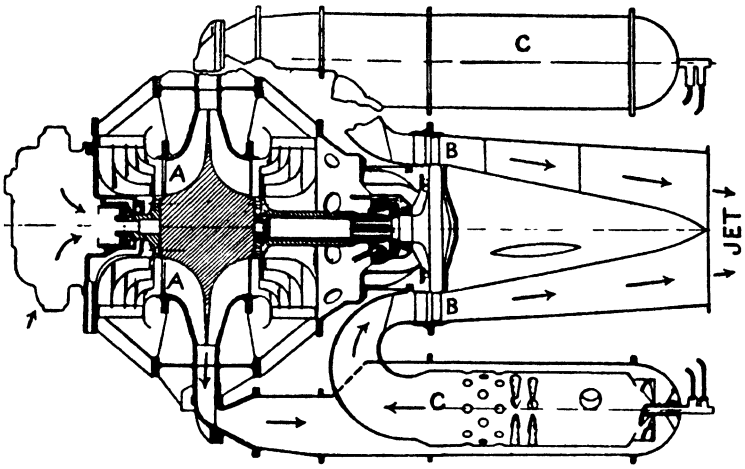
It will be seen that even though these theoretical speeds are unattainable, the three thousand miles per hour of the rocket is quite modest.

We now give some details of some jet-propulsion turbine aero engines and their characteristics.

In a lecture given to the Institution of Mechanical Engineers in October, 1945, Air Commodore Frank Whittle described his researches in the design of gas turbine aero engines up to the time of the production of the W2B engine which was the parent design of the Rolls-Royce Welland engine which powered the Meteor fighter and of the American General Electric Co.'s engines which powered the Airacomet.

Before 1930, Whittle perceived that there were a number of factors which favour the use of jet-propulsion turbine engines for aircraft, quite apart from that of the speed limit set by the properties of the air itself, if airscrews are used. We may summarize these advantages as follows: Firstly, the low temperatures at high altitudes give a greater range of temperature for working a heat engine and this tends towards efficiency of performance. Secondly, in spite of the smaller resistance of the rarified air to the plane at high altitudes, there is a ram effect due to the forward speed of the engine and this helps effective compression. Thirdly,

only a part of the energy of the gases from the combustion is used in rotating the turbine, and most of this energy is available at the jet.[1]



Courtesy Power Jets Ltd.

FIG. 19. Whittle W2B engine.

How the engine works can be understood from the diagram. The engine is mounted in a suitable cowling so that air, already usually under pressure by the forward motion of the engine, is compressed by the rotating fan at A. The air is fed into ten combustion chambers (C) so arranged that it flows between the outer casing and the flame tube, thereby keeping the chamber cool.

The fuel is supplied under pressure, and is burnt at a primus device in the flame tube. The hot expanded gas then passes through the ring of turbine blades (B), which is mounted on the same shaft as the air compressor. The only function of the turbine is to drive the air compressor, and the rest of the energy of the stream of gas is available at the jet.

Simple as is this principle, many technical difficulties

[1] A complete account of the difficulties of the early work in jet-propulsion gas turbine is given in Air Commodore Whittle's first James Clayton lecture of October 5, 1945, published in the proceedings of the Institute of Mechanical Engineers.

had to be overcome before a reliable engine had resulted. The material of the turbine blades, which were the only moving parts of the engine to be subjected to hot gases, had to be carefully considered. Not only were they acted upon by corrosive hot gases under great pressure, but owing to the speed of rotation of the turbine, great centrifugal forces tended to tear the blades from their roots. Many Sheffield alloys, such as Firth Vickers Stayblade and later 'Rex 78', were used. For the compressor, the blades were originally made of Hiduminium RR 59 and the compressor casing was of magnesium alloy No. 299 DTD 350. Research also had to be done on the best design for the turbine blades, and for the flow of the gases through the outer ring of the turbine disc, which Whittle had considered should be different from that generally used in steam turbine practice, in that the flow from the ring of blades should be of a vortex type and turn with a constant angular momentum.

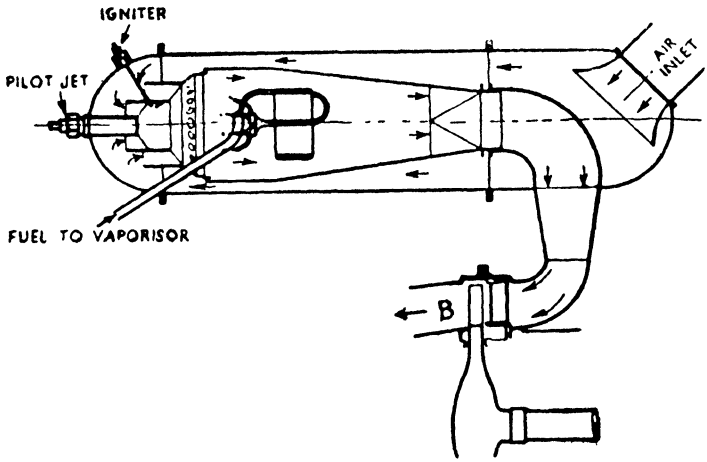


FIG. 20. A combustion chamber. It will be noticed that the air circulates in the outer casing before passing to the burner. This keeps the body of the chamber cool. The turbine blades are at B.

Again, many difficulties were encountered in the design of the combustion chambers, and finally ten such chambers were arranged round the body of the engine, as shown in the picture.

Plate VIII

The Rolls Royce 'Derwent' Engine developed from the Whittle engines. The starting and lubrication mechanisms and the air intake are at the front, the jet is seen at the rear. Engine design has far outstripped that of airframes for *high speeds*. These engines can only be used at part throttle in the best available planes. The engines are reliable to the utmost degree.

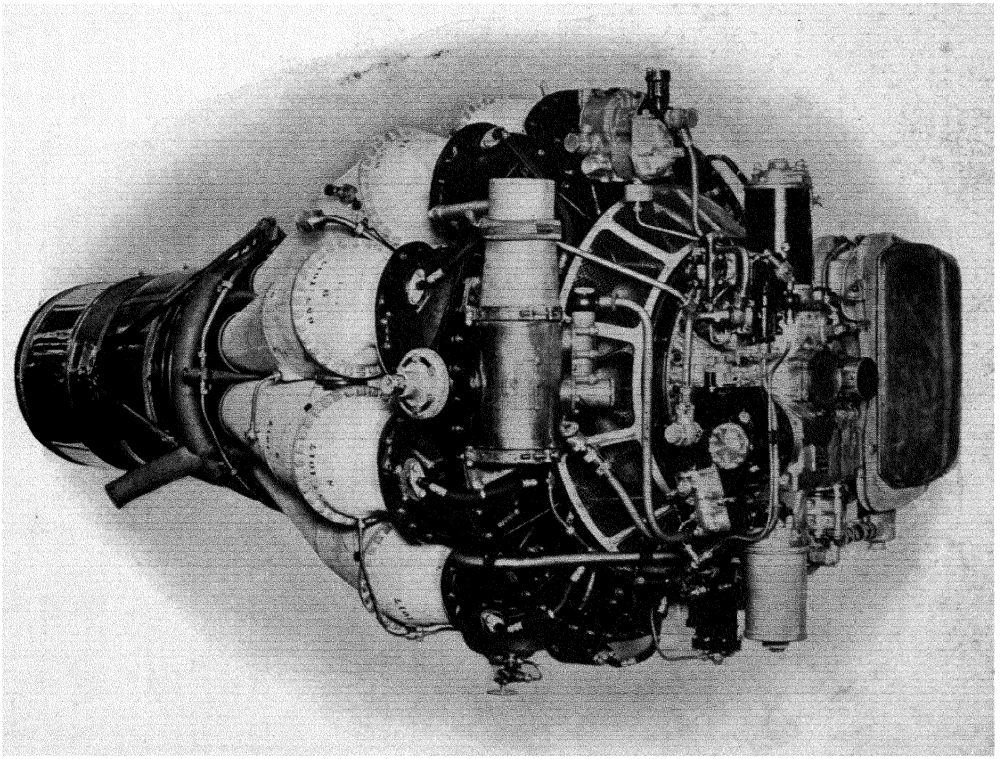


Plate VIII *Courtesy Rolls Royce Ltd.*

The control of the fuel system, the balancing of the flow of fuel to each of the ten burners and methods of securing good combustion without local overheating or carbon deposits, were the subjects of much experiment. Special fuels were supplied by the Asiatic Petroleum Company and a type of paraffin (kerosene) was found to be suitable.

As can easily be imagined from the photographs, the Whittle W2B was the parent of the superb Rolls-Royce Derwent engine. This engine incorporates a centrifugal compressor mounted on the forward end of a shaft carrying a single stage axial flow turbine. This main shaft is carried in three bearings, and is surrounded by ten combustion chambers, or 'cans', which are fed with compressed air from the impeller, and fuel from a high pressure pump driven by the engine. The supply of fuel is governed by a throttle valve which is controlled by the pilot. An automatic control is also fitted to reduce the fuel supply to the burners at altitude, in a similar manner to the automatic boost control on supercharged piston aero engines. For starting up, the fuel is ignited by two ignition plugs, and a high pressure cock which cuts off the supply of fuel is provided for stopping the engine.

Flame tubes are mounted concentrically within the chambers, and combustion is completed before the gas enters the turbine vane ring at the rear. Balance pipes are provided between the combustion chambers to equalize the pressure and to allow the flames to ignite the fuel in adjoining flame tubes when starting up.

Lubrication is obtained from a triple gear type pressure pump to the various bearings, and the oil is then collected by two scavenge pumps and discharged through a thermostatically controlled oil cooler, before being returned to the oil tank.

The engine accessories, including fuel and oil pumps, generator and accessory gearboxes, are mounted on the wheel case at the front of the engine, together with an

electric starter motor. The whole engine is housed in a streamlined cowling, which has a large air intake in front, and a projecting jet-pipe or propelling nozzle at the rear.

The jet propulsion engine is still at an early stage of development. The Rolls-Royce 'River' class of engine, comprising the Welland, Derwent I, IV and V, and the Nene engines, have already established themselves as remarkably reliable and efficient machines, but their development is still continuing. The Derwent engines, on the completion of a hundred hour test at full thrust, showed no signs of 'fatigue' and continued to the limit of the endurance of the technicians employed to test them.

Some details of the performance of the Derwent I engine may be interesting:

Static thrust (while on the test bench) at sea level	2,000 lb.
Maximum revolutions per minute	16,600
Static thrust for cruising	1550 lb.
Maximum revolutions per minute	15,000
Static thrust when 'idling'	120 lb.
Revolutions per minute	6,000
Length to exhaust flange	84 in.
Jet pipe length	38·5 in.
Maximum diameter	41·5 in.
Weight with oil tank and cooler	975 lb.

Single stage axial flow turbine revolving in anti-clockwise direction when viewed from the rear.

The consumption of fuel (paraffin to which has been added 1 per cent of lubricating oil) varies from one ton per hour at maximum speed to 470 lb. per hour when idling. Oil consumption for lubricating at the highest speed is not more than one pint an hour.

The twin-engined Gloster 'Meteor' aircraft is powered with Rolls-Royce 'Derwent V' engines each giving a maximum thrust of 4,000 lb. That is to say, the aircraft is continuously pushed forward at its two jets with a total force, or thrust, of over three and a half tons. A speed of considerably more than six hundred miles an hour (that

is, ten miles a minute) was reached in the speed trials at Herne Bay, and even then the engines were not running at full throttle. Indeed, it was the airframe of the plane which showed signs of strain, and much research on the design of aircraft for these high speeds yet remains to be done. The designers of the Derwent engine hope to decrease its present frontal diameter from 45 inches to only 35 inches, and at the same time to increase its thrust to 6,000 lb. The best piston engines have a weight of rather less than one-pound per horse-power, and if the thrust of the gas turbine engine could be expressed in a similar way, it would be found to yield two horse-power per pound weight. The fuel consumption of the gas turbine engine seems to be high at first sight, but again per horse-power it is less than that of the piston engine. The turbine engine performs most economically at high speeds.

Problems caused by the enormous increase in wind resistance at high speed reach a climax at about the speed of sound (sonic speed, 1,100 feet per second, or 760 miles per hour) and thereafter the matter becomes very little more complex.[1]

Soon we shall see a regular transatlantic passenger service with stratosphere flying, jet propulsion engines built into the wings of the aircraft, hermetically sealed cabins with air at normal atmospheric pressure controlled to the correct oxygen and moisture content, movement and temperature for the comfort of passengers. The journey from America to London by air will become less irksome and absorb no more time than that from the Midlands by train at the time of writing this.

During the war the Germans experimented with and developed many forms of rockets and jet propulsion; but because of the number of different plans and designs they did not succeed soon enough in mass-producing enough machines to alter the course of the war. Particularly

[1] A unit of speed equal to that of sound at the prevailing temperature of the air is known as a MACH.

sinister were their plans for a more intense development of long range 'robot' weapons. Most of these could be made cheaply and with comparatively unskilled labour. The V3, known as the Schmetterling or Butterfly, was a flying bomb with a wing span of 7 ft. It was controlled by a rocket motor and a photo-electric 'eye'; and an 'ear' sensitive to the noise of a bomber enabled it to follow and find the target. It would have been a formidable weapon against our air offensive. The German rocket motors were not of the same type as those employed by the Allies which could not be recharged when expended. The Germans had developed a 'pocket edition' of V2 which used nitric acid instead of liquid oxygen as the supporter of combustion. Nitric acid, HNO_3, contains more than 75 per cent by weight of oxygen, it can readily be made from air and water when hydro-electric power is available, and it is not difficult to handle. As regards gas-turbine engines, the Germans have shown much resource and ingenuity, for when they were faced with a shortage of suitable alloys for their turbines, they designed an ingenious form of air-cooled turbine blade. In the early part of 1945 the Germans were manufacturing nearly 3,000 such engines a month, and production was to rise to a rate of 100,000 each year by the middle of 1946. The Germans had spent enormous sums on testing-plants and wind-tunnels for the testing of their machines. This testing equipment was without rivals in the world. Much of it will probably be transferred to the new aeronautical college at Cranfield, near Bedford.

It is believed that the Germans did succeed in flying a jet propulsion plane a few days before the war, but the first really successful flights were British and were made in May, 1941, and the experimental aeroplane E.28/39 was the first really reliable machine of this kind.

The German aeroplane ME. 262, powered by the Junkers 004 jet propulsion gas turbine, was put into production at too early a stage of the development of its

engine. It had not the efficiency of the British engine, its weight was greater for its power, its life shorter, it had a greater fuel consumption and was slow in response to the throttle. The engine was unreliable and the wing loading of the aeroplane was too great, and this resulted in many fatal accidents. German pilots fought shy of it.

The use of the simple jet engines and the simpler rocket propulsion gave new impetus to airframe design. The motors became a part of the frame and new shapes were called for by the high speeds which had become possible. The aeroplane lost its familiar shape and sometimes looked like a huge paper dart without a tail. The use of the fine wind tunnels at Goettingen and Volkenrode, near Brunswick, had produced revolutionary designs for aircraft, and yet in the words of Sir Roy Fedden, special technical adviser to the Minister of Aircraft Production, 'Yet in spite of it all we won the war with limited equipment and with only the restricted and orthodox range of aircraft evolved by ourselves and our Allies. The Germans failed, and the brilliant efforts and tireless labours of countless scientists and technicians were frittered away by misdirection.'

The gas turbine is a near relation of the turbo-jet aero engine. A set of rapidly rotating fans supply compressed air to combustion chambers where liquid fuel is burnt at a number of nozzles. The hot gases pass into a turbine where they drive a series of rotors of increasing diameter so that the gases give up their energy progressively as they expand. The design of this turbine again depends on the use of alloys which are not readily corroded or rendered brittle by the hot gases. In order that the chemical energy of the fuel, which has been converted into heat in the combustion chamber, shall be turned into mechanical energy with the minimum of loss, it is essential that the final set of turbine blades shall reduce the energy of the gases to the minimum, and that at this stage their temperature shall have fallen as much as possible. The hot exhaust gases can be used to heat the incoming air. An

electric or compressed-air starting motor is necessary for use with the gas turbine. Several large plants in U.S.A. producing 60,000 horse-power, are now using gas turbines which burn crude oil, and smaller models have been used on the Swiss railways for a number of years. Gas turbines can be built which show a lower weight horse-power ratio than any other form of rotary engine.

PLASTICS

FOR thousands of years, and until fairly recently, men had been using the same sort of materials for doing particular jobs. It was rather a shock to many people when it was found that iron and steel could be used for constructing the ships which formerly had been made of wood, and paper was found to have many uses besides that of a writing medium. It is only in the last few decades that those engaged in constructional work of various kinds gave much thought to, or showed much initiative in, the choice of their materials with respect to the peculiar fitness of the thing used, rather than for tradition. The conditions created by two major wars in the first half of this century have meant that substitutes have had to be sought for many raw materials, either because of transport difficulties or non-availability in sufficient quantities in particular areas. Sometimes the substitute has proved to be of more use and durability than the original material. In many cases, there has been a saving of cost and an increase in ease of working and rate of production. All these factors are supremely important at all times, but particularly are they so in the war and post-war years. For instance, at present it is absolutely necessary that we should think of the quickest effective way of building many new houses, complete with their fittings, and that we should consider the best materials to be employed.

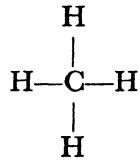
It is obvious that any class of substances which are at once fairly simple to produce, can be readily moulded, are resistant to water, corrosive action, temperature changes, can be used in combination with other substances such as wood, woven materials, 'filling' materials such as wood flour, and in addition are light in weight, strong in texture and can be obtained in glass-like transparency or opaque in any shade of colour, will be of the utmost value

in modern production processes. Plastics must not only be considered as synthetic materials which act as substitutes, but also they must be regarded as substances which offer new possibilities in construction which are of the utmost importance to the life of man. As an example, the problem of providing adequate housing in this and other countries is a serious one, and cannot be separated from public health, happiness, size of population and other important factors. In the houses of the future, plastic fittings and constructed parts will occupy an important position.

Let us now consider what plastics are, and why they are plastic. Plastics are substances which can be moulded under pressure, and after suitable treatment by 'curing' and heat become rigid. They are only really plastic during some process in their manufacture. The majority of plastic substances, after attaining their hard and rigid state, cannot be softened and moulded again. Chemists sometimes divide substances into those that are made up of crystals (even those too small to be seen by the naked eye) and those that are amorphous (that is to say, are 'without form'). Although some plastics have a fairly consistent form of arrangement of their tiny parts or molecules, they cannot be said to have crystalline form. They are therefore amorphous substances. Crystalline substances are usually brittle, and when heated do not show much sign of becoming plastic until they finally melt. At some time in its history a plastic substance can be made to flow by the application of heat and pressure. We can best understand the behaviour of plastics by considering the nature of their molecules. Molecules are formed when atoms join with other atoms and with one another.

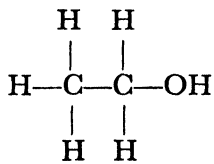
As we have noted in a previous chapter, the chemical properties of atoms are to be found in the outer rings of electrons which surround the positive nucleus. Atoms can be regarded as having a number of bonds, which can be used for joining them to the bonds of other atoms. Two

atoms of hydrogen join with one of oxygen to give water, four atoms of hydrogen join with one of carbon to give methane or marsh gas and so on.

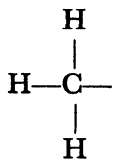


If hydrogen is supposed to have one such bond, oxygen in the water has two and is said to be divalent; and carbon, in the example which is given above, has four and is said to be 4-valent or tetravalent. This property of carbon of having four bonds is a clue to the structures of the thousands of compounds which contain it. The study of the carbon compounds is called organic chemistry, because until the year 1828 it was imagined that the chief carbon compounds could only be produced by vegetables and animals. In that year, Wohler synthesized the substance urea, and the distinction between organic and inorganic chemistry was seen to be purely artificial.

By combining only the three atoms of hydrogen, carbon, oxygen in various ways and with various numbers of each we can arrive both on paper and in practice at many thousands of substances. Sometimes we find that little groups of atoms will pass into and out of the structure of molecules without change. These are called 'radicals', and it is very important to know about them when we are considering synthetic methods in chemistry. A molecule of ordinary alcohol, such as is found in small quantity in beer, is made up from two carbon atoms, six hydrogen atoms and one oxygen atom. It has the formula—

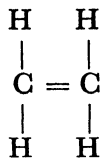


It could be written C_2H_5OH; and C_2H_5 and OH are spoken of as the ethyl and hydroxyl radicals respectively. The methyl radical CH_3 or—

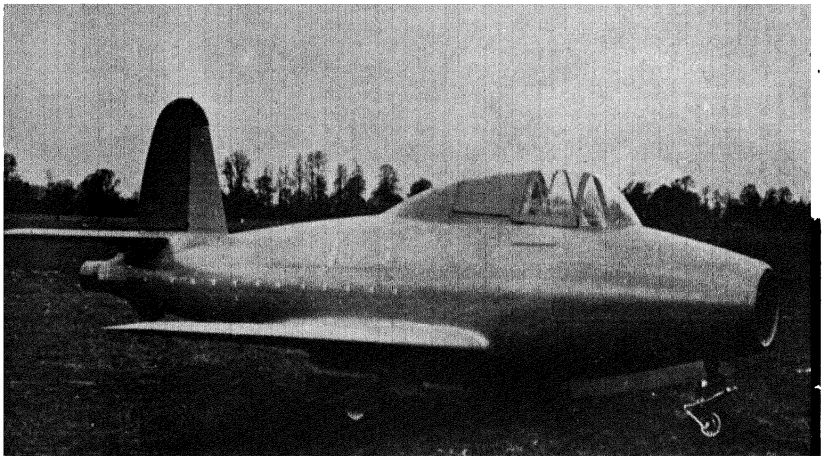


clearly leaves one bond for uniting it with some other atom, or combination of atoms, with a bond which has not been 'satisfied'. It could be combined with the acid or carboxyl radical COOH to give acetic acid CH_3COOH, for instance.

In accordance with our knowledge of the electrons of the carbon atom, it also has the property of linking itself to another carbon atom by two bonds or even by three. Thus, the familiar gas acetylene (formerly so well known to all cyclists) has the formula C_2H_2 or $H—C \equiv C—H$; and the gas ethylene C_2H_4 or—



It must not be thought that these double and triple bonds are a sign of strength and stability. We have to imagine that to make such combinations the bonds must be bent from their normal positions and are in a state of strain and instability. Substances such as the two above, are called unsaturated because the possibilities offered by the four bonds to each carbon atom have not been taken up. A particularly important case of the combining properties of carbon is that of benzene, which is obtained from coal tar, and can be synthesized by heating acetylene. It is the basis of many thousands of the substances most useful to modern life. Drugs, disinfectants, dyes, explosives, plastics and other compounds used in the economy of the twentieth



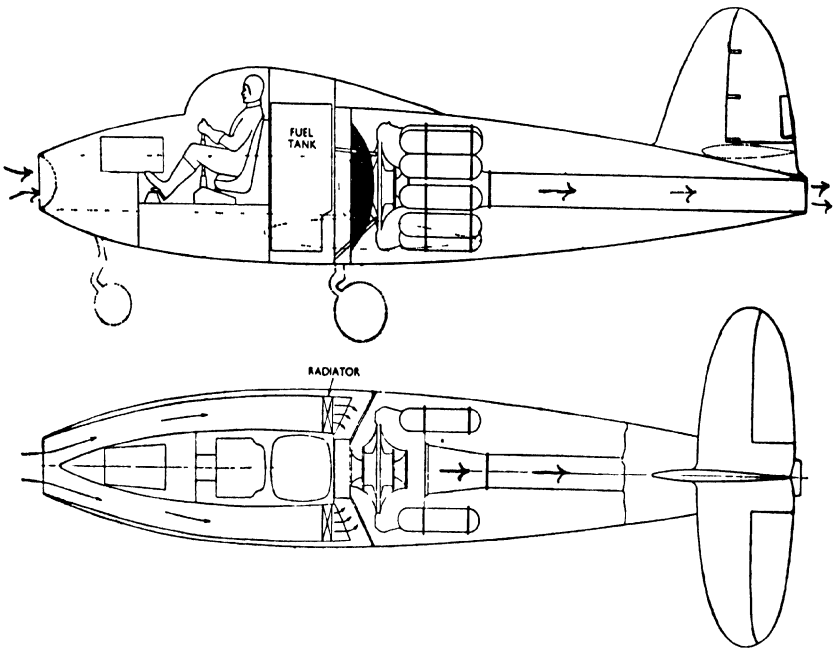


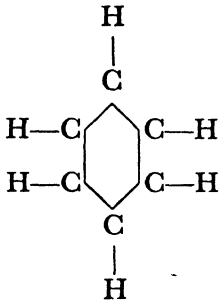
Plate IX *Courtesy Power Jets Ltd.*

Experimental aircraft with Whittle engine E28/39. Notice air intake at front and jet at rear.

Fuselage arrangement of the experimental jet propulsion aircraft, the first successful craft of its type. The Gloster aircraft is different in design and has an engine in each wing structure.

Facing page 109

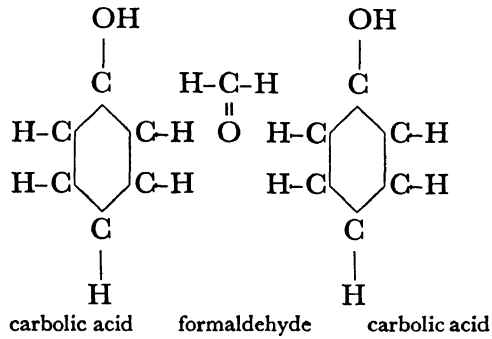
century are all made from it and its derivatives. Benzene is a simple example of the aromatic or closed chain compounds. The benzene ring has the structural formula—



Benzene is a very stable substance and the fourth bond of each carbon atom seems to be directed internally. The hydrogen atoms may be displaced by other radicals, and if two hydrogen atoms are so displaced the relative positions of the radicals are described by the terms ortho, meta and para respectively. As the benzene ring is symmetrical, we should describe radicals in adjacent positions as ortho, with one H radical between them as meta, and with two H radicals between them as para.

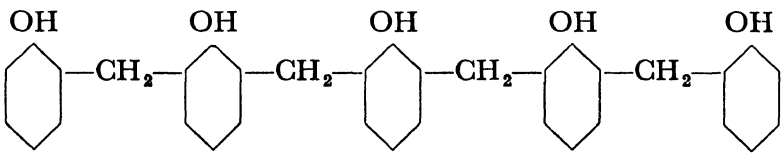
After this preliminary explanation of the combining properties of carbon, which has been understood for some decades, we are now in a position to appreciate the building up of molecules. Simple molecules containing double bonds are capable of joining with one another. This process is called polymerization, and is very important in the production of the large molecules which are characteristic of plastic substances. This action will take place under the influence of heat or sometimes of light. Some carbon compounds will combine with others if suitable linkages are provided. For instance, as was discovered in 1872 by Bayer, carbolic acid (phenol) molecules can be linked together by formaldehyde, and a hard resinous substance is produced with the elimination of water. Such a process

is called condensation. More than forty years ago, Dr. Baekeland investigated this reaction and Bakelite was the result.



carbolic acid formaldehyde carbolic acid

Thus we can imagine carbolic acid molecules being linked together to form long chains like this (after water H_2O has been eliminated from the linkage).



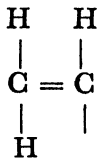
When the plastic is cured by heating, the effect can take place in three dimensions, and the plastic produced becomes one colossal molecule, of considerable strength and resistance.

The phenol plastics had a dull, uninteresting dark-brown colour, and investigations of the condensation of urea and other substances with formaldehyde resulted in the production of 'beetle', which was white, almost transparent, and could be incorporated with coloured substances or dyed to bright hues. Formaldehyde (formalin), H.CHO or CH_2O, is a gas obtained synthetically from methane, CH_4, which is easily made from 'producer gas' (carbon monoxide and hydrogen). This is obtained by passing steam through hot coke. Urea $(NH_2)_2CO$ has been made in Germany during the war in enormous quantities as a basis for syn-

thetic substances, as a fertilizer and as a constituent of pig food. It is synthesized in England and the United States from ammonia and carbon dioxide. Coal and its products, together with a cheap source of power, preferably electric power, are exceedingly important factors in most large-scale commercial synthetic industries. Plastics may broadly be divided into three groups. Thermo plastics are those which can be softened by the action of heat and hardened on cooling, and the process can be repeated more or less indefinitely, so long as the heat is not sufficient to cause decomposition. These plastics are made by polymerization. Thermo-setting plastics, after having been 'cured' by heat and pressure, do not undergo further physical change if re-heated. Bakelite, made by condensation, is an example of this second group. The third group, or cellulose plastics, are not made either by polymerization or condensation, for in their case we start with a large molecule of cellulose, which itself may be regarded as a long chain of condensed glucose units.

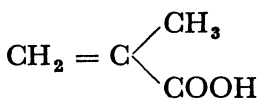
Some of the most useful of synthetic plastics are the glass-like 'acrylics', such as 'perspex' which is so useful in aircraft. The acrylic resins find many uses from the production of dentures, where both teeth and gums look really natural, to plastic lenses which have many advantages over those of glass, but notably because they transmit more actinic light. Acrylics are remarkably light and have a specific gravity hardly greater than that of water. Although improvements in synthetic processes often take the form of 'short cuts' and the use of cheaper and more convenient raw materials and processes, we can best understand the synthesis of acrylics by considering the property of ethylene, C_2H_4, whereby it polymerizes into a long molecular chain. Incidentally, this polymer is known as 'alkathene'. If we imagine that an atom of hydrogen has been removed from ethylene and a linkage bond left, we may

consider the remainder of the ethylene to be a radical. This is usually known as the vinyl radical—



Ethylene is a by-product of the petroleum industry, and it can also be obtained as a by-product in the coke-oven processes in this and other countries.

If vinyl is combined with carbolic acid radical (phenyl) we get styrene $C_6H_5CH = CH_2$, and when heated with a catalyst (or 'helper') the molecules of styrene combine together to give polystyrene or 'distrene', a most useful glass-like resin, with remarkable electrical insulating properties. Many substances obtained from ethylene can be polymerized. If ethylene is combined with chlorine and again with acetic acid, the vinyl chloride and the vinyl acetate will combine together to form long chains, and the result is 'vinylite'. In the case of acrylic resins, two hydrogen atoms of ethylene are displaced by a methyl CH_3 and a carboxyl (acid) COOH group respectively, thus—



which is methyl-acrylic acid. If this acid is made to combine with a further methyl group we get $CH_2 = C\ (CH_3)\ COOCH_3$, which is methyl methacrylate. When this polymerizes and forms large units with great molecular weight we get acrylic resins.

The above short account of the vinyl derivatives is purely theoretical, and in practice different methods are used. For instance, vinyl acetate is obtained by combining acetylene and acetic acid; and vinyl chloride is made from acetylene and hydrochloric acid.

The various polymerization products of these substances have a wide use. Flexible rubber-like sheeting, transparent films, insulating sheathing for wires and cables, new fibres and rods of remarkable strength for use in fabrics and furniture are made from them. Their uses are legion. Again, vinyl acetate may be treated by hydrolysis, and then condensed with acetaldehyde or butaldehyde to produce a safety glass.

The polymerized methyl methacrylate, which we have already mentioned, is prepared by I.C.I. and sold with the name Diakon as a moulding powder, and as 'perspex' in the form of cast sheets or rods. The I.C.I. process uses acetone as a starting point. The acrylic resins are light, strong, not brittle and very resistant to corrosive substances. To make compression mouldings from Diakon a pressure of one to two tons per square inch at a temperature of 130–190° centigrade is required. It will be seen that in the thermo-plastics industry large quantities of ethylene, acetylene, alcohol, acetone and acetic acid are necessary. Acetylene, which is the starting point of so many products, is expensive in this country and the failure to produce it cheaply in large quantities has been a hindrance to the developments of the plastics industry. Where hydro-electric power is cheap, calcium carbide is made by mixing lime and coke together, and heating it electrically to a high temperature. Calcium carbide and water produce acetylene. Cheap calcium carbide is a great asset in many ways, for it is also the basis of various fertilizers containing nitrogen. Acetic acid can be made by the fermentation of alcohol (the dilute solution of this acid, known as vinegar, was originally produced by the souring of light poor-quality wines). Where power is cheap, it is easier to make acetic acid from acetylene by first converting this in acetic anhydride. Acetylene is made cheaply in Canada, and from that country we have imported large quantities of acetic acid.

We have noted the chemical evidence that 'plastics' in general are made of long molecules, each comprising an

enormous number of atoms. Chemists and biologists are more and more indebted to the physicists for instruments necessary for their own research. For instance, any research on nerves, muscles, and movements of organs, such as the heart, would be difficult without amplifying valves and the cathode ray tube to draw a picture of what happens. In the same way, X-rays and the electron microscope are invaluable for research on plastics, including those in the form of new fibres and threads. Since 1910, it has been known that the regularly spaced atoms in crystals will 'diffract' X-rays, so that patterns of 'spots' may be recorded on a photographic plate. In this way, the late Sir William Bragg was able to evolve a comprehensive idea of the structure of crystals. In the case of plastics, we can obtain evidence by X-ray diffraction, that in those which are obtained from cellulose there are molecules in long chains, but the amorphous synthetic resins do not give X-ray patterns. The conception of a plastic substance as a mass of interlaced chain-like molecules or a network of large molecules, linked together, will explain their plastic behaviour. When a substance, made from small and simple molecules, is heated they increase their speed of vibration, the relatively small electrical cohesive forces between them are broken down, and the substance melts. In the case of long molecules, the cohesive forces are very great and the vibrations caused by the heat do not move the whole of the molecule uniformly, and thus it does not melt, but only softens as the temperature rises. This explains the behaviour of thermo-plastics. In the case of thermo-setting plastics, the heat and pressure treatment to which they were subjected when they were being made into a finished product has increased, by condensation, the number of chemical bonds between individual units, so that the effect takes place in three dimensions. Finally, the piece of plastic is to be regarded as one enormous molecule.

We are now reaching the stage when we can ask for a plastic substance that will have particular properties of

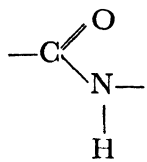
density, tensile strength, plasticity, ease of working and electrical properties. Then we can make molecules 'to measure' for a particular purpose. For instance, in developing substances for use as fibres or threads, such as artificial silks, factors such as strength, durability, colour, and ability to take a dye easily, suitability for spinning, knitting and weaving have to be taken into account. The careful study of the surfaces of the fibre as well as of the way its molecules are placed will give much information concerning its strength. The electron microscope is a useful instrument here.

The production of nylon is an interesting case. Carothers, the distinguished U.S. plastics chemist, and his co-workers produced a group of substances known as superpolyamides, which culminated in the manufacture of nylon thread and Exton fibre. These are known to the general public as textile fibres and 'silk stocking' materials, but they are also important as real plastics. When nylon was first used in the manufacture of hosiery the press greeted it with the words: 'silk stockings from coal, air and water', and it might be of interest to see in outline how this was true.

Towards the end of last century, Emil Fischer, a German chemist, experimented to try to build up protein molecules synthetically. He succeeded in producing short carbon chain molecules with an amino group (NH_2) at one end, and a carboxyl (acid) group (COOH) at the other. These would combine together by condensation, water being eliminated when the NH_2 group and COOH group combine. What remains is an 'amide' group—

$$\underset{\text{radical}}{H_2N} \text{ and } \underset{\text{radical}}{COOH} = \underset{\text{water}}{H_2O} \text{ and } \underset{\text{radical}}{CO(NH)}$$

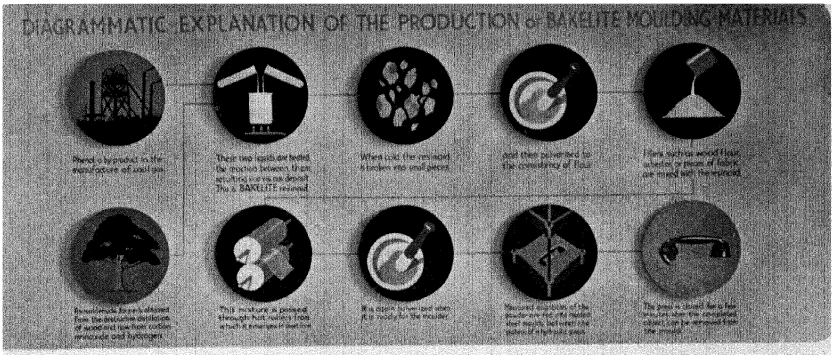
which we might think of as a linkage like this—



Fischer did not succeed in producing plastics, nor did he have any idea of doing so, but his work on the constitution of protein molecules paved the way for Carothers who, more than forty years after, was seeking to imitate and improve the type of protein molecules to be found in silk. Short chains containing five, six or seven carbon atoms are linked up by means of amide groups into long molecules called superpolyamides, which may contain as many as seventy of the short chain units. By varying the size of his short carbon chains, and regulating the number of these in long molecules, Carothers was able to provide an end-product giving properties which could be predicted. Nylon has a molecule twice as long as those of silk, it has double the strength of this substance, and is much more elastic and resistant to damp. It is spun by drawing it out from a melted mass and then it is still further drawn out, so that its length is greatly increased. This has the effect of arranging the long molecules so that they lie in the direction of the length of the fibre. Thus, the large cohesive forces between their long sides are brought into play and give the material great strength. Research still continues on this useful material and other related substances. Plant to the value of many millions of dollars for its production is in use in the United States of America. The raw materials for the manufacture of nylon are obtained from coal-tar and ammonia. Both of these are obtainable from coal, but in some parts of the world it is cheaper to synthesize the ammonia from the nitrogen of the air and the hydrogen of water, by an electrical process. Hence, we get silk stockings from coal, air and water!

Although the chief developments in plastics have taken place quite recently it should be realized that these substances have quite a long history. Resins and wax-like substances were known to the Egyptians, Greeks and Romans; and the properties of pitch and bitumen have been known and exploited for some centuries. The synthetic plastics have usually resulted from deliberate attempts

Plate X—Making Bakelite.
Lamp and table decorations made from acrylic resins. (I.C.I.)


DIAGRAMMATIC EXPLANATION OF THE PRODUCTION of BAKELITE MOULDING MATERIALS
Phenol is produced in the manufacture of coal gas
Their two liquids are heated, the reaction between them resulting in a viscous resin known as Resinoid. This is BAKELITE resinoid
When cold, the resinoid is broken into small pieces
and then pulverised to the consistency of flour
Fibre, such as wood flour, asbestos or pieces of fabric, are mixed with the resinoid
Phenol is made, largely, from the destructive distillation of wood and, now that coal is in short supply, from petroleum
This mixture is passed through hot rollers from which it emerges in sheet form
It is then pulverised when it is ready for the moulder
Measured quantities of the powder are put into heated steel moulds, between the plates of hydraulic presses
The press is closed, and a few minutes later the completed object can be removed from the mould

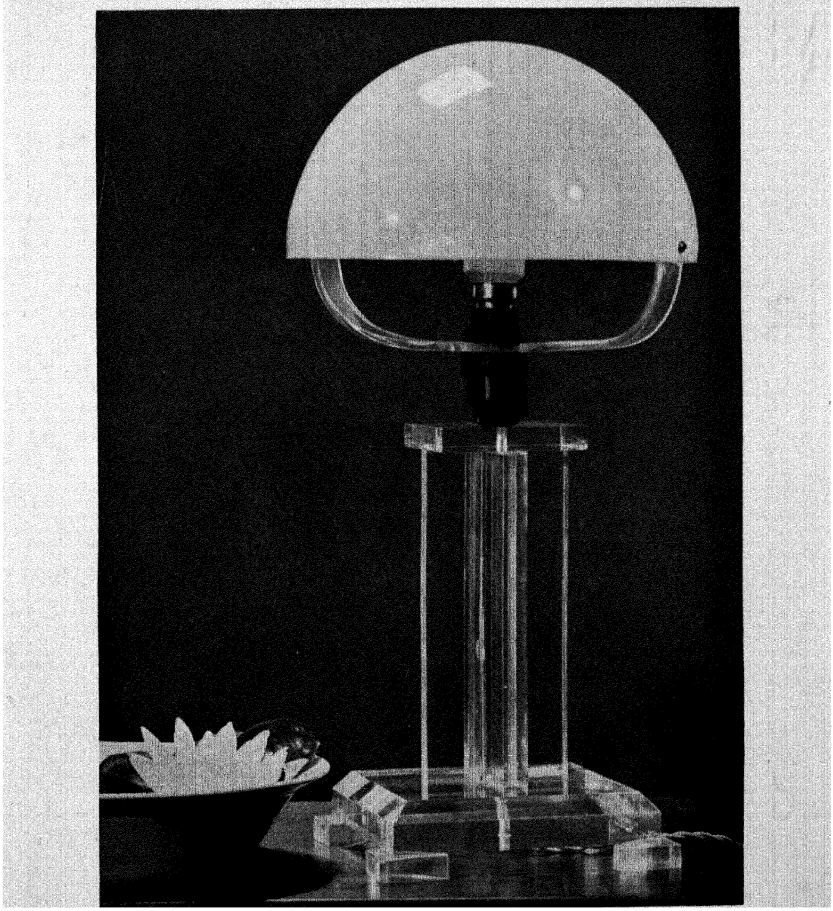


Plate X

to find substitutes for natural substances such as ivory or horn. Eighty years ago, in Birmingham, Alexander Parkes discovered that nitro-cellulose (of which gun-cotton is a form) when dissolved in alcohol and mixed with camphor, produced a tough substance which could be moulded. The product was called Parkesite and subsequently celluloid. A later development of it called Xylonite was exported from this country in considerable quantities. The use of camphor is interesting as it was the first of a number of substances called plasticizers, which act as internal lubricants, so that the long molecules of the plastics move more easily over one another, and flexibility gives place to the brittleness which would otherwise render the cellulose plastics useless. The molecules of the plasticizer are attracted by the large cohesive forces of the sides of the long molecules. Many substances have been used as plasticizers: these include glycerine products and certain phosphate compounds of coal-tar derivatives. Much research has gone on to find an ideal lubricant for cellulose acetate just as camphor is for cellulose nitrate. This last substance burns with almost explosive violence in its own oxygen, and this property has limited the use of celluloid, or made it positively dangerous. Cellulose acetate was discovered by Schutzenberger almost in the same month that Parkes made Parkesite, but it was not manufactured commercially until the end of last century. Cellulose acetate is well known as the substance from which celanese, rayon, non-inflammable cinema films, lacquers and 'dopes' are made. 'Non-flam' films do not show quite the same excellent qualities of those made from celluloid, but with the improvement of plasticizers there is no reason why they should not displace them completely, and put an end to the dangers of the cinema projection box. The raw materials of cellulose plastics are cotton 'linters' and various acids. Cotton linters are the cotton remainders after the long fibres for spinning have been removed. Before the war, more than three thousand tons of cotton linters were

imported into England for making cellulose plastics and synthetic fabrics. Many other vegetable substances yield cellulose, and developments in the purification of wood pulp have produced material which is suitable for making cellulose plastics, though it is nearly always inferior to cotton linters for this purpose. Cellulose acetate is usually made by treating cotton linters with a mixture of sulphuric acid, strong acetic acid and a product of the latter known as acetic anhydride. This reaction is accompanied by the evolution of heat, and the mixture is carefully cooled during the process or otherwise the long cellulose molecules would be damaged or destroyed. After a time, the cellulose dissolves in the acetylating mixture and a syrup is formed. The excess of acid is removed by adding water and an alkali and allowing the mixture to ripen. When more water is added to the syrup, the cellulose acetate is precipitated as a white substance intermediate in form between powder and fibre. After washing, this may be dissolved in acetone. Careful investigation has led to a control of the degree of acetylation and thus the resultant viscosity of the substance. When mixed with a plasticizer, of which the ideal is yet to be found, transparent glass-like sheets, tubes and compression mouldings may be obtained. Dilute solutions of the substance can be used for the manufacture of 'dopes', lacquers and cinema films. 'Celanese' fibre is made by forcing a solution of cellulose acetate in acetone through tiny holes and evaporating off the solvent, which can be recovered and used again. The fine thread so obtained is then spun with others to give a fibre of considerable strength.

The casein plastics are not the result of a recent development, but are worth mentioning. Casein (the cheese or curd content of milk) is mentioned by the Egyptians as a useful substance for making 'paints' permanent, but the idea of 'lactolith' (milkstone) or imitation ivory did not come until at the end of the last century two Germans, Krische and Spitteler, showed how casein could be hard-

ened by the use of formaldehyde. Casein is obtained by curdling milk with rennet; and milk which is useless for human consumption can be used. In the case of good milk the fatty content and other valuable contents can still be utilized for other purposes. The casein can be combined with an inorganic 'filler' and a dye or pigment and moulded under heat and pressure. The casein becomes hard and resistant to water and to a certain extent heat, by the prolonged action of formaldehyde. Imitation tortoise-shell and ivory articles were often produced from casein.

The insulating and general resistant properties of many plastics make researches to improve their heat-resisting properties a necessity. The element silicon, which is so common in the earth's crust in sand and soil, has four combining bonds like carbon. Molecules containing silicon, analogous to some of the carbon compounds, were developed and investigated at the beginning of this century, by Professor Kipping of University College, Nottingham. This was then regarded as an interesting piece of 'pure' research with no utilitarian applications. Recent developments of these silicon compounds have produced polymers of methyl silicons, the molecules of which are not linked by carbon to carbon bonds. Thus, these new plastics will withstand temperatures which will cause break-down in the carbon plastics. Incidentally, this is only one of many hundred examples of the useful application of a scientific principle which at the time of its discovery was thought to have no application. The methyl silicons can be combined with mica, and then have important applications in the electrical industry. British Thomson Houston Ltd. hold a patent for their development. At present the most useful silicon plastic is a flexible rubber-like substance which is resistant to heat and is a good insulator.

An interesting application of plastics is the combination of plastics and plywood, with laminations of other constructional materials or sawdust and so on. This principle solved many problems in the mass production of certain

types of air frames during the war. Whether the plastic is used alone in a pressure mould or it is incorporated in wood or fabric, the 'curing' can be effected by heating it internally by electronic means in the manner we have mentioned in a previous chapter. Here the plastic acts as the dielectric between two condenser plates which are connected to a source of high frequency electric current, generated by a suitable valve circuit.

The future of plastics is assured. It is an interesting mental exercise to consider the various devices demanded by modern life, and to consider how many of them could be made from plastic substances. In plastics we have a great variety of synthetic substances which can be moulded under heat and pressure, extruded through holes of small diameter or drawn into fibres. Sheets of great hardness which can be cut by a saw, or so flexible that they can be used for articles of clothing, can be produced from plastics. Most plastics are inert, resistant to damp and reasonable degrees of heat; they can be dyed, can be made to take a beautiful surface and are pleasant to the touch. They have uncanny strength in view of their light weight, and are being developed to the limit of their theoretical molecular forces of attraction. The fittings of house, school and hospital, many domestic and toilet appliances, telephones, wireless sets, cameras, opera glasses, our cinema and camera film, spectacles and dentures, and, if artificial fabrics can be considered as plastics, the very clothes which we wear. Parts of our cars, aeroplanes, boats and insulators for large-scale electrical engineering can all be made of plastics. New substances bring new designs, techniques and standards. We are at the beginning of the plastics age!

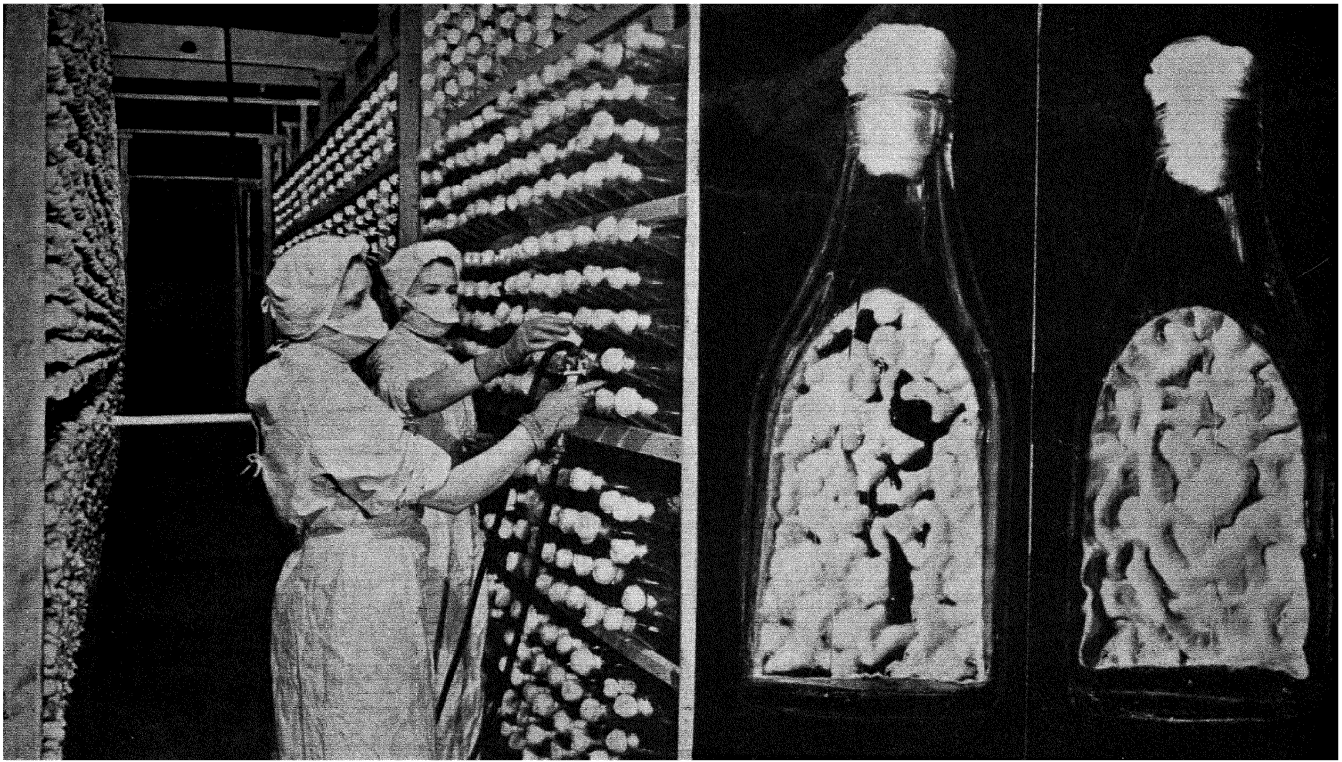


Plate XI

(*a*)

(*b*) Courtesy Lord Fitz Gerald

CHEMOTHERAPY: THE STORY OF SULPHONAMIDES, PENICILLIN AND OTHER NEW DRUGS

FOR centuries drugs have been used in an endeavour to cure diseases, and when the discovery was made that small living organisms, commonly known as germs, were the cause of many human ills, attempts were made to find substances which would attack and destroy the organism responsible for any particular complaint. With the exceptions of quinine for malaria, and emetine the active substance in ipecacuanha for amoebic dysentery, no other drugs had been found until in 1910 Paul Ehrlich, a German Jewish chemist, discovered salvarsan or arsphenamine. Here was a compound, derived from arsenic and coal-tar products, which destroyed the spirochaete of syphilis and at the same time was not very poisonous to living cells and tissue. This was the starting point of chemotherapy, or the application of chemistry to medicine.

Lord Lister had seen clearly that the use of carbolic acid and allied substances as antiseptics was limited if they not only destroyed the disease-causing germs, but also damaged the cells, fluids and other substances or organisms which were necessary for the repair of body tissue or were themselves disease resistant. Lister died in 1912, two years before the outbreak of the first Great War. In his lifetime he had developed the technique of antiseptic surgery, whereby the germs which infected wounds were destroyed or prevented from developing by the use of certain chemicals obtained from the coal-tar industry, notably carbolic acid, which is known to chemists as phenol. Lister's methods were rather crude, for his antiseptic substances not only destroyed germs, but to a greater or lesser degree were poisons which damaged healthy living cells. His surgical wounds did not become septic but equally they did not heal quickly. Antiseptic surgery has given way to aseptic surgery where the plan is to prevent germs reaching the

wound altogether, by the proper sterilization of instruments, dressings, the hands and 'overalls' of the surgeon and nurses. Nevertheless, Lister saw plainly that if a substance could be discovered which would prove to be capable of destroying or preventing the development of germs and at the same time would be harmless to living tissue, an enormous step forward in the art of healing would result. It would be fatal to try to cure a cold by drinking carbolic acid! Since the time of Lord Lister much research has been done and new antiseptics, many of which are obtained from coal-tar, have been found.

For a quarter of a century after Ehrlich's discovery, comparatively little progress was made in the production of drugs which would be of value in the treatment of bacterial infections. Even Fleming's original work on penicillin was set aside for a number of years. The reasons for this delay are easy to see. Firstly, at that time we had no conception of the control of a disease-producing organism, apart from poisoning it outright; and secondly, there was a curious lack of co-ordination between chemist, clinician, pharmacist and bacteriologist. It will be recalled that both Pasteur and Ehrlich were in an advantageous position as regards the subjects of their researches, *but not otherwise*, because they were chemists. These difficulties have now been remedied, and since 1931 there has been a Therapeutic Trials Committee appointed by the Medical Research Council, and new drugs can be tested clinically. Since 1941, forty new drugs of prime importance have been included in the addenda to the British Pharmacopoeia.

Sulphonamide drugs are known to everybody in Britain under such names as M. and B. 693, the test-substance number of a series of sulphonamide compounds developed by the manufacturing chemists, May and Baker. Few people, however, know anything of the variety of these compounds and their uses or limitations.

In 1932, a German chemist, Domagk, discovered prontosil, a red dyestuff (a coal-tar product), and three years

later it was used for treating bacterial infections. It had the remarkable property of killing germs in the body but of being inactive 'in the test tube'. It was soon found that prontosil was broken down chemically by the body to a simpler compound—para-aminobenzenesulphonamide or sulphanilamide, which had actually been prepared by Gelmo as long ago as 1908.

In 1909, the year after Gelmo's discovery of sulphanilamide in Vienna, Horlein and his colleagues prepared a series of dyestuffs from similar substances and reported that their compounds 'were distinguished by greater fastness in washing and milling than those of sulphonamide-free products'. These qualities were attributed to the intimate union of the protein cells of the wool and the dye, but no attempt appears to have been made to apply these preparations to the control of bacteria. Although the medicinal sulphonamides are usually colourless they must be regarded as members of the coal-tar dyestuffs group. In 1917, Jacobs and Heidelberger prepared sulphanilamide by Gelmo's method and from it they developed a further series of 'azo' dyes. In their account, they described the bactericidal properties of these substances, but unfortunately for mankind these preliminary observations were not extended.

The first clinical reports on the use of sulphonamide compounds were reported in the German medical journals in 1933 and 1934, but on February 15th of the following year there appeared in the *Deutsche Medizinische Wochenschrift*[1] Domagk's epoch-making communication, which described the effect of prontosil in controlling many germ infections of the staphylococcal and streptococcal type in mice and rabbits. After this progress became comparatively rapid.

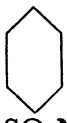
In the laboratories of May and Baker many sulphonamide compounds were examined with a view to the discovery of a substance which should not only control

[1] *German Medical Weekly.*

blood-poisoning staphylococci but also the pneumonia infections, and at the same time have little toxicity, that is, negligible general poisoning of the body system. A substance, which had been entered in the register as T. 693, was found by Dr. L. E. H. Whitby of the Bland Sutton Institute of Pathology of the Middlesex Hospital to possess these desiderata as far as animals were concerned. The full name of this compound was 2-(para-aminobenzene-sulphonamide)-pyridine or 2-sulphanilyl-aminopyridine. This became popular under the name of M. and B. 693, or sulphapyridine.

On March 18, 1938, a Norfolk farm-worker who was suffering from pneumonia was quickly cured by the drug, in spite of the fact that his case was already apparently hopeless. After this many cases of remarkable cures, which had resulted from the use of these drugs, appeared in the medical press of the world.

In spite of its name the sulphanilamide molecule is quite simple and may be represented like this:



Two hydrogen atoms in the benzene ring have been replaced respectively by an amino group NH_2 and in the para position by SO_2NH_2, a sulphonamide group which is the distinguishing factor in these chemicals.

The sulphonamides were tested widely throughout the world and up to 1940 over thirteen hundred had been examined. Their discovery was a major advance in medicine. The streptococci of blood-poisoning, the germs of pneumonia, puerperal fever, gonorrhoea, meningitis in certain forms, bacillary dysentery and many others would, under suitable circumstances, yield to treatment with these drugs.

The most important sulphonamide compounds are sulphanilamide, sulphapyridine, sulphacetamide, sulphathiazole, sulphaguanidine, succinyl-sulphathiazole, sulphadiazine and sulphadimethylpyridine.

The choice of a particular drug depends on a number of factors. The sulphonamides, unlike penicillin and some antiseptics, are not specific in their action for certain bacteria. Their difference is quantitative rather than qualitive. The more active compounds such as sulphapyridine or sulphathiazole are more useful against resistant bacteria such as those causing pneumonia. The factors which determine the choice of a particular drug concern its solubility, its rate of excretion, or whether compounds which will inhibit its effect will be formed in the body.

For instance, sulphaguanidine and succinylsulphathiazole are not readily absorbed by the intestines and are not very toxic. They are useful in such complaints as bacillary dysentery, gastro-enteritis and the form of intestinal infection so prevalent in the Near East and known as 'Gyppy-tummy'. These drugs are also invaluable when used before intestinal operations. Sulphadiazine was discovered in America at the beginning of the war. It is rapidly absorbed, slowly excreted and has very low toxicity; that is, it rarely produces nausea or other secondary effects. Sulphanilamide is good for blood-poisoning (haemolytic streptococcal infections) and kidney and bladder infections. Sulphathiazole is excellent for the treatment of pneumococcal, meningococcal and gonococcal infections, where the patient is unable to tolerate sulphapyridine.

Recently Boot's Pure Drug Co. of Nottingham has introduced a substance known as Flavazole, which is a chemical compound of diamino-acridine (pro-flavine base) and sulphathiazole. The value of the acridines or 'flavines' (yellow dyestuffs obtained from coal-tar), as antiseptics, was discovered by Browning during the 1914–1918 war, and they have never lost favour. The chemical combination of flavine and sulphonamide has produced a compound of quite extraordinary properties. This is called Flavazole. The action of sulphonamides is inhibited by dead tissue and pus and even penicillin is not effective against such organisms as Ps. pyocyaneus and proteus. Flavazole gives

excellent results either in a powder for dusting, or as a solution for the irrigation of infected wounds.

MINIMUM CONCENTRATION REQUIRED TO PREVENT GROWTH OF VARIOUS ORGANISMS AT 37° C. OVER A PERIOD OF TWENTY-FOUR HOURS GIVEN IN MILLIGRAMS OF THE DRUG IN 100 c.cs.

	Cl. welchii	*Cl. oedematiens*	*Cl. septicum*	*Staph. aureus*	*Strept. pyogenes*	*Coliform bacilli*	*Ps. pyocyaneus*	*Proteus*
Sulphathiazole	200	200	0·4	0·6	0·15–0·6	0·6–40	40	40
Proflavine	0·6	0·15	0·15	0·6–1·2	0·15	2·5–10	10–40	1·2–2·5
Flavazole	0·6	0·3	0·15	0·6	0·08	0·6–10	2·5–5	0·3–2·5
5–Amino-acridine-sulphathiazole compound	1·2	0·6	0·15	1·2	0·3	0·6	2·5–10	1·2
Marfanil	7·5	1·5	3·0	100–1000	2·5	200	7·5	1000
V 187	12·5–25	0·4	0·8	250	—	400–800	400–800	400–800
V 335	1·5	0·8	0·8	40–80	—	500–2000	250–2000	500–2000
Penicillin	0·008	0·001	0·008	0·001	0·0005	—	—	—

The enormous potency of small quantities of penicillin, compared with much larger concentrations of such excellent drugs as sulphathiazole for many types of germs, is at once apparent. The following explanations may be of value: Marfanil was a sulphonamide drug used in the German Army for local application to wounds.

V 187 and V 335 are two new synthetic dye-stuff drugs, which are not true sulphonamides, and have given excellent results in curing gas gangrene infection in animals.

Clostrodium welchii, oedematiens and septicum are present in gas gangrene infections, coliform bacilli are present in diseases of the intestines.

Ps. pyocyaneus is found in pyaemic abscesses, and proteus, which is often associated with typhus infections, affects the kidneys and abdominal organs. Streptococci are often present in sore throats, and staphylococcus in 'blood-poisoning'.

Investigations in many parts of the world seem to show that the action of sulphonamides is bacteriostatic, or in other words, they slow down the rate of growth of the bacteria, which can then be killed by the phagocytes of the body. A number of substances have been found which prevent the drugs from doing their useful work, and p-

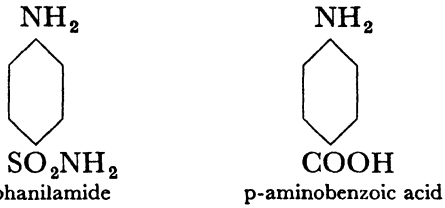
Plate XII

Harvesting Penicillium.

Plate XII *Courtesy Boot's Pure Drug Co.*

Facing page 127

aminobenzoic acid has been proved to be a notable example. The chemical structural formula for p-aminobenzoic acid is very similar to that of sulphanilamide, and this has not only suggested an explanation of the action of these drugs, but has given a clue to chemists concerning the type of substances which are likely to have an anti-bacterial action.



sulphanilamide p-aminobenzoic acid

Woods has suggested that in their growth bacteria require p-aminobenzoic acid, which is produced by an enzyme or ferment action, and that owing to their similarity of structure sulphonamides may displace the p-aminobenzoic acid and in this case the bacteria can thrive no longer. Experiments show that to overcome the effects of one part of p-aminobenzoic acid, sixteen hundred parts of sulphanilamide are required. Thus, repeated small doses of sulphonamides (for example, 'one tablet after each meal') are obviously not the correct way of administering these drugs. A relatively large concentration should be prescribed by the doctor as soon as possible. Nor should these compounds be self-administered. It is possible that with too large a dose of the wrong type of drug untoward effects would appear, and repeated small doses might cause a strain of sulphonamide-resistant germs to build up, and these could be passed on to other people with unfortunate effects.

A new approach to the study of anti-bacterial substances would be to find out what chemical growth factors are necessary for the multiplication of certain bacteria. Then in the laboratory we must find a substance of similar chemical structure which will neutralize the growth factor. Already it has been found that pantothenic acid is necessary for the growth of those streptococci which produce

haemolysis (blood-poisoning caused by the lysis or destruction of the red blood cells). Chemists have prepared a substance called pantoyltaurine which is similar in chemical structure to pantothenic acid. The former substance saved the lives of animals which had been infected with a particularly virulent strain of streptococci. It may be that pantoyltaurine has no permanent value as a drug, but at least it has suggested a new approach to a very important problem.

In 1929, at St. Mary's Hospital, Paddington, Professor Alexander Fleming was making certain cultures or colonies of germs by growing them in a specially prepared jelly in a shallow glass dish or culture plate. The germs are allowed to develop in the warmth of an incubator and can then be seen as colonies on the plate. By accident a spore (seed) of a mould had found its way into the laboratory from the murky atmosphere of London, and had settled on one of Fleming's culture plates. When he examined it later he found that a part of his 'jelly' had grown greenish grey 'whiskers'. Perhaps if we had been in his place we should have regarded the process as a failure and destroyed or rejected the plate contaminated with the mould, just as we might scrape from the top of a jar of jam or a bottle of preserved fruit the brush-like green-grey or green-blue mould and reject it. Fleming showed more of the scientific spirit, for he noticed that where the mould had grown the germs had not multiplied, and further, that even at some distance from the unwanted contamination the germs appeared to have dissolved away. Here was the starting point of a discovery which was to become immensely important to mankind, though even Fleming did not realize this at the time. He reported his discovery in the *British Journal of Experimental Pathology*, 1929, 10, pages 226–236, with the title, 'On the Anti-bacterial Action of Extracts of Penicillin,[1] with special reference to their use

[1] The mould penicillium is so called from the Latin penicillus, a painter's brush, from an obvious resemblance. Its origin is thus the same as that of the English word pencil.

in the isolation of B. influenzae.'[1] It may be of interest to give a quotation from the original paper.

'While working with Staphylococcus variants, a number of culture plates were set aside on the laboratory bench and examined from time to time. In the examination these plates were necessarily exposed to the air and became contaminated with various micro-organisms. It was noticed that around a large colony of a contamination mould the staphylococcus colonies became transparent and were obviously undergoing lysis. Subcultures of this mould were made and experiments conducted with a view to ascertaining something of the properties of the bacteriolytic substances which had evidently been formed in the mould culture and which had diffused into the surrounding medium. It was found that broth in which the mould had been grown at room temperature for one or two weeks had acquired marked inhibitory bactericidal and bacteriolytic properties to many of the more common pathogenic bacteria.[2]

'The colony (of the penicillium mould) appears as a white fluffy mass which rapidly increases in size and after a few days sporulates,[3] the centre becoming dark green and later in old cultures almost black. In four or five days a bright yellow colour is produced which diffuses into the medium. . . .

'In broth the mould grows on the surface as a white fluffy growth changing in a few days to a dark green felted mass. The broth becomes bright yellow.'

Many other moulds, including eight other strains of penicillin were tested, but only one at that time was found to have anti-bacterial properties. It was at first thought to be penicillium rubrum, but was later seen to be penicillium notatum.

Fleming pursued his researches to the extent of finding the effect of heat and filtration on the new substance and

[1] B. influenzae—the germs of influenza.
[2] Pathogenic bacteria are those that produce disease.
[3] Produces spores or seeds.

its rate of development under different conditions. He noted that it has a negligible toxicity to animals and that it did not upset the functions of the white 'guard' cells or leucocytes of the body. He noticed that staphylococci, streptococci and pneumococci are readily affected by it, that it had an immediate action on the germs of diphtheria and anthrax, but had little effect on the organisms of the colon-typhoid group.

In 1932, Fleming suggested that penicillin would be useful for the isolation of certain types of bacteria from those which were sensitive to it, that it could be used for treating infections caused by certain sensitive organisms and for demonstrating the effects of certain inhibitors of bacterial action. Until the last war, there was little interest in the application of Fleming's work to the art and science of healing, but it must be remembered that no proper technique for the extraction of penicillin had been developed, nor had we a proper conception of anti-bacterial effects other than those of germicides at that time.

In 1940, a team of workers under Professor (now Sir) Howard Florey at the Sir William Dunn School of Pathology at Oxford University, succeeded in extending the work of Fleming, finding a suitable culture medium and suggesting a means of extracting the penicillin in a fairly pure state. Their results were published in the *Lancet*, August, 1940, over the names of Chain, Florey, Gardner, Heatley, Jennings, Orr-Ewing and Sanders. Even with a crude preparation containing not much more than 1 per cent of penicillin the anti-bacterial effect was so great, and its harmful effect on the tissues so small, that it was obvious that here was a drug with a wide range of uses and of potency undreamed.

At first the Oxford workers were only able to prepare a brown powder containing 1 per cent to 2 per cent of penicillin, but after a time they improved their methods until they were able to obtain a yellow substance containing 5 per cent of the drug.

Plate XIII

Freeze drying of penicillin salt under reduced pressure. Notice the vacuum pump on the right.

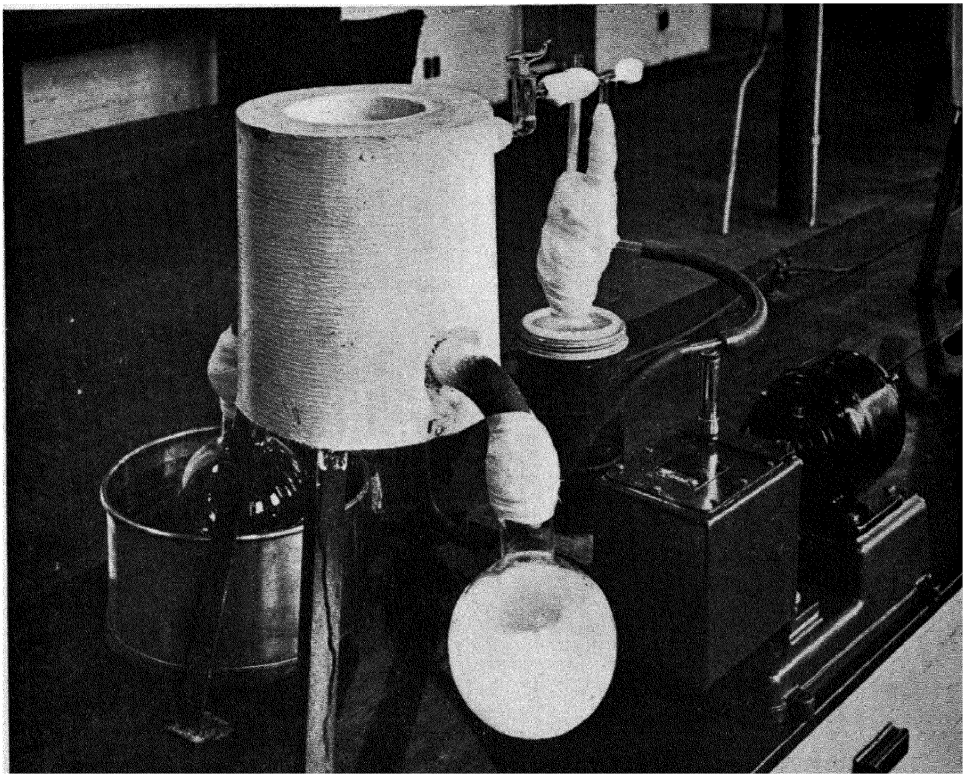


Plate XIII

Courtesy ***Boot's Pure Drug*** *Co.*

Penicillin may be manufactured by (*a*) surface culture, (*b*) submerged or mass culture favoured in the U.S.A. and (*c*) on bran. The last method is comparatively very productive of the drug, but it is difficult to make the medium aseptic and the penicillin growth is easily displaced by contaminating organisms.

The following is a brief description of the manufacture of penicillin at an English factory, which has been adapted from the official account of the process.

It is by collecting the ripe spores and dispersing them on to a nutrient medium kept at the best temperature that successive generations of mould can be grown. The particular strains of the mould, which are used in the commercial manufacture of penicillin, have been carefully chosen because of their penicillin-producing properties, and elaborate precautions are taken to maintain these strains constant and free from contamination by inferior variants.

The operations necessary for the commercial production of penicillin may be conveniently divided into seven groups:

Preparation of the nutrient growing medium and filling into bottles.

Bottle sterilization and cooling.

Inoculation and incubation.

Harvesting and bottle washing.

Isolation of penicillin from harvested liquor.

Preparation of dry sterile calcium salt of penicillin.

Pharmaceutical presentation.

The nutrient medium is prepared by dissolving suitable quantities of lactose and glucose in water, adding a proportion of cornstoop liquor, a by-product of the starch industry, and certain mineral salts, including sodium nitrate, potassium chloride, magnesium and ferrous sulphates and potassium biphosphate. This medium, containing in suspension certain insoluble substances derived from the cornstoop liquor, is fed to mechanical bottle-filling machines which discharge 250 c.cs. of medium into eight clean quart milk bottles simultaneously. The bottles

are placed in crates, each holding twelve, and then moved on roller conveyors to be plugged with cotton wool and passed to the sterilizers. The sterilizers are large steel pressure chambers with a door at each end and they each hold 960 bottles in eighty crates. The bottles, complete with cotton wool plugs, are heated by means of live steam which is gradually raised in pressure to 10 lb. sq. inch, thus bringing the temperature to 238–240° F. These conditions are maintained for thirty minutes and suffice to kill all bacteria, spores and moulds which may have been present in the medium, bottle and cotton wool. The pressure is then carefully released and the crates are removed to cooling areas where they are sheeted down with cloths impregnated with a disinfectant and allowed to cool for about fifteen hours.

The bottles are then placed on trucks and taken to the incubators where they are stacked and made ready for inoculation with the spores of *penicillium notatum*. The four incubators are large rooms with heat insulated walls and ceiling, and are maintained at a temperature of 70–72° F. by an elaborate system of air ducts supplied from the large air conditioning plant situated outside the incubator. Here air is taken from the outside atmosphere through large banks of oiled glass filters which remove dust, bacteria and moulds from the air. The air is then cooled and washed between powerful water jets and finally dried and automatically adjusted to the controlled temperature range below 70° F. This cooling is necessary as heat is given out during the growth of the mould. The actual temperature inside the bottles is 75–77° F., which is the best for the production of penicillin.

The cooled bottles, still in crates, are transported into the incubators while still observing precautions against carrying bacterial contamination in with them. All operatives must pass through a special air-lock and put on clean coats and overshoes. The bottles are stacked on their sides on racks about ten feet high and each incubator holds

180,000 bottles. Each day 70,000 bottles are brought in and stacked and a similar number taken out. 100 litres of the liquid yield about five to ten grams of active material.

The next operation, that of inoculating the bottles with special spores, is carried out only after the whole area has been thoroughly sprayed with antiseptic and full operation theatre technique is employed. The girls are clothed in sterile coats and wear face masks, rubber gloves and special shoes. Containers of an aqueous suspension of spores, containing about 5,000,000 spores per cubic centimetre, are connected to spray guns operated by sterile compressed air. Each milk bottle receives about ½ c.c. of the suspension, introduced by a spray gun, after momentarily removing the sterile cotton wool plug. Regular bacterial examination of the air and racks in the incubator room, and in fact of the whole factory, is carried out by skilled bacteriologists. The spores which are deposited on the surface of the sterile medium in the bottles find conditions exactly right for development into the vegetative phase of the life cycle of the mould, and after thirty-six to forty hours visible evidence can be seen by the appearance of small white colonies on the surface. During the next few days these colonies expand until the whole surface is covered with mould, now described as a 'mycolial felt'. This presents a corrugated surface which, after seven days from inoculation, begins to show typical dove-grey spores on its upper side. During this growth period the sugars in the medium have been used up, partly in building up the felt itself and partly oxidized into carbon dioxide and other products by the respiration of the mould, and this lack of food speeds on the sporulation phase. Spores will remain dormant for years if conditions for growth are unfavourable but rapidly develop when they are suitable. The changes in the colour of the mould are accompanied by alterations in acidity (or pH) of the medium.[1] Penicillin

[1] pH is a measure of the acidity or alkalinity of a solution. It is determined by an electrical method which finds the hydrogen ion concentration.

is formed towards the end of the growth when the pH is seven, that is, the neutral point.

The colour of the liquid under the mycolial felt gradually assumes a yellow colour due to the production of pigments, but at the same time it contains penicillin and other metabolism products.

At this stage the bottles are removed and emptied, or, as it is usually described, harvested. The felt is removed and discarded, the liquid containing the penicillin is pumped to the processing room for extraction. The felt contains protein, carbohydrates and fats and experiments are in progress to evaluate its worth as an animal feeding stuff. Until this is proved it is burnt to prevent it from going 'mouldy' or decomposing owing to bacterial growth.

The dirty bottles are thoroughly washed in high pressure jet washing machines and come out clean and ready to pass to the medium filling machines and receive their charge of nutrient medium and thus repeat the cycle all over again.

The penicillin-containing liquid, is pumped into enamelled cast-iron vessels and rapidly cooled to just above freezing point. This is achieved by passing cold brine, obtained from a large ammonia refrigeration plant installed in the factory, around the jacket of the vessel. Throughout the processing stages the penicillin solutions must be kept cool to prevent decomposition. The cooled liquid is stirred with a little diatomaceous earth—Kieselguhr—and pumped through a clarifying filter press. The clear liquid is then stirred with activated charcoal which abstracts the penicillin, pigments and some of the other products, and after filtration, the liquid now stripped of its penicillin, is run to waste.

The penicillin absorbed on the charcoal is then removed by the action of a mixture of acetone and water, and then by adjusting the acidity of this solution and stirring rapidly with chloroform the penicillin passes into this latter solvent. The heavy chloroform phase is separated from the less

dense aqueous-acetone by means of a high speed centrifugal machine similar to a cream separator. The process is repeated and each time the penicillin is transferred from one solvent to another its purity and concentration is increased by a suitable choice of solvent and the quantities used. A 250-fold increase in concentration is achieved by the time the last solution of the calcium salt of penicillin in water is reached.

As stated earlier, penicillin is very sensitive to heat and therefore the dry product cannot be prepared from the solution by the usual method of evaporation. It can, however, be achieved by 'freeze drying'. The solution of calcium salt is rendered sterile by filtration through a bacteria-retaining pad and is introduced under aseptic conditions into a glass container and then frozen hard by cooling to $-70°$ F. in a mixture of solid carbon dioxide and alcohol. The container with its cake of ice is then attached to a condenser cooled to $-70°$ C. and the air is exhausted down to the very low pressure of about 0·1 mm. of mercury, and under these conditions the ice gradually sublimes and is collected on the condenser. A small amount of heat is applied to speed this process, but the ice cake containing the penicillin is never allowed to melt. After several hours the ice has totally disappeared and leaves a yellow porous solid, still retaining the shape of the ice cake. This is the dry penicillin calcium salt.

The material is then collected under sterile conditions and submitted for analysis, testing by the bacteriologist for the absence of bacteria and estimating its bacteriocidal potency, and by the pharmacologist for absence of toxic properties.

Pure penicillin is colourless and the yellow colour of commercial samples is due to pigments which accompany it through the extraction stages. The 'strength' or activity of these samples is determined by comparing their efficiency, against the standard sample of penicillin, in preventing the growth of certain test bacteria under standard conditions in the laboratory.

Penicillin calcium salt is issued for use either in the form of sterile tablets or powder for making solutions for injection or as a dusting powder for application to open wound surfaces. In this case it is often diluted with sulphathiazole which also possesses bacteriocidal properties. These methods of using penicillin restrict its application and research is progressing on its successful incorporation into pastilles, ointments and creams.

The output of the Nottingham penicillin factory, which employed about 250 people and handled 60,000 quart bottles of culture medium a day, was originally about 20 lb. of penicillin a week. This represented a quarter of a million doses. Certain American factories work on a much larger scale.

The method here described is not now used. It was a marvel of war-time improvization and its results saved countless lives and assisted in the restoration of thousands to complete health. The process was wasteful in its use of the rich culture medium and it has been displaced by the more economical and productive mass culture methods the difficulties attending which have been surmounted.

Penicillin must be regarded as a drug which, in spite of some limitations, is nearly perfect. It is practically without any toxic effect on the tissues and its use in the treatment of war wounds has saved many thousands of lives and much permanent disability. A number of organisms are insusceptible to penicillin and these include certain colityphoid, dysentery diseases, tuberculosis and influenza. Proteus vulgaris and Ps. pyocyaneus are not affected by the drug. Penicillin should not be given by the mouth as it is destroyed by the acids of the stomach, but penicillin pastilles have given good results in throat infections, and without doubt the near future will bring penicillin tooth-pastes, ointments and creams. Powders containing penicillin and sulphonamides have already proved to be of great use to medical men.

Penicillin is an acid of low molecular weight and con-

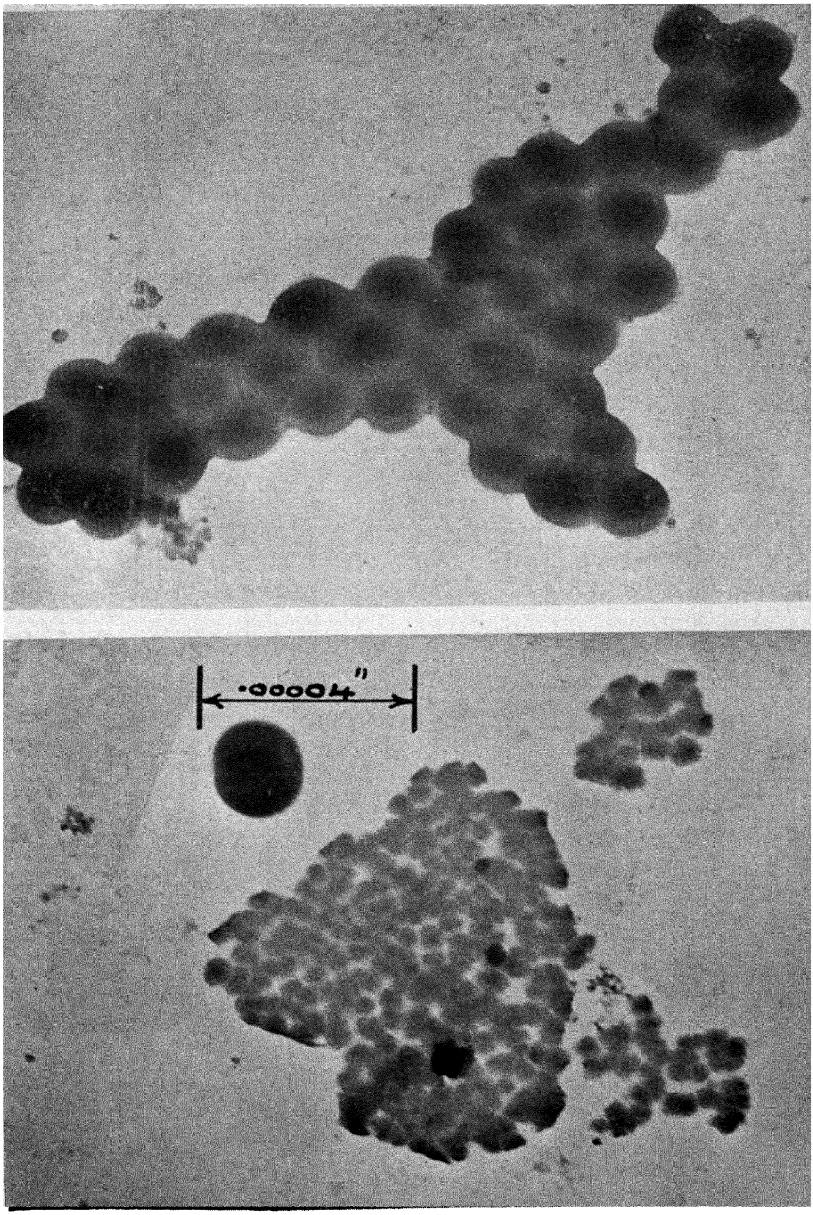


Plate XIV *Courtesy R.C.A.*

The first photographs to reveal the effect of penicillin on disease causing bacteria. These micrographs show staphylococcus aureus bacteria magnified 38,000 times with the electron microscope. The bacteria are shown as a grape-like cluster before penicillin is introduced (top) and after penicillin has contacted the infectious germs (bottom).

stant research is continuing in an attempt to synthesize it. When eventually this is achieved, it is by no means certain that the synthetic method will be cheaper or more convenient than the present processes.

It has been necessary to develop a method of estimating the potency of a sample of penicillin. Recently, penicillin has been further purified and obtained in crystalline form. Whereas British commercial penicillin has an activity of 200–400 units per milligram, the pure substance has a value of 1,650 units. International agreement on a world-wide uniform standard has been reached by the Health Committee of the League of Nations. The International unit is approximately the same as the Oxford unit. The method of estimating potency used by Boot's Pure Drug Co. is described as follows. 'In the cylinder plates test, small porcelain cylinders are placed in the surface of an agar culture medium which has been heavily sown with sensitive organism such as *staphylococcus aureus*. Penicillin solution and a solution of standard penicillin are placed in the cylinders and the solutions diffuse into the agar. After incubation at 37° C. for eighteen hours, the diameter of the circular zone caused by the bacterial inhibition is measured. This bears a relationship to the amount of penicillin present in the sample and in the standard preparation.'

Research on the possibilities of producing other useful drugs from fungi is continuing. Patulin, sometimes called claviformin, clavacin or clavatin, can be obtained from at least four different species of fungi. Considerable publicity was given to reports that it was effective against the common cold, but extensive investigations have shown that it had no specific effect against a complaint which costs us 40,000,000 days of work a year in our relatively small industrial population. A substance called 'notatin' was isolated from penicillium notatum when this was grown on a special medium. Against germs it is even more potent than penicillin, but it is also highly poisonous and thus does not appear to have any clinical value.

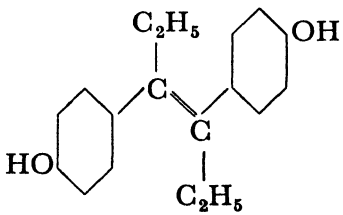
As we have already noted, penicillin will not attack the organisms which produce tuberculosis, influenzal meningitis and internal infections caused by typhoid, proteus, or the germs which often give trouble in the colon and other abdominal organs.

It is too early to know exactly how useful the new drug streptomycin will prove in dealing with bacteria which are not touched by penicillin, but the results are promising; and it may be that other substances of similar origin will also prove to be efficacious. Streptomycin is produced from certain strains of *Actinomyces griseus*, which is found abundantly in soils, silt, and dust, and is closely related to the bacteria of fungi. To make the drug, a suitable strain is selected and 'master spores' are freeze-dried in small tubes, in which state they may be preserved for months without deterioration. The process has some similarity to that used for penicillin. The *Actinomyces griseus* is grown in a nutrient liquid through which air is passed to supply oxygen for the growing organism. After fourteen days the liquid is filtered off, acidified and treated with charcoal to remove impurities. The solution is then neutralized and again treated with charcoal, which takes up the streptomycin. The drug can then be dissolved away from the charcoal with acidified alcohol. Thereafter, it is purified by various processes of solution and precipitation. The method of administering streptomycin has not been fully worked out for all the diseases where it may prove useful, but the main point to bear in mind is that an effective concentration of the drug must be maintained in the tissues for as long as possible. Unlike penicillin, streptomycin is quite stable and is not rendered inactive in the digestive tract and can be taken in small quantities in water or milk.

It has been known for a number of decades that certain small glands found in various parts of the body, and known as endocrine, or erroneously, ductless glands, secreted small quantities of chemical substances which exerted enormous effects on the body and mind. These secretions, which were

called 'hormones' (or 'urgers'), are carried by the blood and control many bodily processes. Personality and temperament are largely determined by the ductless gland 'pattern' and although it is foolish to predict, as an American medical man did twenty years ago, that endocrinology would soon replace psychology, the sum total effect of the glandular secretions on the individual 'body-mind' is exceedingly important. The secretions of various parts of the pituitary body in the brain not only have a controlling effect on the size and shape of the skeleton, but various metabolistic[1] changes which were formerly thought to be due to actions occurring in the abdomen are now seen to be controlled by the secretions of the pituitary body. Researches continue to find the best methods of extracting and using the active principles of the ductless glands and many diseases can be controlled by the use of such extracts.

For half a century it has been known that substances secreted by the reproductive organs play a very important role in the control of bodily processes. In 1933, Professor Dodds produced in the laboratory a substance which in large doses had properties similar to the oestrins or the internal secretions associated with the reproductive organs of the female, and by 1938 a hundred and twenty-six of such preparations had been made and tested. At the end of that year Dodds and Robinson had produced a substance with the chemical formula:



which was white and crystalline, easily soluble in alcohol and had a melting point of 170° C. It was found to be at least two and a half times as active as the natural 'oestrin'.

[1] Metabolism—chemical changes which go on in living matter.

This substance, known as diethylstilboestrol or stilboestrol, was followed in 1940 by hexoestrol which was less toxic and in 1944 dienoestrol was introduced. This was an even more active and less toxic preparation than the two previous substances. Apart from the use of these drugs in diseases and derangements of the reproductive system, they have a remarkable effect in controlling carcinoma, a form of cancer, of the prostate gland of males. Used at the correct time they produce an increase and extension of the milk yield and, in many cases, of the quality of milk in cattle. It must be remembered, however, that the cow can only convert to milk the foods which contain the necessary chemical constituents, and the artificial forcing of animals to produce a yield of a substance rich in food value may lead to the weakening and disease of the body of the animal unless the process is carefully controlled.

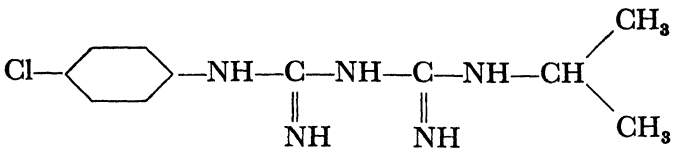
The production of synthetic oestrins and investigations concerning their effects are only one example of a great field of useful bio-chemical research. Improvements in the methods of extracting insulin, which is used for the treatment of diabetes and for certain mental complaints (when administered in such doses that a controlled prolonged state of coma is produced), have so reduced the costs of production that insulin is now no more expensive than it was before the war. One of the defects of ordinary insulin was that it could only be injected at intervals and it was soon absorbed, whereas that which was secreted by the pancreas glands in normal persons was continuous in its action throughout the day and night.

Attempts which have been made to prolong the action of insulin have met with much success. In 1936, Hagedorn combined insulin with a protein obtained from the roe of the salmon and called the compound protamine insulin; and later, Scott and Fisher of Toronto found that if a little zinc is added to protamine insulin a very prolonged action is obtained. In America, attempts to improve the drug have resulted in the production of globin insulin. To make

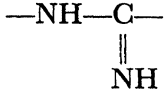
this, ox globin, which is obtained from the red blood cells of the ox by removing the colouring matter, is combined with the insulin. These new substances enable diabetes to be controlled much more easily.

When the Japanese invaded the Dutch East Indies they captured the bulk of the world's supply of cinchona, the bark from which the useful drug quinine is made. Malaria was a more deadly enemy than the Japanese, and it was fortunate that in 1941 the United States had a stock of six million ounces of quinine sulphate. The other Allies had negligible stocks. Attempts made in the Latin American countries to increase cinchona production could not succeed in producing more than a tiny fraction of the amount of the drug required as a specific against the scourge of malaria. During the war, world deaths from malaria have been placed at six million per year, which is probably a 50 per cent increase on pre-war figures. The problem of quinine shortage was a very grave one and here again substances synthesized from coal-tar sources have proved to be the solution. A perfect anti-malarial substance should kill the malarial parasite at all stages. It is not only necessary to destroy the asexual forms of the organism in the blood and cure the patient of the attack of fever. It is also essential to eliminate the gametocytes or sexual forms of the parasite, which hand on the disease by infecting anopheline mosquitoes which in their turn transfer it to human hosts. The synthetic drug atebrine or mepacrine is invaluable in the first (schizont) stage of malaria and plasmoquine is toxic to the gametocytes, which in many cases are resistant to natural quinine. The complementary use of the two synthetic drugs may not only act as a substitute for quinine treatment but point the way to a great improvement on it. Synthetic quinine substitutes are at present rather expensive. Towards the end of 1945 tests were made in Liverpool of a new drug made by I.C.I. This is known as paludrine and is ten times more potent than quinine as an anti-malarial drug.

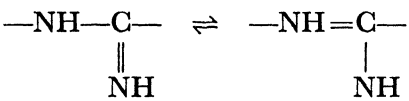
This was discovered by Rose, Curd and Davey, and has the formula—



which is a chemical type not met with before in chemotherapy. The group



which occurs in the formula is known as an amidine group and shows the remarkable property that the outer (or valency) electrons of the carbon can move from one nitrogen atom to the other and back again with a consequent displacement of electric charge, thus—



This is known as a resonance system and a more complex type occurs in the mepacrine molecule. It is known that such a resonance system influences the properties of a drug but its exact biological significance still awaits further investigation.

Another remarkable substance is folic acid which is used in the treatment of pernicious anaemia, for which purpose it is superior to extracts of liver. Formerly pernicious anaemia was quickly fatal, for the red blood cells which carry oxygen to our tissues and keep us alive are destroyed while still in an immature state. Folic acid, which is really a mixture of five organic acids, was first extracted from fresh green leaves, then from liver and yeast, and finally it can be made synthetically, though not all its constituents use benzene as a basis.

Enough has been said to show how hopeful is the outlook in this matter of researching for chemical substances which will destroy disease-producing organisms and arrest degenerative changes.

NEW PLANTS FOR OLD: PLANT GENETICS

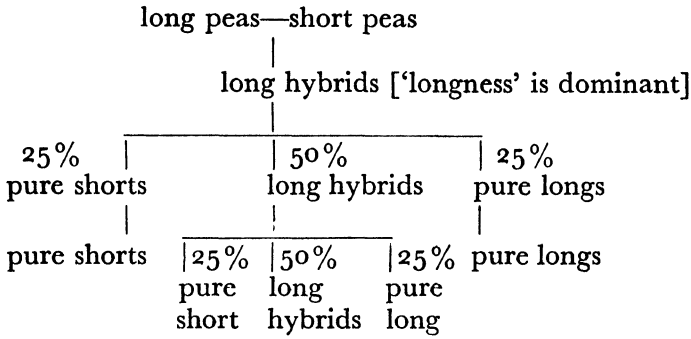
AT the very beginning of the twentieth century, there took place one of the most important events not only in the history of science, but also in the history of the civilization of man. This was the rediscovery of the laws of Mendel, the importance of whose work was appreciated simultaneously by the biologists Correns, Tschermak and De Vries, and almost immediately found application to the improvement of plants and animals in the hands of Biffen, Nilsson-Ehle and others.

Gregor Mendel (1822–1884), an abbot living at Königskloster (Brünn) in Austro Silesia, experimented with plants such as peas to find the laws which govern inheritance, and he published his results in 1866. These were not rediscovered for thirty-five years. The subsequent study of genetics, or the laws of breeding, was founded on Mendel's patient and humble work. The simple arithmetical or quantitative aspects of Mendel's work are well known, and although Mendel could not have known it, they follow from subsequent discoveries of factors in the cells which combine to initiate reproduction both in plants and animals. In order to make clear to the reader the nature of more recent work, it may be useful to recall the simple facts of Mendelism.

Mendel crossed tall peas with short peas by transferring pollen from the flowers of one to those of the other. He used 'pure' strains of each type of pea, by using seeds which had come from plants which had maintained their long or short characteristics for a number of previous generations. All the peas of the generation caused by his first cross were tall. The peas of this generation were mated together and he found that when the seeds were planted, three-quarters of the peas were tall and a quarter were short. The short peas bred true, and continued in sub-

sequent generations to produce only short peas. With regard to the tall peas, one-third of these bred true as tall peas, and two-thirds were 'hybrids', and when planted these latter produced pure shorts, hybrid talls and pure talls in the ratio 1:2:1.

This may be expressed in diagrammatic form as follows—



It should be noticed that the ratio 1:2:1 is that of the probability of throwing two heads, one head and one tail, and two tails respectively when two coins are tossed together a sufficiently large number of times. The connection between this and Mendel's law is obvious when we consider the heredity factors of the cells which combine in breeding. This tiny example will serve to show the value of the mathematical methods of statistics and probability, when they are applied to the problems of combining these heredity factors. Researches by T. H. Morgan into the structure of cells which are responsible for reproduction, made it clear that the dark spot or nucleus of each cell contained a number of thread-like bodies which readily took up certain dyes, and were called chromosomes or 'colour-bodies'. These play an important part in transmitting characters and determining the nature of an offspring. When two germ cells unite in reproduction, the fertilized female cell or ovum will contain the sum of the chromosomes of the parents. When the cell is going to divide after fertilization two spindle centres appear, one on each side of the

cell. Much activity is then seen in the nucleus, and a number of chromosomes arrange themselves in a circle at the middle of the cell with tiny threads connecting each chromosome with the spindle point. After a few minutes each chromosome splits down the middle and the parts are pulled to opposite sides of the cell, a process which takes from five to ten minutes. After further activity the cell itself divides and forms two cells, and this takes about half an hour.

The body or somatic cells contain chromosomes from both parents but in the reproductive or germ cells the chromosomes lie together in pairs and unite, and the total number is therefore halved. Sutton pointed out that this phenomenon was the cellular counterpart of Mendel's findings.

The garden pea has seven chromosomes, the mouse twenty, and man apparently twenty-four, but even with twenty over a million types of germ cell are possible. In order to explain the existence of all the factors which are transmitted from parents to offspring, it is necessary to suppose that the chromosomes contain even smaller bodies, called genes, which are arranged in particular patterns and from which arise the characters which are transmissible. The idea of the existence of genes is consistent with what we know about heredity in plants and animals. It is well known that certain hereditary factors are sex linked, that is to say, that although they may be carried in the reproductive cells of both sexes, they will only show in the bodies of one of the sexes. Bleeder's disease and colour blindness are handed on through the female, but they only appear in the male. The genes responsible for these conditions are linked to the chromosome which carries the factor determining the 'maleness' of the organism. This principle is applied to the breeding of chickens. It is often necessary for the farmer to distinguish the sexes of day-old chicks, and this was difficult or impossible with normal examination, except apparently to a few Japanese.

Sex linkage has made the matter easy. If a golden male, such as a Rhode Island Red, is crossed with a Light Sussex silver hen the male chicks show a white or cream plumage and take after their mother, whereas the female chicks show the red buff of their father. Other examples occur between Brown Leghorn cocks and Light Sussex hens, and between the Cambridge Legbar and the Sussex.

Chromosomes have been likened to a necklace, and the genes are then thought of as the beads. Chromosomes have the power of splitting down the middle in the process of cell division, so that each half becomes a new chromosome with a full complement of genes. There is thus a tendency for groups of characteristics to be transmitted together to the next generation. Sometimes the chromosomes which lie side by side during the formation of male and female reproduction cells become entangled, and when they separate it sometimes happens that a part of one with its appropriate gene content has exchanged places with another. This produces a mutation.

SUGAR BEET

FIG. 21. By careful selection for nearly a century the fine plant on the left has been developed from the wild beet on the right.

It readily follows from Mendel's laws that, in some cases, by repeated self-fertilization, careful selection and segregation of plants bearing desirable features, a pure line, containing all the wished-for characters, can be achieved. In a century, by the method of careful selection, sugar beet has been made to increase its sugar content from 9 per cent to nearly 20 per cent and to produce larger and finer roots.

The importance of the sugar beet plant needs little stressing. In England, the amount of beet sugar produced has been equivalent to the domestic sugar ration of the whole country during the period of the war. Not only do the leaves of the plant combine the carbon from the carbon dioxide of the air with the water of the soil to synthesize sugar, but the tops and leaves of the beet, together with the waste products of the extraction process, make admirable feeding material for cattle, and the molasses when fermented yields alcohol, the basis of many useful synthetic chemicals. Thus, simple selection throughout the years has had an enormous effect on our supply of sugar, milk, beef, mutton and wool.

This method of single plant selection in which plants with desired qualities were used for propagation has had many other applications. In Ireland, the shortage of the imported Russian seeds gave a great stimulus to the selection of flax, and the resulting Stormont Gossamer and Cirrus were excellent lines. During the recent war, linseed has become a popular crop as it could be grown on newly-ploughed land which was infected with wire worm. The Egyptian cotton-growing industry would probably have failed completely but for the variety known as U4, selected and developed by Fahmy in 1931, and resistant to the jassid insect. This new strain was produced from a plant which stood out from the others as a clean, healthy growth, while the rest were heavily infected.

It is well known that the wild forms of such plants as the pea, lentil or vetch contain a poison which at once removes their value as a food-stuff for animals which would otherwise be high. No variety of the lupin which was free from this alkaloid poison was known, but in view of the fact that cultivated peas and beans were so useful, it was thought that an extensive search might reveal one and provide an easily grown 'body-building' food for cattle. In 1931, Sengbusch succeeded in isolating strains with very little poison, but the work was kept secret. The

Russian botanists took up the search, and moreover developed a technique whereby the poison content of thousands of plants could be examined every week. So rare were the desired forms that in the case of lupin angustifolius, only one out of 31,591 plants was free from poison. Further, sweet forms of the lupin were later found in the Western Mediterranean regions. The sweet lupins breed true, and now that they have been multiplied, they provide a rich source of protein for feeding stock, and the green seeds when cooked make a new green vegetable which is an excellent change from the cooking pea. Breeding by selection within a single species, is also applied to animals. Long-legged sheep in America gave much trouble by constantly escaping from their pens. By continuously breeding from any short-legged specimens which appeared, at last was produced a whole flock of short-legged sheep which were easily penned. Other and more important factors have also been developed in both animals and plants.

One of the simplest, yet most important developments in plant breeding was due to the work of N. I. Vavilov and his colleagues of the Lenin Academy of Agricultural Science. Expeditions to many parts of the world were undertaken to find the original homes of various plants, to collect as many varieties of each in the wild or cultivated state and to use much of this material for the purpose of improving existing varieties or propagating new types in Russia. Incidentally, the Russians discovered the original site of the 'Garden of Eden' in the Persian jungle, and found that it contained a great wealth of fruit trees in the wild state. Each plant was studied and classified, not only from the botanical angle, but with respect to its hereditary factors and its cell structure. These useful geographical studies are also helped by a large-scale correspondence with botanists and plant breeders in all parts of the world. Here was a real attempt to put a subject, which is important not only from the botanical angle but also from that

of man's food and well-being, on a systematic basis. Hitherto, only local genetical material had been drawn upon, private breeders working with empirical methods had kept their secrets, and the 'changes had been rung' on the same breeding material. Russia offered immense opportunities. It occupies a sixth of the world's land surface, and from the north to the south it stretches from the bleak coldness of the Arctic to the warmth of the Mediterranean countries. Vavilov found that cultivated plants usually showed the same geographical type of distribution as the wild variety. Each type of plant seemed to grow with great profusion of variety in a particular centre. It was as though this was the cradle of the plant, and that nature was still experimenting with it in a relatively small zone. The very existence of certain types of plants had hardly been suspected outside their particular localities until the Soviet expeditions found them. For instance, the 'home' of wheat was found in Abyssinia, and the discovery of so many forms of the hard wheats during the expeditions of 1926 and 1927 completely altered our conception of the genetical nature of this important plant. All possible varieties of grain size, colour, protein and starch content, size of ear and glume, disease resistance, keeping, threshing, milling and baking qualities, and many other factors were found here in altitudes between 8,000 and 9,000 feet.

The great number of new 'genes' thus discovered by the Russians enabled them to solve many of their wheat-breeding problems. They found that the genetical material was even greater than at first sight appeared, for many of the characteristics only became apparent by crossing the Abyssinian varieties with recessive forms. The soft wheats were found to have their centre of diversity in Afghanistan, and the oats in North-West Spain and the Pyrenees. Again, Abyssinia was the home of the barleys, and in the last decade Orlov has found one hundred and twenty botanical varieties, of which only three were of wide distribution. Thus, he obtained all the raw material for the breeding

of barleys which should have a high yield, be awnless, resistant to disease and drought, adaptable to extreme conditions and produce excellent malt and straw.

The centres of variety of fruits have not only been found in the Persian 'Garden of Eden', but also in the mountains of Central Asia and the Caucasus. Whole forests consisting entirely of many varieties of plum in a wild or semi-cultivated form were found. Michurin specialized in the breeding of fruits and it is largely due to him that Russia has a greater number of fruits, some of which are quite unknown in Britain, than are to be found in the rest of the world. Many square miles of cold, barren and bleak North Russia have been turned into orchards owing to his work. Hundreds of new types of vine, peach, apricot, apple, pear, cherry, plum and all manner of nuts and fruit have been developed. The powers of resistance, the freedom from disease and the quality and size of the fruit are in many cases extraordinary. It is claimed by Kovalev that the new apricots will survive with temperature conditions of 72° Fahrenheit below freezing point. Entirely new fruits have been made by cross-breeding. A mountain ash with large, sweet, frost-resistant berries which make excellent preserves, an eatable honey-suckle, soft fruits and apples which are resistant to all the diseases so well known to the British gardener, now flourish in Russia. There seem to be eight chief centres of diversity for cultivated plants throughout the world, and there is still much opportunity to study and combine the wealth of breeding material which they yield. This will enable the breeders to produce and multiply plants with exactly the qualities which are needed and which will grow under local conditions.

The story of the improvement of the potato is an interesting example of Russian methods. For more than three and a half centuries in Europe all attempts at improving the potato had taken the form of selection and crossing in a single species (*solanum tuberosum*). For a long time

tradition had it that the potato was introduced into England by Sir Walter Raleigh, who brought it from Virginia. This is not true, and it is probable that a South American potato was included in a collection of plants sent from Virginia, and that Raleigh grew it on his Irish estate at the end of the sixteenth century. Before 1930 no attempt had been made to introduce 'new blood' into the potato, and all new varieties were produced from year to year by ringing the changes on the same set of genes present in the original species. A time was not far distant when new combinations of the old set of characters would be played out and no further improvement would be possible. Little real progress had been made since 1900. In the words of S. M. Bukasov, the chief potato expert of the Institute of Plant Industry at Leningrad: 'Potato breeding was stewing in its own juice, using for the introduction of new varieties always the same old parents in innumerable combinations. A cul-de-sac had been reached, with many problems still unsolved.' Now the potato is a most valuable article of diet, it is rich in mineral constituents and contains proteins and vitamins B and C. It is not a complete food in itself, but it still goes far to the solution of many problems of finding adequate diet for large masses of people.

Accordingly, expeditions on three successive years were sent to America to find the home of the potato. The countries visited included Mexico, Guatemala and Colombia and Peru, Bolivia, Ecuador and Argentina. Over a thousand different specimens were taken back to Leningrad. The results of the Russian researches seemed to show that the original home of the European potato was Chile and the neighbouring island of Chiloe. Besides this investigation to find new kinds of potato the Soviet botanists went into regions where Europeans had never penetrated, and they were rewarded with material from the cradle of the potato, which contained genetical characteristics that could be used for the improvement of this

useful vegetable. Not only were the potatoes of the Andes found to be entirely different from the cultivated European potato, but the conditions of environment were also quite unlike those found nearer home. Potatoes were found growing from the latitude 40° South to the Tropic of Cancer, and from the sea level to altitudes of 13,000 feet in the Cordilleras. At least fifteen separate species were investigated, and examination showed that they could be arranged in groups with 24, 36, 48 and 60 chromosomes. Many other wild species were obtained, and it was found impossible to distinguish clearly between the wild and cultivated types. One of the main difficulties in obtaining new varieties was due to the sterility of most of the Chilean types and it was impossible to obtain fertile flowers from them. On the other hand, the mountain potatoes from the Andes, in spite of the fact that they only develop in the short days of their native latitude, readily set seed. Hence they can be crossed and adapted for European needs. The Russians have thus succeeded in producing a potato which is resistant to cold and is capable of withstanding 14° Fahrenheit of frost. In 1933, Bukasov, by making use of all the potato-breeding material which had been collected in South America, commenced hybridization work on a large scale. It was not only necessary to produce potatoes which should have a long day reaction and be resistant to frost, but the questions of productivity, quality, earliness and resistance to various diseases had to be considered. The genetical factors still hidden in the potatoes imported from South America will give the Soviet scientists material for experiment for a long time. Most of the South American potatoes were immune to wart disease, and others were resistant to potato blight. This scourge (*Phytophthora infestans*) was the cause of the Irish potato famine of 1845 and 1846, which was said to have caused the deaths through starvation and disease of a million people in Ireland, the emigration of a million others and, even after a century, unhappy memories. The 'short day' types of

potatoes offer immense possibilities for tropical districts such as those of India and Ceylon.

Until fairly recently the production of animals and plants by hybridization between species has not been regarded as a practical method, owing to the sterility of the crosses. The lack of fertility of the mule and the loganberry has been known for many years. An increasing knowledge of genetics, and the use of repeated crosses to secure the desired forms, has gone far to solve the problem of the high degree of infertility usually associated with distant crosses. The production of the wheat known as Hope, by McFadden, has been of the utmost value in supplying rust-free varieties for use in North America and Canada. The cross was made between two species (*Triticum vulgare* and *Yaroslav emmer*) of different chromosome number. Only one plant was obtained, and this in turn produced a hundred shrivelled seeds of poor quality. Further generations were grown and only the large seeds were used to continue the line. After this a process of selection was made to give varieties which were resistant to drought, damage by the weather and the worst forms of rust and bunt.

A similar method of inter-specific crossing saved the Java sugar industry, when in 1880 it was threatened by a new disease known as sereh. The process is one which necessitates performing the crosses in easy stages. The properties of chunnee, a wild variety of sugar cane found in Northern India and immune to the disease, were gradually incorporated into the cultivated varieties of the sugar cane. Harland, in 1928, commenced a series of crosses with cotton, which he hoped would result in plants free from disease, insect-resistant and possessing an excellent quality of lint. Even crosses between species of the same chromosome number may be far from simple, owing to the fact that by mutations and other genetical changes over long periods of time, they now have few hereditary factors in common. A species is not a fixed static thing, but is in a dynamic

equilibrium changing with its environment. Attempts to breed between species of wheat and cotton respectively have shown this forcibly. Nevertheless, even in difficult cases of interspecific crossing it is possible to secure the transfer of a gene or a small group of genes, which will often be sufficient to endow the new plant with just the character which is required.

Crosses between plants of different genus are even more rare and difficult. The hybrids are usually completely sterile, but very occasionally a highly fertile exception appears. These phenomena occur not only in crosses between species but also in those between genera, and usually in those hybrids which normally show the greatest degree of sterility. One of the first of these cases to be noticed, and for which an explanation was given, was the Kew Primula or Primula Kewensis. The hybrid was first obtained in 1899 and was quite sterile. It was propagated by vegetative methods, that is, by taking cuttings, until in 1905 it astonished the botanists by producing seeds, becoming perfectly fertile and thus producing a new species. The explanation was not forthcoming until 1930, when the phenomenon had been re-examined by Newton and Pellew. They showed that each of the parents had a chromosome number of eighteen, and this was also the number in the sterile hybrid. As we have already seen, in order to carry out reproduction, pairing of the chromosomes must take place, and this was impossible in the hybrid which had obtained nine chromosomes from each parent. During the division of one of the cells of the plant, chromosome doubling must have taken place, that is, the chromosomes had bisected but complete separation into two cells had not happened. Conditions were now satisfactory for reproduction, and by division germ cells were produced, with the double chromosome number of thirty-six. When chromosomes double, or multiply themselves by some simple number, we speak of the phenomenon as *polyploidy*. The principle is an important one in the

production of new species of plants which are used by man, and we shall meet it again when we discuss mutations. The Russian cereal growers have solved many of their problems by similar methods. The wheat-rye hybrids, which have great resistance to cold and drought, have fifty-six chromosomes and are appropriately called tetraploids, or more generally amphidiploids.

The useful Townsend cordgrass, or *spartina Townsendii*, which has been so useful in reclaiming land or preventing erosion from the sea on the English, French and Dutch coasts, arose in a similar way. About the year 1870, the American grass *S. stricta*, probably brought to this country in the ballast tank of a ship, appeared in Southampton water. A sterile hybrid was formed from its cross with the local *S. alterniflora*, and eventually, by chromosome doubling, the new species, *spartina Townsendii*, appeared and spread with amazing rapidity. In 1931, Huskins showed that the new species was an amphidiploid with 126 chromosomes, whereas the parents have 28 and 35 respectively—$2(28 + 35) = 126$. The appearance of new species in nature from time to time, and the genetical nature of many existing species, can clearly be explained by amphidiploidy; and the artificial production of fertile types from sterile hybrids is becoming common. The best known and most spectacular was the production of raphanobrassica in 1927 by Karpechenko from a hybrid between the radish and the cabbage, of different genus. The raphanobrassica may grow to a considerable height and in appearance gives little clue as to its origin. Again, Karpechenko showed that this fertile plant produces a sterile hybrid when crossed back with either of the original parents. By chromosome duplication in these crosses he obtained a fertile tetraploid cabbage of great size and utility. This principle of back-crossing is very useful in the solving of some of the problems of practical breeding. No doubt many of our most valued of cultivated vegetables and fruits have developed their present qualities of size

and lusciousness through a long history of natural amphidiploidy. Botanists and breeders have often wished that they could produce chromosome duplication at will, and, as will be seen, our control of the behaviour of chromosomes is increasing. More than ten years ago it was realized by workers in many parts of the world that rigorous growth conditions tended to promote chromosome doubling in plants, and hence the appearance of new species. Such hybrids were often noticed after an exceptionally cold winter, after a period of drought or exceptional heat and in other unfavourable situations. The body cells of plants can sometimes be made to yield polyploid reproductive cells by repeated decapitation. This has already been successful in the case of the cabbage family, and it offers a promise of new types of tomato plants which are so much desired in England.

From time to time, the genes of both plants and animals occasionally undergo sudden changes, known as mutations. Consequently, new characteristics appear in the organism and these will continue in the offspring. Mutations have been called 'jerks in the genes', and their cause has not been fully explained. The cosmic rays from outer space, which constantly bombard all living things on the earth, are not sufficient in quantity to account for these changes. It was found by Muller and Dobzhansky, who experimented on the fruit fly, that mutation rates could be speeded up to about two hundred times the normal rate by the action of X-rays. (The fruit fly is a most valuable creature to biologists who experiment with heredity factors, for it has well-marked characteristics such as colour, nature of its eyes and the size and shape of its legs, which arise from the arrangement of genes in its chromosomes. Also, it produces nearly forty generations each year; that is, a new generation every ten days.)

Up to the beginning of the war, many hundreds of artificial 'mutants' of plants had been obtained by subjecting their seeds to varying doses of X-rays. A Coolidge

X-ray tube, fed with a current of 5 milliamperes at 72,000 volts, and at a distance of about 30 inches from the seeds,

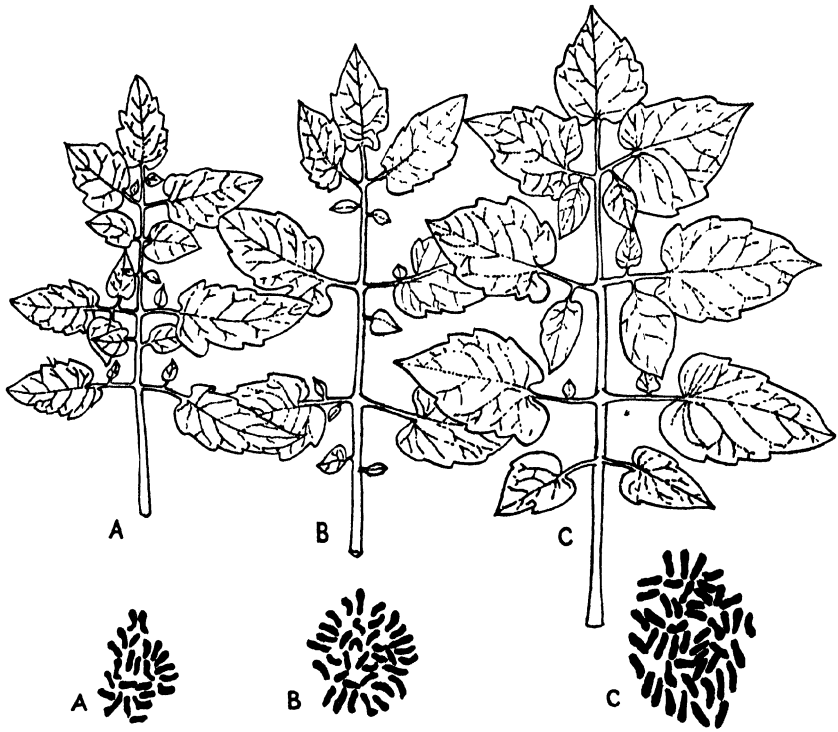


FIG. 22. The effect of chromosome multiplication. The leaves and fruits of the tomato plants increase in size with the chromosome number of the reproductive cells.

(A) A diploid with 24 chromosomes.
(B) A triploid with 36 chromosomes.
(C) A tetraploid with 48 chromosomes.

Larger and finer varieties of many plants and fruits may be produced by chromosome multiplication.

will give satisfactory results. The effects of the X-rays vary with the stage of development of the germinating seeds. Germination is delayed in the case of resting seeds, and where the chromosomes have started to double they are retarded and set back to the resting stage. When they again continue germinating they behave as though there were double or a multiple of the original chromosomes. In these polyploids the plant is usually larger, the fruit are

heavier and the yield is greater. Later, it has been found that other physical and chemical agencies will produce similar results. Low temperatures, by restricting the supply of nucleic acid for the chromosomes, have an important effect. The development of the spindle and chromosome spirals can also be controlled by adjusting the temperatures at germination between 3° centigrade and −5° centigrade; that is, a few degrees above or below freezing point. Muller has continued to produce mutations by modifying artificially the concentration of nucleic acid in the cell round the chromosomes. This appears to him to be the most promising method of altering 'gene patterns', and therefore, inheritable characteristics.

Temperatures of 44° centigrade (about 111° Fahrenheit) for a period of from five to forty-eight hours will also cause polyploid conditions in certain plants. Other conditions were found to modify the changes in the chromosomes at cell division (mitosis). One of these was centrifuging. The seeds are put in a tube which is then revolved at the edge of a disc at a great speed. Considerable forces thus act on the seeds and will tend to separate their heavier and lighter constituents. Allowing seeds to age before commencing germination is another means of inducing special nuclear changes.

Certain vegetable poisons and substances which assist plant growth, known as plant-hormones, may also cause changes in the dividing cell. One of the most useful extracts for this purpose is colchicine, which is obtained from the autumn crocus or meadow saffron. Buds, seeds or runners of various plants are treated with dilute solutions of colchicine, varying in strength from one part in ten thousand to one part in sixty, for periods of half a day to a week.

A great future was predicted for these artificial mutants, but in the great majority of cases this was doomed to disappointment. Most of the mutations, apart from polyploidy, appeared to give unwanted recessive characteristics,

and only rarely did any improvements result. The desirable characters would appear to be limited to those with a neutral or negative survival value, but which may under cultivation become useful and desirable from an economic point of view. Examples where this method will prove to be useful are the production of various leguminous seeds without the poisonous qualities which often render them unsuitable for feeding animals, the development of wheat with greater frost resistance and a tobacco plant with low nicotine content. The quest for varieties of the sweet lupin, which have been so often sought for, particularly in Europe, finds these methods of artificially-produced mutations very valuable.

Another important development in plant breeding, and one which has been the subject of much discussion and controversy, is known as vernalization. For many years, gardeners have allowed their seed potatoes to 'sprout' before planting them, and vernalization is really an extension of this principle. Ten years ago, Lysenko of Odessa published a theory that plant growth and plant development were two separate and distinct phenomena. According to Lysenko, development depends on various external conditions which may differ at different stages; and that if these factors are understood and can be provided artificially, if necessary, development will proceed at a rate which can be controlled without much growth taking place. Thus, the early developmental stages of a seedling can be hurried, and after it has been planted out, it will grow rapidly and soon set its seeds. Accordingly, material for plant breeding can be obtained rapidly, and it is even possible to obtain several generations in one year. By sowing seeds of wheat in August, immediately after harvesting, and giving them suitable light and heat treatment, the Russian botanists were able to obtain mature grains of barley at the end of September and wheat at the beginning of December. They claim that two or three years are saved by this method when making a cross. Normally,

the plant breeder has to take nature's time in waiting for his results, but the Russians have shown how these important operations in plant genetics could be speeded up.

The early development of a plant shows a number of distinct stages, and the length of each stage is different in each variety of plant. For instance, in the case of wheat, the first stage demands a temperature just above freezing point for a definite number of days, and this has to be followed by the light of long days, also for a definite period. After this, the plant can pass on to growth and maturity without any further period of low temperature or even long hours of light, and, in fact, a comparatively high temperature will hasten the process. By studying a number of varieties of wheat, Lysenko was able to show that certain types of wheat were late in maturing because the first stage took so long to accomplish, although all the others passed very rapidly. Other varieties were slow in the second stage of development only. Lysenko obtained crosses from these two types which gave early maturing plants, and he obtained thirty varieties which were earlier than either of their respective parents. These early types all show a combination of the genes of a variety from the extreme north such as Ladoga, and a variety from a warm country such as India. The northern type develops in the comparative cold of the almost continuous day of such latitudes, whereas the southern type needs warmth but is almost neutral to light. This research, which deals with fundamental characters so necessary in agriculture rather than with the inheritance of simple Mendelian factors, has been instrumental in bringing immense new areas in Russia under cultivation.

The most important characteristic of a plant which is used as a food-stuff is its yield. Empirical methods of selecting the plants, which seemed to give the highest crop, were the only means employed to improve yield for many decades. Within the last twelve years, systematic attempts have been made to analyse scientifically the factors con-

cerned in productivity of plants. In 1933, Rasmusson, working in Sweden, found that between a hundred and two hundred genes are concerned in the inheritance of such characters as yield and quality. Further, he showed that the effect of a particular gene is not constant, but depends on the number of other genes which have a determining effect, and diminishes as this number increases. As in psychology and neurology, where the method of isolation of single factors has had to give way to patterns or configurations as is shown in the gestalt psychology, so we find in genetics certain analogous effects, where the whole gene pattern has to be considered and Mendelism does not offer the whole explanation. In view of the many factors which control the yield, statistical methods have been applied in this study. These require a mathematical method for working out the probabilities that certain characteristics will appear, and the classification of large numbers of different factors. Ingenious machines, electrically operated, have eased the toil of calculation; and, in fact, so many variables had to be considered that in most cases the matter would not have been practicable without such instruments as the Hollerith calculator. Boonstra in Holland has made a systematic study of yield, which he finds to be determined by all the processes which have occurred at each stage of the development of the plant. The problem is only one of genetics in so far that each of these processes is determined by inherited characteristics. In particular, Boonstra stressed the importance of an efficient root system to the yield of the plant, and showed that a high yield in parental forms does not guarantee the same performance in the offspring. A given yield may be built up in many ways, and this end point gives no indication of how it was built up. As an example, the extent of the assimilation of carbon dioxide by leaf surface may explain yield in one plant, in another by the long useful life of the leaves, and in others because of their ability to absorb nourishment through their root system or their

powers to carry quickly the assimilated products from one part of the plant to another.

In this chapter we have considered only the nature or heredity of the plant. Its nurture, that is, its environment and feeding, is obviously important. The mature state, whether of man, animal or plant, is a product of the influence of both nature and nurture. The soil needs feeding with the chemical substances which are essential to plant life, and if these can be obtained in a natural or organic form there is often an advantage to the plant. The necessity of tiny quantities of certain elements for its successful growth is an interesting fact. Such trace elements are boron, copper, zinc, manganese, iron, selenium and others. The list of elements is quite a long one, and certain of them seem to be essential to the growth of particular plants. Traces of molybdenum seem to be necessary for the growth of tomatoes, as is zinc for maintaining the health of the citrus fruits such as oranges and lemons. The living organisms of the soil are also important to the health of the plant. Although some of them are destructive to plant growth, others cleanse the soil, and by breaking it up make its contents more easily assimilable and aerate it. An important group of bacteria fix the nitrogen of the air, and help to provide the 'building stones' of the plants' protein content.

Perhaps there was not much encouragement to English plant breeders from the economic point of view before the war. The 'kindly fruits of the earth' were often thought of only in terms of finance and not from the aspect of a varied and healthy diet for every one in the world. The war has forced this latter outlook of vegetable and animal yields on us. There is a world food shortage at present, and if the botanist, plant or fruit grower can make two blades of grass appear in the place of one, and, moreover, produce better grass, he is indeed a man who should have the thanks of his fellows. Excellent plant-breeding work is done in England at Cambridge, where is the Imperial Bureau of

Plant Genetics, which has a world-wide outlook. Many remarkable new plants have been produced at the John Innes Research Station at Merton. In the U.S.A., there is a large institute at Beltsville, Maryland, where new types of plants and animals are developed. An 'all white' meat turkey, hens which lay eggs of standard types, onions which produce no 'weeping' and new types of fruits are amongst its recent achievements.

It may be permissible to conclude a section concerning the improvement of plants by mentioning some recent work on selective weed control. Attempts were made about half a century ago to spray plants with dilute solutions of copper salts with the intention of destroying the weeds but damaging the plant as little as possible. In 1933-35 Blackman and Templeman, working in England, had shown that an increase of well over 200 per cent in grain yield might result by controlling weeds in cereal crops by a spray of dilute sulphuric acid. Shortly before this Truffaut and Pastac took out a patent in France for a yellow synthetic dyestuff known as dinitro-orthocresol or D.N.O.C. which was found to control annual weeds in cereals. It has formerly been used as a 'slimming-salt' and an insecticide but its use had been abandoned as it was too poisonous for the one and not toxic enough for the other! When the war came and France fell our supply of onions practically vanished. To grow onions successfully on a commercial scale armies of weeders, locally known as 'crawlers', have to be employed. It was found that this laborious process could be obviated by spraying with dilute sulphuric acid before the tiny onion shoots emerged.

For some years it has been known that certain plant growth-substances, called plant-hormones, exercise control in the growth of plants, causing cell division, elongation, and increased root formation.

In 1940 it was noticed that dilute solutions of these substances would also destroy the annual weeds which infect cereal seedlings. Moreover, it was possible to

synthesize these and similar substances in reasonable quantities. Two in particular proved to be very useful: methyl-chloro-phenyloxy-acetic acid (M.C.P.A.) and dichloro-phenoxy-acetic acid (D.C.P.A.). Copper chloride was also found to be a useful herbicide. Much investigation has been undertaken to find an appropriate substance, how to apply it and at what time of the year in order to kill the chief weeds but not to damage the plant. Selective control of annual weeds has now become possible and M.C.P.A. and D.C.P.A. also kill some perennial weeds such as the thistle. Considerable research, which has already yielded most valuable economic results, still continues.

SCIENCE NOW AND IN THE FUTURE

In the previous chapters, we have seen something of the applications of scientific research to technical developments which change fundamentally the nature of the world around us and the very life which we lead. As an instrument for the healing and improvement of mankind, science has still a credit balance to show over its destructive powers when it has been misapplied; and this in spite of two devastating world wars in a third of a century. Up to date, more lives have been saved by science than have been destroyed by it. Drugs from coal-tar have healed more wounds than explosives made from it have caused. The future of science and its powers for good or evil cannot be secure in the hands of a race who do not understand it, and whose moral development has not kept pace with its technical achievements. In another war, the debit side will predominate, and civilization as we know it will cease to exist.

The story of the growth of science shows that during the last century the applications of physics and chemistry, as seen in technical developments, far outstrip the corresponding use and developments of biological sciences. There is an obvious reason for this. The types of science which could be applied to industry and commerce, such as chemistry, heat and electricity, received great impetus and encouragement. It was not until the twentieth century that the science of living things was seen to have great commercial value. In fact, the conditions caused by two wars made the exploitation of biological principles absolutely imperative in order to avert disease and starvation. The need for extending the methods of science to economics, political issues and above all to a study of the individual and social mind is one which is gradually being realized. This has an importance which is greater, not

less, than that of the physical sciences. The proper study of mankind is man; and social biology, a subject or group of subjects, the study of which is necessary to the life and well-being of civilization, should be regarded as of the utmost importance.

Biological and psychological studies are on the whole more difficult than those of the physical sciences. In the latter, it is fairly easy to proceed from cause to effect when dealing with matter in all but the tiniest quantities. Also, various factors can be isolated and examined separately. But in the sciences of life and mind such easy isolation, supported by a mathematical analysis, is not usually possible. There are often many causes and many effects all intermixed in one big pattern. For example, we lose our way badly when we attempt to break down the integrated action of the human body and mind as a whole into separate parts or systems, but in view of the complexity of the problem, 'systems' present an easy and misleading way of tackling the problems. The analytical methods of physics and chemistry find no useful analogy when dealing with the conception of the mind. Nevertheless, it must be remembered that a method of investigation may still be scientific, even if it cannot be supported by measurement on a metric scale and mathematical calculations.

During the war, when problems requiring quick solution have arisen, the old method of intelligent 'trial and error' has often succeeded. If we can command enough scientific workers and enough materials, the mere number of new juxtapositions of many things is bound sooner or later to bring something useful. This is the manner by which so much useful knowledge has come to mankind through the centuries. The method of trial and error when applied intelligently is still as effective in science for limited researches, as it was in the days of Edison. An example is the discovery of the properties of D.D.T., the use of which is already appreciated by hundreds of thousands of service

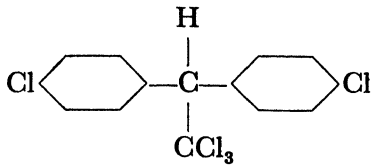
men; and in the future it will also prove to be a great boon for domestic and public-health uses.

At the beginning of the war, many insecticides were tried. To be effective an insecticide must kill many varieties of pests even at considerable dilution, it must make its presence felt to insects that venture near and it must not be very toxic or irritating to human beings. Dichlor-diphenyl-trichloroethane, or D.D.T., a coal-tar product which is much more simple to make than its name suggests, fulfils these requirements and more. If small quantities of it are mixed with paints and distemper, the effect is preserved in the walls of the building for many months, and the room is kept free from insects. Its use was discovered in Switzerland by the Geigy Company, and when, with other substances, it was tested for official purposes our pestologists and infection-experts were amazed at its superiority. In the Far Eastern wars, insects with the germs of tropical disease which they carried were often more deadly than the Jap. D.D.T. killed one enemy, and left our human resources in a better position to deal with the other. It has been truly said of insect-borne tropical infections that in the deaths which they cause they make the slaughter of war a comparatively mild affair.

Many of the problems of man concerning sanitation and disease are due to insects. D.D.T., by acting on the nerve ganglia of insects, is the greatest step forward in our attempt to conquer insect-borne disease. The discovery of the properties of D.D.T. may not be a great triumph of either theoretical or practical science, but in the possibilities which it opens up in the prevention of disease by the control of insects it will prove to be of calculable value to mankind. For not only in the tropics do insects carry plague-producing organisms; but even in Europe at present, without such controls as science has supplied us, the threat of typhus would be ever with us.

D.D.T. is quite simple to produce even in considerable quantities. It is made from sulphuric acid, chlorine,

alcohol, and benzene from coal tar. It has the chemical formula—



Towards the end of the war it was made in the United States at the rate of 24 million pounds a year and considerable quantities were manufactured elsewhere. During the early part of the war much developmental work on insecticides had been undertaken by British scientists. The loss of the supplies of pyrethrum powder, which was obtained from a Japanese crysanthemum-like plant, made this all the more urgent. It is difficult to exaggerate the value of D.D.T. in the control of disease-bearing insects and other pests but it may be well to mention two small troubles. Although D.D.T. is fatal to insects in small dilution and is only poisonous to human beings when taken internally in considerable quantities, it has a slow 'knock-down' effect. The insect dies but not immediately. I.C.I. has developed another insecticide made from benzene and known as 666 (because its formula is $C_6H_6Cl_6$) which kills the insect at once. The second point which must be kept in mind is that insecticides do not distinguish between good and bad insects. Bees which fertilize our plants and fruit trees, and insects which prey on other pests and thus do useful work, are all alike affected by it.

One of the greatest advances in medicine in recent years is the improvement in methods of immunization against germ diseases. Prevention is better than cure, and many such diseases can be prevented or rendered less severe by a resistance which has been built up in the body by the injection of vaccines. Diphtheria still kills some thousands of children each year in this country, and many others are left with various weaknesses because of the damage to human tissues which it causes. An increasing public

awareness of the benefits which result from the diphtheria immunization of young children has led to a rapid fall in the number of fatal cases. By a general acceptance of the facilities offered by the public health authorities, diphtheria cases could be reduced to numbers only as large as those of smallpox and typhoid fever in this country. The amount of trouble which this would give parents and children would be negligible.

The production of suitable vaccines for the prevention of some of the germ diseases has not yet been successfully accomplished; in other cases, the matter is not an easy one. Typhus, a deadly disease which is carried by body lice, usually follows privations, wars and the migrations of populations. It is the handmaid of squalor, hunger and poverty. In the United States, Cox and Goodpasture found a method of growing the typhus virus. As it is only nourished by living tissue, bacteriologists formerly had to grow it in living animals; but in the years immediately before the war it was found that a rich virus could be made by infecting fertile eggs with the microbes of the disease. The virus was then used for making thousands of doses of the vaccine, by its action on the blood serum of animals. Goodpasture's technique was also applied to the production of a vaccine to prevent yellow fever, a disease which is carried by mosquitoes. Yellow fever is rife in West Africa and the South American jungle, and in these days of the transport plane it is quite possible, in spite of all precautions, for disease-bearing insects to carry the scourge to other countries. Elaborate measures to prevent such epidemics are well worth while.

Improvements in certain aspects of medical science, particularly in diagnosis, make great demands on the technique of the physicist. Not only does a scientific investigation need good team work in some particular study, but it often requires the methods and results of several branches of science. The detection of heart trouble and the investigation of its nature have been rendered easy by

the use of electrical amplifying and recording instruments. To an increasing extent, the tiny electric currents which accompany nervous action in the body can be amplified by valves and made to record their traces in a cathode-ray tube. New methods of detecting easily, quickly and cheaply any tendencies to tuberculosis of the lungs have been evolved. X-ray apparatus throws a radiograph of the chest on a large fluorescent screen, which is then photographed on a tiny film, of the same 35 mm. width as ordinary cinema film, in a special camera. A single small 'frame' of the film serves for each person, and hundreds of exposures can be made on a short length of film. When the film is developed, each tiny picture is enlarged by a projector and thrown on a screen long enough for the physician to examine it and detect any irregularity. John Bunyan called tuberculosis 'the captain of the men of death', but by detection in its early stages, suitable treatment and an improvement in housing, the hygiene of milk and food-stuffs and our mode of life in general, it could be eradicated completely.

Artificial radio-active compounds, which can be made by bombarding such substances as common salt with the high speed particles generated by the cyclotron, offer possibilities for the cure of cancer and other growths. Radio-active atoms can be made to pass into the material of living substances, and, as they carry a 'label' in the form of their radio-activity, new possibilities are offered to physiologists who desire to study the processes of absorption of food-stuffs, the building up of tissue and the passage of atoms in and out of the matter caught up and held for a time by living things.

One of the simplest but most interesting of biological principles, which has been solved by the physicist, concerns the effect of vitamin B_2, or riboflavin, on general health, and, in particular, on the eye. A number of members of the Canadian Air Force in Labrador and Newfoundland were found to be suffering from soreness of the eyes,

decreasing efficiency of vision and bloodshot corneas. It was believed that riboflavin was an important factor in the elimination of the waste products of the action of the cells of the body. In the case of the eye, particularly if it has been subject to overwork and strain, a riboflavin deficiency shows itself in tiny capillaries or blood pipes which are sent into the white of the eye (the cornea) to do the scavenging, and to carry fresh oxygen. It was necessary to devise some means of recording photographically the state of these capillaries, so that improvement of the condition under riboflavin treatment, or deterioration owing to progressive vitamin shortage, could be recorded. The problem was to illuminate the white of the eye with a sufficiently powerful source of light so that a photograph could be taken. A powerful enough flash would normally cause temporary blindness and much discomfort to the patient. Accordingly, Professor Harold Egerton, head of the Electrical Engineering Department of the Massachusetts Institute of Technology, designed a small enclosed krypton-xenon gas arc which gave a two million watt flash lasting only $\frac{1}{30,000}$th of a second. (Krypton and xenon are two rare gases belonging to the same 'family' as neon.) The light was adequate for the taking of the photograph, but the time of the flash was not sufficient to cause any irritation to the eye. Thus an easy way of checking and correcting vitamin B_2 balance has been devised.

As we have already seen, our increasing knowledge of germs and drugs which control them has shown the way to a method of conquering sepsis and many fatal diseases. New anaesthetics such as the gas cyclopropane produce general anaesthesia, and drugs such as avertin, a compound of ethylene and bromine, when injected into the fluid of the spine produce nerve blocking in that great nerve cable the spinal cord, so that extensive abdominal operations can be performed without loss of consciousness and with very little risk to the patient. There still remains the problem of shock. Sometimes quite slight

burns or injuries due to crushing will result in alarming symptoms, and, after an interval, death. The patient collapses, appears to be pale, bloodless and extremely feeble, the body becomes cold and death may ensue. We can overcome pain and poisoning due to germs, but shock has baffled us for many years. Experience in the war with air raid victims has brought the solution of the mystery considerably nearer. For many years it has been known that in a condition of shock the tiny blood vessels of the body, known as capillaries, are very much enlarged and the blood, failing to circulate, engorges them. Nearly forty years ago, Bayliss and Cannon, the eminent physiologists, had shown that if the circulation of blood to injured muscles of animals was blocked no symptoms of shock resulted, but as soon as the confined blood was released, shock developed. Sir Henry Dale discovered later that the crushed muscle cells of animals contained a substance called 'histamine', and it was reasonable to suppose that this caused the symptoms of shock. This supposition found confirmation in the fact that injections of histamine would produce artificial shock. Thus, we see a possible explanation for the symptoms which may follow the crushing or burning of tissue, even if there are no obvious extensive injuries nor immediate grave symptoms. Histamine is a protein-like substance; and as is the case of so many substances in the body, such as vitamins and the secretions of the endocrine glands, called hormones, a little goes a long way. Histamine is found normally in all living cells, and it can be released and its production stepped up when the cells are injured by the action of certain bacteria or even by an overdose of sunlight. People vary in their reactions to the substance and some are particularly allergic or over-sensitive to it. Thus, histamine appears to act like those substances known as allergens, to which some people are very sensitive. Pollen may produce hay fever; strawberries may give hives; dust and certain drugs may produce grave symptoms out of all proportion to the

amount of the substance producing the effects. It is possible that research on histamine may throw some light on such medical mysteries as the common cold, migraine headaches and hay fever. Prickmann of Minnesota believes that various food allergies are due to over-sensitivity to histamine, and that a process of vaccination or 'desensitization' would relieve many unpleasant conditions. Such a treatment takes about a month, and consists of daily injections of histamine or related substances, starting with extremely tiny doses and very gradually increasing the amount. Resistance to histamine is thus gradually built up by the blood. There is so much chronic ill-health due to allergies and related troubles that research on this matter should bring much relief. There is some evidence to show that in a number of cases calcium compounds and increasing doses of vitamins may cause desensitization of the blood, but this may only be due to the building up of the natural resistance of the body in other ways.

A major triumph of the recent war was the very high percentage of the badly wounded who were saved and returned to life in a healthy and useful condition. We have already mentioned the new drugs which have removed so many of the terrors of bacterial infection. There were many other reasons for the great increase in the successful treatments of injuries, and one of the most important was an improvement in the technique of blood transfusion. A well-organized transfusion service has been set up in this country, and regionalized. There are blood banks, facilities for testing blood, separating, purifying and drying the serum. No longer is there any fear that a patient will receive blood which is not compatible with his own. The mixture of bloods of different groups might lead to alarming results owing to the coagulation of the blood and the separation of the red cells from the serum, or in other cases lysing, that is, the breaking up of the red corpuscles, the haemaglobin then appearing in solution. The discovery of a new blood group factor by Landsteiner and Wiener

in 1941 has proved to be of great interest to serologists, that is, those interested in blood and its serum, and geneticists, or researchers into the problems of inheritance. The new substance is known as the Rh factor, as it was first recognized in the red blood cells of the Rhesus monkey. It is present in the blood of about 85 per cent of the population of this country, and these people are called Rh positive. The importance of the factor in medical work lies in the fact that Rh negative people may develop anti-Rh qualities or antibodies if the substance is introduced into their tissues. This may happen either by the transfusion of blood from an Rh positive donor, or by the growth of an Rh positive foetus within an Rh negative mother. As the Rh factor is transmissible as an inherited factor according to the laws of Mendel, it will readily be seen how the latter case can arise. Under these circumstances the mother develops anti-Rh antibodies in her blood, these pass across the placenta and produce damaging effects on the tissues of the foetus, especially on the red blood cells. Thus, we have an explanation of many previously inexplicable blood transfusion effects; and we can now understand the grave condition known as haemolytic disease of the new born (*erythroblastosis foetalis*). Since this discovery of five years ago, seven sub-types of the Rh factor and six different anti-Rh antibodies have been demonstrated. These are of great interest for the serologist and geneticist.

The study of the nature and treatment of cancer still continues. The reason why groups of cells in the body run wild and no longer conform to their normal order and function seems to be hidden in the very nature of the nucleus of the cell itself. Scientists have not been slow to try to use the lessons of the control of chromosomes in plant breeding in attempts to an analogous control of the cells of the body. In America, the use of drugs of the stilboestrol type to control the growth of 'rogue' cells has yielded some promising results. Attempts have been made

to destroy the growth by X-rays whose pulses are adjusted to the size of cells; and all manner of radiations from natural and artificial radio-active substances have been experimented with. Cancer research has already yielded an enormous literature; and in the long quest, much useful information concerning human tissues has been forthcoming. Early diagnosis and treatment to eradicate the growth still offers the best hope of cure, and to this end surgical technique has so improved that it is even possible to remove a whole lung with extremely small risk to the patient.

The treatment of mental complaints has advanced considerably in recent years, but much remains to be done in the field of neurology. Many forms of treatment which are apparently successful are based on empirical knowledge, and the exact changes in the cells of the brain and nerves are not known. This is the case with a number of physical methods which are now in general use for treating mental complaints. Many depressive conditions respond to electric convulsion therapy in which electric shocks of only 80 to 100 volts, for small fractions of a second, are passed between the temples of the patient—a process which should be quite painless. A less pleasant way of producing the convulsion is to administer leptazol or a similar drug. Some very remarkable cures have been obtained by these means, and it is probable that depressive states may result from over-inhibition of the driving forces of the cerebrum of the brain by the action of the frontal cells which are sometimes called the anterior lobes. In fact, extreme anxiety and depressive states have been cured by severing surgically the connecting links between these cells and the rest of the brain.

The mechanism of the process is not yet understood and research on the matter continues. Again, other severe cases of mental disturbance can be treated by the injection of carefully regulated but comparatively large doses of insulin, so that a state of coma is induced for a number of

days. When the patient recovers he is given a meal which is rich in carbohydrates, to restore his blood sugar level, and thereafter he is often able to resume his ordinary work with a calm, clear mind.

During the 1914–1918 war, the work of the Viennese school of psychoanalysts, of whom Sigmund Freud was the leader, bore fruit in the work of Rivers and others who successfully treated thousands of cases of war neuroses. 'Shell shock', as it was miscalled, was seen to result from a conflict which arose from the inability of the individual to reconcile two opposing mental forces. The conscious demands of duty might find themselves in conflict with hidden and unconscious fears which would find their origin in the instincts or in the experiences of early life. Such conflicts may grow in the favourable soil of a weak nervous system, to which may be added an exhausting or terrifying experience, physical illness and so on. The condition may lead to psychological symptoms which render the patient an ineffective citizen, or even bring about his mental collapse. The conflict can only be resolved, and rendered harmless to the personality, by breaking down the mental barriers and bringing it openly into the sphere of consciousness. Formerly, psycho-analytic methods were lengthy and not always satisfactory, and hypnosis was an uncertain and undesirable means of securing the reduction of the disturbing mental processes. An injection of sodium evipan, a synthetic substance of the barbiturate class, into a vein, quickly produces a state of hypnosis under which the patient will respond to the suggestions of the physician.

There is still much scope for investigations on the effect of drugs on the brain and nervous system. Synthetic 'coal-tar' substances such as methedrine and benzedrine appear to increase the sustaining power of the brain and prevent the onset of fatigue, even after long periods of work, without causing much after effect. It is not sufficient for the physiologist to be able to trace the chemical effect of various drugs and diets on nervous tissue, and much

research remains to be done on the working of the brain. In fact, our knowledge of this is negligible compared with our ignorance of it. It is even difficult to find terms in which to discuss the interaction of the body and the mind, for the body is a thing and the mind is a conception. To talk too readily about the bridge between body and mind is a confusion of terms; and to use such phrases as the 'structure of the mind' is to open the way for many wrong ideas of the subject. Observations on nervous tissue can be made by electrical instruments which are capable of magnifying the tiny currents which accompany nervous action; and again, localized diseases of, or growths on parts of the brain can be studied by the symptoms which they produce in the patient's movements, speech, mode of life and so on. The encephalograph, an instrument which records electric wave-like currents which pass through parts of the brain, is used by neurologists but its findings are difficult to interpret. There seems to be evidence that sensory experience is not to be thought of as the result of 'atoms' or 'units' of stimulation arriving along a few fibres of nerve conductors, but rather as a reaction in the whole pattern of experience. Thus, there is good evidence in nerve and brain researches in favour of the gestalt psychology which deals with configurations or patterns in mental reactions. Neurologists are only beginning to see dimly the nature of the nervous changes which take place in the brain; such problems as memory and free-will are still left to the philosophers. Adrian, Woollard, Weddell and many other workers are using the new electrical techniques for tracing the changes in nervous tissue which take place under various stimuli, in order to explore the complexities of the nervous system. There is evidence to show that the idea of personality or the phenomenon of subjectivization, that is, the feeling of being oneself, is localized in the basal ganglia of the brain. The outer 'crinkled' surface of the brain or cortex appears to act as a synthesizing mechanism which puts together the many units of stimuli, but the cortex does not in itself

evolve mental experience which seems to arise from the action of the deep-seated ganglia or nerve cells of the brain. A large centre of the brain known as the thalamus shows exact localization within it in respect of the impulses which reach it from different parts of the body, and near to the thalamus is the third ventricle which seems to have an important function in connection with consciousness. A tumour which presses on this third ventricle will produce a condition of complete passivity, and electrical stimulation of it will induce sleep. Clearly, in these and related matters there is an enormous field for research, and one which will be of the utmost value in helping man to understand and control himself.

We cannot deal with the health of mankind without considering food. The war has thrown the problem of feeding the world into relief. Dieticians and physiologists know what are the chemical needs of human beings in the constituents of their diets. Foods not only supply us with energy, but they also build our bodies and repair the destruction and wastage which is always going on even in a state of health and growth. Psychologists have told us something of the best circumstances for eating, the preparation of our food and its aesthetic aspects. Food is not to be considered merely in terms of calories and vitamin units. The dehydration of foods, so that their value to human beings shall suffer as little as possible, has been undertaken during the war, both to preserve the food in storage and also to reduce its bulk during transport. The preservation of food by refrigeration, antisepsis and packing in inert gases in sealed containers, has been the subject of much research during the war. We have already seen in the chapter on the hybridization of plants how new sources of food have been produced by the development of types of plant which will grow under given conditions of climate and soil, will be disease-resistant and produce good yields. A scientific survey of all the earth's surface will have to be made in the future, so that the most valuable

and economical use can be made of it. In England, this has been done already. It would be folly to build on land which would yield rich root crops, for instance.

The Mendelian laws of breeding apply not only to plants but to animals. The present shortage of meat and milk can only be overcome by building up large, vigorous herds of cattle in Europe. High quality bulls, capable of passing on the much needed factors of vigour and large and rich milk yield to their female offspring, are comparatively rare. In ordinary methods of breeding, the number of calves of which a bull can be the father is limited. Artificial insemination enables a much more extensive and economical use to be made of first-class bulls. It is said that over fifty million head of cattle have recently been produced in Russia by methods of artificial insemination. It is even possible for a bull in America to become the father of a calf in England, by packing a tube of the semen in a container kept at a temperature of 38° F. and flying it to this country.

It is satisfactory to think that scientific research will receive more worthy official support in the future. Even so, the grants in aid of the immense tasks which lie before us seem small in proportion to those which are spent in a much less effective manner. The country owes much to its scientists, who have been sustained in the past by their interest and enthusiasm in their quest for knowledge rather than by pecuniary gain. Undoubtedly research under the auspices of government departments will continue on major problems such as the development of the use of atomic energy, aviation, the utilization of our minerals, the problems of prefabrication and the best use of the land of the country for agricultural purposes.

Commercial firms employ considerable numbers of scientists to develop their own products, and there is much useful knowledge which could be pooled for the general public good. There are many patents which have been acquired in order to prevent their development and use.

Thus, the research worker and inventor are not able to realize the value of their creative originality through the use which might have been made by the general distribution of the products which result from their work. Research work should not be confined to mere technical or utilitarian problems. It is the business of the scientist to pursue truth for its own sake. The specialist worker in the field of science 'knows more about less and less'. It is necessary more than ever to try to fit the 'jigsaw' puzzle together and to conceive it as a part of a larger philosophical system. It is remarkable that so many researches which were pursued for the joy of discovery and as a hobby have subsequently proved to be useful in the service of man. Indeed, many scientists of the past century would have been horrified had they known that their work could have been exploited commercially. For instance, even the study of insects, known as entomology, is of the utmost value for finding means of destroying pests which prey upon man, animal and plant. Immense quantities of food, to the total value of many millions of pounds, are saved each year by our knowledge of the habits of insects. Sometimes one insect can be employed to destroy another. The scourges of yellow fever, malaria, to mention only two diseases, were only understood when the life cycles of certain insects had been investigated. A knowledge of moulds and fungi is very useful to us, for this group of organisms can cause destruction on the one hand and produce very valuable substances such as penicillin on the other.

In the next volume of this work the author proposes to include an account of the new computing machines, sometimes popularly called 'electronic brains'. Devices for calculating such as bead-frames were in use before mankind had mastered the pencil and paper method. Many interesting pieces of apparatus were made for calculating astronomical events, tides, and tables of figures during the nineteenth century. Kelvin's tide calculator and Babbage's 'difference engine' can still be seen in the Science Museum

at South Kensington. For many years the British Nautical Almanack has been made by the use of computing machines. The use of valve circuits, in another application of electronics, has rendered it possible to combine statistical information fed to the machine in the form of punched cards, or by the combination of keys each bearing a number, in a more complex manner than ever before. The machine cannot think for itself but it can perform the 'donkey-work' of computation which would absorb millions of mathematical man hours otherwise.

In the previous chapters we have seen something of man's power to control the forces and materials of nature and to combine them in new ways for his own use. Although remarkable new products are obtained from the synthesis of simple substances and the utilization of products which formerly would have been wasted, and great storehouses of energy can now be tapped, it is foolish to think that these will solve all man's problems. When the atomic bomb burst upon the world, many people imagined that here was something which might solve all man's difficulties and create a new age if properly used. In addition to atomic energy there remain vast sources of power which are yet untapped. Hydro-electric power, whether it is combined with proper irrigation schemes or not, is still in a youthful state of development. The proper utilization of coal throughout the world is essential, and not only as regards heat and power but also in the production of the enormously important coal-tar products which are the basis of so many synthetic processes. Even the devices for producing atomic energy cannot do this. The days of petroleum, its derivatives and allied products, are not yet numbered, and comparatively large quantities of energy can still be obtained from waste organic matter and even sewage by chemical action. It is probably not necessary to use uranium to solve the energy problem during the present century, though it would be foolish to close our eyes to a method of producing much energy from little matter. At

present, atomic energy is not cheap, owing to the great expense of the plant which is necessary to separate the requisite materials.

The appearance of the atomic bomb has marked the occasion of some 'loose' thinking concerning the nature of science, its methods and its limitations. The scientist examines the mechanism of nature and describes it as accurately as he can. Sometimes the models and structures he creates make little appeal to his senses and he is forced to leave his description in mathematical terms. Again, when he is dealing with atoms and other small particles he is often forced to consider them statistically. As we have already seen, an electron (one of the ultimate units of matter) cannot be defined in both position and speed of movement at the same time. To observe it would change it. We can only deal with it in terms of probability. Science tries to describe the nature and behaviour of things in the terms of the senses, and the instruments which scientists use are to be regarded as means of aiding the senses and overcoming their limitations. Mathematics is an aid to precise description, and the results of the manipulation of formulae may suggest further lines of investigation or generate new ideas. Because science does so many things which shape our mode of life, uncritical people may not be aware of its limitations. Experimental methods of science are comparatively new, and many problems yet remain to be solved. Some sciences, such as psychology, are yet in their infancy, and even in the ancient science of astronomy what happens in the vastness of the cosmos has only been hinted at. Science knows little of beginnings and ends, it does not describe the phenomena with which it deals in absolute terms, but only in as impersonal and unprejudiced a manner as possible. Science is dynamic, it alters its methods according to the task in hand, it is progressive and in its search after truth it cannot be fettered to political or commercial systems. If the scientists by their directness of purpose, intelligence and application to their

work have shown how to improve our understanding of the forces around us, it is the duty of everybody to cherish the heritage that they have given us and to see that it is used for the well-being of mankind. Administrators and politicians should try to do their work as efficiently as the scientists.

Many scientists have not shown much social sense in the past. Disappointed with the ineffectiveness of so many aspects of twentieth-century life, many of them have seemed to turn with relief to the more satisfying work of research. Nevertheless, science does not offer the only valid way of describing things and forces, and even a scientific description will only be made at a particular level. For instance, if we are considering a process of digestion, a knowledge of the chemical and physical changes which take place will suffice. It is not necessary to consider the structure of the nuclei of the atoms which form the molecules of the substances which are eaten! We do not describe the beauty of a sunset in terms of electro-magnetic radiations of different wavelength and the scattering of the light waves by tiny particles; nor do we describe the playing of one of Beethoven's symphonies in terms of complex compounds of compressional waves in the air. Physical science does not help us much in the study of counterpoint!

There is no reason to believe that science and true religion are antagonistic. Each should have a qualifying effect on the other; they deal with different modes of thought and they are to be regarded as complementary.

In this book we have dealt with some of the technical achievements of science, and it is necessary that we should have a keen appreciation of the nature and possibilities of these, for they are the forces which will mould the future according to the wisdom with which we apply them. Technology is only one aspect of the matter, and science should have a broader vision than that which is limited by its utilitarian applications.

The broad study of science should increase the humanity

of man. Technology alone will not do this and may prove to be positively dangerous. In spite of the miraculous powers which man controls owing to the application of scientific methods in recent years, these do not necessarily bring true happiness and enrichment of life. Amazing as is our recent scientific progress it is yet simpler to understand than the problems which concern its proper use as a true aid to humanity so that man shall lead the noble, significant existence for which he has the potentialities in his spiritual and physical nature.