

SCIENCE NEWS

EDITED BY J. L. CRAMMER

19

PENGUIN BOOKS

HARMONDSWORTH · MIDDLESEX

7L
A-1-10
psl. 12

Subs
SCIP

CONTENTS	
EDITORIAL	7
ASTRONOMY TODAY	9
David S. Evans	
GUIDANCE DEVICES FOR THE BLIND	29
Franklin S. Cooper	
FIFTY YEARS OF PHYSICS	46
Professor Max Born, F.R.S.	
STUDYING PLANTS WITH X-RAYS	61
ELUSIVE CHEMICALS	65
George Porter	
RESEARCH REPORT	77
A. W. Haslett	
LIGHTNING AND THE SPARK DISCHARGE	89
R. D. Connor	
CONTROLLED CORROSION	109
F. A. Fox	
HORMONES AND CARBOHYDRATE METABOLISM	113
E. Reid	
CORRESPONDENCE	133
BOOKS RECEIVED	139
ABOUT OUR CONTRIBUTORS	143
INDEX	144

27 illustrations between pages 64 and 65

EDITORIAL

THE last fifty years have seen astounding advances in science, and particularly in physics. If we look back beyond the half century a further six years we survey an immense development of basic knowledge about matter and the fundamental laws of nature. The electron was discovered in 1894, X-rays in 1895 – the year in which Marconi first succeeded in transmitting by wireless – and 1896 saw the discovery of radioactivity: and so to modern atomic theory and the atom bomb. Professor Max Born in his rapid penetrating glance over all this recent history shows what a remarkable amount has happened in a short time, and indicates some of the lines of future growth. Wireless is one such line, used first to study the higher regions of the earth's atmosphere, then in radar, and now in the study of molecular structure on the one hand, and of stars on the other. In fact radio-telescopes, which detect the emission of radio waves from points in the sky as ordinary telescopes detect light from the stars, are leading to the discovery of radio-stars, not hitherto observed, and to a whole radio-astronomy which will reshape our ideas of the universe. That is one of the subjects David S. Evans discusses in *Astronomy To-day*. As well as reaching out across the light-years to probe nebulae, physicists still have plenty of problems nearer home, as R. D. Connor shows as he discusses current theories of lightning.

But if the first half of the twentieth century has been the Age of Physics, the second half promises to be an Age of Medicine, an age which has indeed already opened. Penicillin, streptomycin, chloromycetin, aureomycin, terramycin ... the antibiotics made by moulds and so effective against a host of infective diseases are all less than ten years old and have changed the face of medical practice. Cortisone and A.C.T.H. (adrenocorticotrophic hormone), which produce such dramatic effects in the treatment of rheumatoid arthritis and may prove valuable also in other diseases, are leading to new general ideas in the theoretical basis of medicine. The study of hormones, the chemical controllers of the

INSTRUMENTS

There are at the present time a surprising number of new telescopes under construction or being designed, and several more which have recently been brought into operation. Of the latter the most famous is the 200-inch telescope on Mount Palomar in California. Final tests on the mirror of this instrument have recently been reported by Dr Bowen, Director of the Mount Wilson and Palomar Observatories, and it may now be assumed that the teething stages of this telescope are past. This instrument, the Hale telescope, is not only the largest in the world, having a light grasp almost four times that of the 100-inch Mount Wilson telescope and a capacity for resolving detail which is twice as great, but it is also one of the most revolutionary in design. The instrument has been described so often that it is hardly necessary to consider it in much detail, but some of its most striking features must be noted.

The first of these is the astonishing thinness and flexibility of the mirror. The mirrors of most large telescopes are just huge chunks of Pyrex glass in which care is taken that the thickness of the mirror is not too small for its diameter. The usual minimum is a thickness of one-eighth of the diameter. A mirror of this type is then supported in a cell provided with a mechanical flotation system, which usually takes the form of a complex system of counterbalanced levers and pads. These supports all act on the outside of the glass, which is so rigid that the mirror will not sag and lose its form under its own weight. However, the preservation of the same proportionate dimensions in mirrors of various sizes means that the weight of the glass increases rapidly (varying as the cube of the dimensions) with increasing size. Thus, if a mirror of, say, 67 inches in diameter weighed about a ton and a quarter, a mirror of three times this diameter and of similar proportions would weigh 27 times as much, or about 34 tons. The problem of mounting such a huge load in a movable tube, in such a way that the optical axis of the mirror remained fixed to the necessary degree of accuracy, would be a most severe one, and the solution would be extremely expensive to realize mechanically. In addition, the great thickness of such

a disc (25 inches) would present severe thermal problems. The passage of waves of high temperature through such a mass of glass would be extremely slow, and, to put it popularly, the disc would have a memory some months long of all the thermal changes to which it had been subject. Since temperature changes involve expansion and contraction even in the special low-expansion glass used for large mirrors, this long thermal memory would express itself as slight distortions of figure which might take months to settle down.

The 200-inch mirror was therefore constructed on an entirely different plan. It has a ribbed structure, none of the ribs being more than 4 inches thick, and no point of the glass being more than 6 inches from a surface. This simplifies the thermal problem, but complicates the mechanical one. Such a thin mirror is so flexible that it is no longer sufficient to balance out the external stresses of the supports. It is now necessary to provide support at a number of internal points. As an analogy we may think of a short train of trucks, the relative positions of which can be maintained exactly by means of the spring buffers between them. But if the train becomes long these relative positions can be maintained only by providing traction at several points along the train.

These 'internal' supports are provided in the case of the 200-inch mirror by a system of 36 screw supports, each of which has to be adjusted so as to carry the correct proportion of the load. With such a revolutionary system great care had to be exercised, and when the mirror was first installed in 1948 the shape of the outside zones had been deliberately left too high in the expectation that the outer overhanging zone would sag under its own weight. This in fact happened, but some further work was found to be necessary before the shape of the mirror surface as mounted in the telescope conformed exactly to the paraboloidal form which brings the reflected rays exactly to a true focus.

The second revolutionary feature is the north bearing of the mounting, which is constructed in the form of a gigantic horse-shoe to enable the tube of the telescope to be pointed exactly at the north pole of the heavens. This form of mounting is a

12

Science News 19

development of that of the 100-inch telescope (Inset, 1), which consists essentially of a long rectangular frame, the short edges of the rectangle carrying the pivots on which the telescope turns east and west, while the tube itself is mounted symmetrically between the long edges, and can turn north or south between them. If the short northern end is straight, as in the 100-inch telescope, the tube is limited in its northward movement, but in the 200-inch instrument the northern end is, as it were, scooped out into a horseshoe to allow the tube to lie parallel to the earth's axis (Inset, 2).

The third striking feature is the provision made for observation at the prime focus of the mirror. A carriage into which the observer climbs is placed in the centre of the tube. The reflected rays from the mirror then come to a focus between his knees as he sits with nothing but the sky above him, and nothing but the great mirror below him, and he is carried with the telescope as it moves to follow the stars. Naturally the interposition of this carriage cuts off some of the light to the main mirror, but the proportion is small, and the loss is less than would be entailed if a small secondary mirror were used to reflect the light to the side of the tube. These revolutionary features are likely to be copied, with modifications, in the design of other large telescopes.

A second instrument brought into operation at about the same time was the 74-inch reflector of the Radcliffe Observatory at Pretoria, South Africa. This instrument, of conventional design, would hardly arouse very wide comment merely on grounds of size, so blasé have we become, but for the fact that it is the largest telescope south of the equator. It is the fourth largest instrument in the world, although it will soon be deprived of that distinction, but its nearest rivals south of the equator are the instruments at the Harvard station at Bloemfontein, South Africa, and at the Argentine National Observatory at Córdoba. It has, however, a considerable advantage in light-gathering power over both these instruments, and work has already been in progress for some time on the relatively poorly explored southern skies.

Two telescopes larger than this will soon be seen. One is the Isaac Newton telescope for the Royal Greenwich Observatory at Herstmonceux Castle, Sussex. This instrument will employ a 98-inch glass disc presented by the University of Michigan, and will be of somewhat unusual design, for the primary mirror will be spherical. The focus of a spherical mirror is not perfect, but its figuring is much simpler than the production of a paraboloid. Used with a suitable small secondary mirror enough accuracy of focus will be attained for feeding the starlight into a spectroscope, while for direct photography a correcting plate – a plate of glass on which has been ground a rather complex surface form – will be provided to perfect the focus over a wide field of the sky. This dual purpose instrument should provide very flexible operation and, probably one of the considerations which the designers have in mind, great convenience in use in a climate where short breaks in cloudy weather may make up a good deal of the available observing time.

At the Lick Observatory, Mount Hamilton, California, work is under way on the construction of the dome for the new 120-inch telescope, which will rank second in the world when completed.

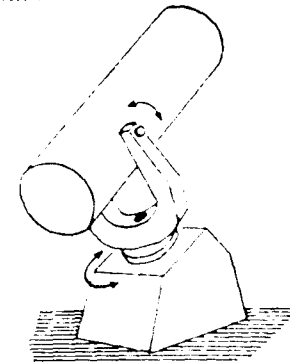


Fig. 1. Fork mounting: the telescope turns east and west, and up and down, as indicated by the arrows.

The mirror is to be ground from a flat of 120 inches in diameter originally constructed as an auxiliary for the testing of the

200-inch, but not used for that purpose. Now this disc is to become a mirror in its own right. An unusual feature of the project is that the figuring of the mirror will be carried out in the dome of the new telescope itself, and for this purpose the authorities have bought much of the equipment used for grinding the 200-inch mirror. The tube construction will be somewhat similar to that of the 200-inch telescope, and it is also proposed to follow the lead given by the Hale telescope in providing an observing position at the prime focus. In other respects, however, the new telescope will differ, for example in the mounting, which will be of the fork type. (Figure 1).

In addition to these new giants a number of telescopes, of what has almost come to be a conventional size – about 74 inches in diameter – are in prospect, including one for the Commonwealth Observatory at Canberra, Australia, and one for the Egyptian National Observatory at Helwan. A third, somewhat larger, is under construction for the new French astronomical centre at St Michel, in the south of France, where a complete astronomical village is being formed.

All these instruments are of more or less similar design, and although they incorporate detailed engineering features of a revolutionary kind, and are of enormous size, in optical principle they differ little from the original reflecting telescope of Newton. The remaining instruments to be described are of a relatively novel type, deriving from the camera constructed 20 years ago by Bernhard Schmidt, an associate of Hamburg Observatory. To understand the principle of this instrument we must consider the principles on which an ordinary reflecting telescope works. The mirror is made paraboloidal in shape because all rays parallel to the axis of the mirror are reflected to a perfect focus. This is not true of any other shape of mirror, and it is not true of rays parallel to any other direction (Fig. 2). This means that a paraboloidal mirror forms a perfect image of a star if the telescope in which the mirror is mounted is pointed exactly at the star, but not if the telescope is pointed a little way off the star so that the image is off-centre in the field of view. The defects increase in importance very rapidly with increasing distance from

the centre of the field, and in effect limit the field of view of large telescopes of conventional pattern. To fix the ideas one can say that many large telescopes have a field of view of perfect image formation covering an area of sky less than a quarter of that covered by the full moon.

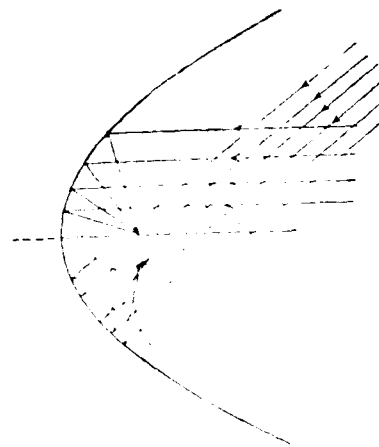


Fig. 2. Geometry of a parabolic mirror. In the upper half rays parallel to the axes are reflected to a perfect focus: in the lower half off-axis rays are reflected to an imperfect focus. The reflected rays all touch the dotted line.

The second important point concerns the brightness of the images formed by the telescope. A large mirror is a receiver of light, and the bigger the mirror the more light it receives from a particular source, such as a star. Hence, the bigger the telescope the brighter any given star will look when observed with it. In the case of an extended object such as a nebula, things are a little different, because the total light received by the mirror is spread out into an image of a certain size. The size of the image depends only on the focal length of the telescope: roughly, a telescope ten feet long will give an image of the moon an inch in diameter and the image size will increase proportionately with

the length. In a word, length determines image size (of an extended object); telescope diameter determines the amount of light available to form that image. Image brilliance is therefore increased for a telescope of given diameter by making the focal length as short as possible, *i.e.*, by packing the same amount of available light into a smaller image. Most reflecting telescopes have a length at least five times their diameter, and it is impossible to compress them further because the off-axis errors already mentioned become important closer and closer to the axis.

Schmidt's solution was to use a spherical mirror: this is limited of course by its own edge, but each part of the surface is just like any other, *i.e.*, optically there is no special axis. A parallel bunch

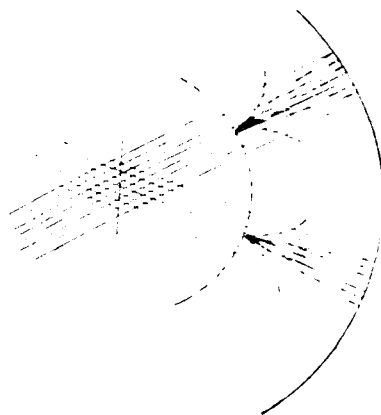


Fig. 3. Reflection at a spherical mirror: all parallel bundles of rays are reflected alike. The reflected rays come to an (imperfect) focus on a surface half the radius of the mirror. For each bundle the reflected rays touch a certain curve (shown dotted).

of rays coming in normal to the mirror is reflected to a focus at a point above the mirror which is half-way between the mirror and the centre of curvature. If we put a curved film there we should get a photograph covering a large range of angular directions, and the quality of the images should be almost

uniform over the film (Fig. 3). The problem posed and solved by Schmidt was the problem of how to have the best of both worlds; how to retain the wide field of the spherical mirror and yet perfect the image formation. This was done by the interposition of a correcting plate – in effect a thin lens of small but complicated curvature – in the path of the incoming rays at the centre of curvature of the main mirror (Fig. 4). This essentially is the Schmidt camera, with all the complicated details of the form of the correcting plate, the quality of image formation, and so forth, left out. In fact, the camera has a tremendous field: some Schmidt cameras can photograph the whole of the Orion constellation on one film. It can be made very short, with a focal length twice the diameter (or less) – this gives images of extended objects six times (or more) as intense as those for a conventional reflecting telescope. The image size is small, but

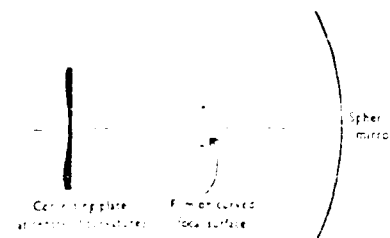


Fig. 4. The Schmidt Camera.

the film can be enlarged or studied under a microscope, so that this is no disadvantage; the film has to be bent to a spherical shape, and this is something of a disadvantage.

The chief use for a telescope of this type is as a scout for a large instrument of conventional type, or for the photography of extended objects of low surface brightnesses. Recently there has been brought into operation on Mount Palomar a Schmidt camera with a mirror of 72 inches diameter with a correcting plate of 48 inches diameter which will serve as a scout for the 200-inch telescope. The field of the latter is so small that any discovery made with it is likely to be a mere matter of luck,

but the Schmidt has an enormous field, and is so fast that photographic exposures of more than, probably, half an hour will bring up the dim light of the night sky to a level at which it will constitute a heavy background fog on the film. So in half an hour an area of several square degrees of sky can be surveyed. Anything of special interest can then be studied in detail with the 200-inch telescope. As an example of what can be done we may cite the recent discovery by Baade of the minor planet Icarus, whose eccentric orbit carries it from beyond the orbit of Mars to a distance closer to the sun than that known for any other planet. Incidentally it will now be realised that the Isaac Newton telescope will be a convertible Schmidt camera.

The disadvantage that the film has to be curved has been overcome by modifying the original Schmidt design in several ways. One form is the Baker-Schmidt, which uses a convex mirror in addition to the primary spherical mirror. This retains the advantages of the Schmidt form but flattens the field, and also shortens the telescope by doubling the light beam back on itself. It is one of the chief defects of the original Schmidt form that the correcting plate has to be at the centre of curvature of the mirror, which is distant from the main mirror twice its focal length. That is, the tube of a Schmidt camera has to be twice as long as that of a conventional reflecting telescope, and this entails a much larger and more expensive dome for housing it. A Baker-Schmidt telescope with a primary mirror 36 inches in diameter is now being erected at the Harvard College southern station at Bloemfontein for work under the direction of Dr Bart J. Bok. The project is a joint one by Harvard, Dunsink Observatory in Eire, and Armagh Observatory in Northern Ireland. Dr Bok is one of the world's experts on Milky Way structure, and such an instrument as this, capable of showing up faint extended detail of the Milky Way in very short exposures, is ideal for the project to be undertaken, a survey of the central parts of the Galaxy.

In Britain an interesting project is being undertaken at St Andrews, where a type of modified Schmidt telescope is being constructed to designs worked out by Linfoot, the British

specialist in this field of optical design. The construction is actually being carried out at the Observatory, and a pilot reduced-scale model of the final instrument has already been produced.

THE PHOTOMULTIPLIER TUBE

The fact that certain metals emit electrons when light falls upon them has been known and used in industrial and scientific applications for many years. The standard forms of photoelectric cell, as they came to be known in the thirties, were the barrier layer cell and the vacuum cell. The former, much used in photographic exposure meters, has received little or no application in astronomy. The latter type, developed to a high pitch of commercial manufacture by the needs of the cinema and other industries, found many astronomical applications. Light falls on a photosensitive metal surface and electrons are ejected with a velocity depending on the wavelength of the incident light and the nature of the metal employed. The number of electrons emitted is closely proportional to the intensity of the incident light. To measure the number of emitted electrons these are collected at an anode by the application of a potential difference between it and the sensitive surface. The electrons are thus impelled across the evacuated space in which the components are housed, and delivered at the anode in the form of an electric current.

For large light intensities these currents can be measured directly, but in many cases the current is fed to a D.C. amplifier which enables much fainter light sources to be measured. The currents produced by stellar images even in large telescopes are excessively small, and the process of amplification is attended by great difficulties. Although the amplifier designs look simple enough on paper, in practice the difficulties associated with securing stability are very great, and the whole amplifier is sometimes enclosed in an evacuated casing. The only alternative is to feed the electron output to some kind of electrometer which gradually collects the charge until it becomes measurable. However, such measurements take time, during which the

transparency of the sky may be changing, thus upsetting the results.

A tremendous leap forward has been taken with the introduction of the photomultiplier tube, a device which was in the laboratory stages during the late thirties, and whose development was greatly stimulated by the electronic advances made during the war. Light falls on an emissive surface which throws off electrons in the usual way, but these, instead of being collected immediately, are propelled by means of a potential difference of about 90 volts to a second surface, at which each incoming electron is energetic enough to expel about five new ones. These in turn are brought, by means of a further potential difference of 90 volts, to a third dynode, where further amplification takes place in the ejection of secondary electrons. With nine dynodes an overall amplification of more than a million times can be secured. In a sense, the replacement of the separate cell and amplifier in its own evacuated casing by the enclosure of the whole arrangement in a single envelope is the logical development of the pre-war trend which we have already noted. The application of the photomultiplier tube to astronomy is due largely to G. Kron of Lick Observatory, but the gain in sensitivity to light of about twenty times over anything previously known and the stability of the arrangement have already brought it into widespread astronomical use.

For very intense sources the tube may be connected directly to a galvanometer or oscillograph, but it is more usual to interpose some suitable electrical device. For moderately bright sources this may be a D.C. amplifier of modern design leading to a recorder such as the Esterlin-Angus or Brown potentiometer. When plenty of light is available, for instance with a large telescope, or with bright stars on smaller instruments, this system makes it possible to measure the brightnesses of stars in several colours very easily and rapidly. It has been applied both to standard magnitude work and to the study of star clusters, in order to determine the relative proportions in them of stars of different colours (temperatures). By traversing the image of an extended object such as a nebula across the cell it has been

possible to map out the lines of equal brightness (isophotes) on these structures, much as a surveyor marks contour lines on a map. Most work of this kind can also be done by photographic methods, and at present there is a good deal of friendly rivalry between the exponents of the two schools.

The sensitivity of the photomultiplier tube is so great that account has to be taken of the atomic nature of light and electricity. From very faint sources the number of quanta arriving on the cell may be very small, so that, although over an appreciable period of time the rate of arrival may be sensibly constant, in periods of the order of a millisecond or less there may be an appreciable random variation about the mean. This statistical fluctuation plus similar fluctuations in the amplifiers themselves are responsible for what is called 'noise', and these original statistical fluctuations are all amplified along with the steady average value which it is desired to measure. Noise can be reduced by cooling the cell, usually with dry ice. Or on the other hand the input from the star may be regarded as a series of pulses and an arrangement made to count the number of pulses arriving in a certain period of time. The advantage here is that it is possible to arrange the electronic counter so that it disregards pulses smaller than a certain arbitrary minimum, counting only those which definitely have their origin in the light from the star and are not due to random fluctuations in the circuits.

While it is unlikely that these cells will oust the photographic plate – if only because the photographic plate can get to much fainter limits of brightness by building up an impression throughout a long exposure – nevertheless the arrival of the photomultiplier tube is likely to have an effect on astronomy comparable with that produced by the introduction of the photographic plate.

RADIO ASTRONOMY

Telescopes are receivers of electromagnetic radiation, effective in a range from something below 4,000 Angstrom units to about 6,500 Angstrom units. An Angstrom unit is a length equal to

the one hundred millionth part of a centimetre, and the wavelengths quoted are the limiting ones to which the eye and the ordinary panchromatic plate are sensitive. It is possible to extend the limit a little on the short wavelength side by the use of aluminised mirrors, but there is a complete cut-off in the near ultraviolet, where the earth's atmosphere is completely opaque. In an important astronomical development not discussed here, high altitude rockets have been used to get above the atmosphere and to record the solar radiation at still shorter wavelengths. In the long wavelength region specially sensitized photographic plates (which are not too satisfactory) and various forms of radiometric receiver have been used to extend the band of usable wavelengths to more than 20,000 Angstroms - *i.e.*, to the region of wavelengths of a few thousandths of a millimetre.

Light rays are, of course, of the same nature as radio waves and differ only in wavelength. Normal short wave radio communication is on bands in the region of ten metres and upwards which can be transmitted over considerable distances because they are reflected at high altitude ionized layers in the atmosphere, that is, the earth's atmosphere is effectively opaque to the vertical transmission of such wavelengths. The frequency bands exploited for radar purposes during the war correspond to shorter wavelengths - of the order of 10 centimetres and upwards - and these are capable of passing through the ionospheric layers. It is in this band of wavelengths between the longest 'light' rays and the shortest 'radio' waves that radio astronomy has developed during the last decade. Radio astronomy falls into two parts: first, radar astronomy, the detection of reflections by external bodies of waves generated on the earth; secondly, radio astronomy proper, the detection of waves generated naturally in space.

In the first category fall such projects as the detection of a reflection from the moon carried out by the U.S. Signal Corps. In principle this is a method of determining lunar distance, but so far technical considerations have limited the possible accuracy of any such determination, and although this method may become so, it is not yet a rival to the older astronomical methods.

Of much more interest is the use of radar methods for the detection and counting of meteors. The echoes detected are produced not by the meteors themselves but by the much more extensive columns of ionized air produced by the meteors in their passage through the upper atmosphere. The most detailed work on this subject is by Lovell and his collaborators at Manchester, and they have not only been able to detect and count meteors and to correlate their observations with visual records, but, in addition, have been able to detect new meteor streams, previously undiscovered because of the fact that the earth encounters them in summer during the hours of daylight.

The discovery that the sun emits radio waves was made a number of years ago, but the initial observation could be exploited only when radar equipment operating on short waves was developed during the war. Unexplained noise detected by radar receivers was eventually traced to the sun. It appears that the sun radiates radio waves of two types, one originating in the quiescent sun, the other in sunspots. The problem of ascribing radiation to large sunspots is attended by the difficulty that the large receiving aerials used to pick up and focus the incoming waves represent, at radio wavelengths, telescopes whose dimensions are not very many multiples of the wavelengths employed. It is well known from the theory of electromagnetic waves that under such conditions the capacity of the instrument (a 'radio telescope' if one chooses so to name it) for resolving detail is strictly limited. To give an example, a radio mirror of say 5 metres in diameter operating on a wavelength of 50 centimetres is capable of indicating that the sun is the source of the radiation received, but it is incapable of 'seeing' detail on the sun. A variety of ways of getting over this has been tried, of which the most interesting is that developed at Cambridge by Ryle and his co-workers. Here a very extensive aerial array is used which in the radar field is analogous to the device used in visual optics for increasing the effective resolving power of a telescope, the Michelson interferometer.

This work made it certain that some sunspots are sources of radio waves. It has also been shown that solar flares - short-lived

imagine starting a star off at other than its proper place in the diagram it might be expected either to warm up or cool down until a balance between the various factors had been struck.

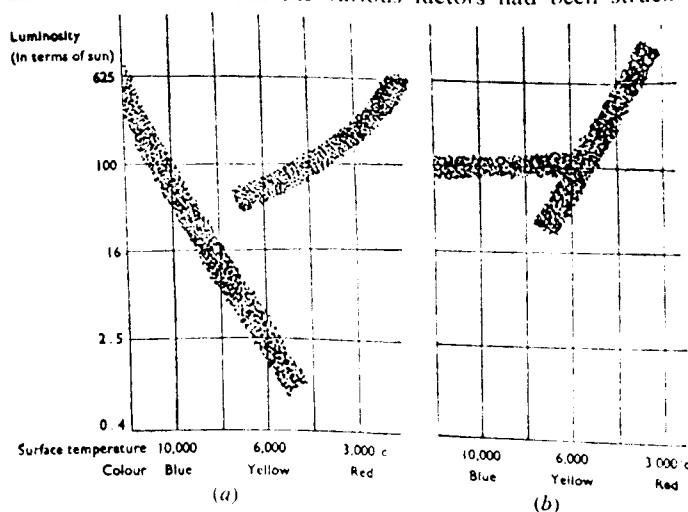


Fig. 5. Star populations.

- (a) *Population I.* Classical Hertzsprung-Russell Diagram. Star population near the sun and in open clusters.
- (b) *Population II.* Star population in elliptical nebulae and in globular clusters.

The fact that stars of a particular temperature seem to be constructed according to a regular pattern is therefore something which begins to touch the most fundamental and deep-laid notions of astrophysics – the nature of stellar energy generation and the problem of stellar evolution. But in addition the facts have very great practical application, for if we know that a star of a certain colour represents something like a standard article, then we can, on observing such a star, immediately guess at its distance, even though this may be so great that the star only just shows on a long exposure photograph. See a star which is blue enough to justify an estimate of a surface temperature

of 10,000°C.: deduce from the diagram that it is in reality 100 times as bright as the sun: solve the simple problem of how far off this star must be to look as faint as it does.

All this assumes that the diagram, which represents a sample of the population near the sun, is a sample of star population anywhere. Now this assumption is being questioned. Clearly a diagram of such deep significance and such great practical value is an astrophysical datum of outstanding importance, and any doubts as to its universal applicability are of vital interest to astronomers.

We have put on the diagram all stars whose distances can be measured by direct geometrical methods, and these are all near the sun. What further information can we obtain? Most of it is somewhat indirect. More than 20 years ago Oort, the Dutch astronomer, noted significant differences between the type of stars moving slowly round the centre of the Milky Way and those moving rapidly. The American astronomer Trumpler studying star clusters found that they had Hertzsprung-Russell diagrams which were abnormal. This last method is a rather general way of getting new information: stars which on appearance may be classed as belonging to a cluster are presumably all at the same distance, so that in this case apparent brightness is an indication of true brightness (Fig. 5b). Plotting apparent brightness against colour will then give an indication of the population diagram for that cluster. A very significant step was taken by Baade in 1944 when, using the 100-inch telescope, he was just able to resolve into stars certain elliptical nebulae which before had always appeared as amorphous oval patches on astronomical photographs. This considerable technical feat showed that in elliptical nebulae (Inset, 6) (as was shown 20 years ago to be the case in globular clusters) the population was of a kind in which the brightest stars were red and not blue. It is also possible that this new kind of population (called population II) may be the kind which is characteristic of the centres of many spiral nebulae, where there is often an apparently amorphous oval mass, presumably consisting of a vast number of individual stars (Inset, 7). So far the matter has hardly gone

beyond the stage of significant pointers, but the further investigation of these problems is likely to be of very great importance. The final establishment of the existence of two types of stellar population, the classification of the types of structure in which each occurs, and so forth, will at once throw light not only on the possibilities of stellar evolution, but also on problems of the evolution of clusters of stars and of nebulae of various types, and this in turn is bound to affect our views of the origin of stellar energy. Like so many important problems when seen from the wrong side – that is, before they are solved, – this one seems rather diffuse and abstruse. Only after the answers have been found will it seem simple and obvious.

GUIDANCE DEVICES FOR THE BLIND

FRANKLIN S. COOPER

INTRODUCTION

FREEDOM means many things. For the blind, one of its essential elements is independence of movement. Yet, despite the remarkable skills of some gifted individuals, the number of those who travel by themselves is only a small fraction of all the able-bodied blind. Too often, blindness means staying at home. But blindness is not, as people sometimes assume, a total handicap, although freedom and effectiveness are often severely restricted. There is no lack of capacity for action; only the information on which to act is missing. Thus the problems of the blind are, at the base, problems of communication. Blindness may even be characterized as a cybernetic deficiency – a missing link in the feedback mechanism – though this view tends to overemphasize automatic performance as compared with conscious behaviour.

Guidance for the blind in the restricted sense of aids to travel becomes then a matter of supplying information. This appears to be a concise statement of the problem in engineering terms, and the reader might reasonably expect to find in what follows an account of that latest technological marvel, the Electronic Informer. Many devices intended to perform this function have indeed been built, but none has thus far been a practical success. So, of necessity, it is with problems rather than solutions that we must deal.

What it is like to be blind

First of all, what kinds of information are needed for independent travel? This question was asked of a group serving as subjects in a research programme at Haskins Laboratories. All were totally blind able-bodied young men accustomed to travelling alone in New York City. Their answers are most

illuminating, although the views of so small a group can hardly be considered as broadly representative.

The travel diaries of the group show quite clearly that many more problem situations arise during outdoor travel than indoors. Home and office are not without the hazards of a misplaced chair or a half-open door, but these are known dangers and they exist in a familiar environment. Orientation is easily maintained here, in marked contrast with travel out of doors. Constant vigilance and much ingenuity are needed, as a single excerpt from one of the diaries will illustrate:

'Inasmuch as I have been travelling from Brooklyn to New York for approximately three months, I find that memory has helped me considerably. For example, upon getting out of the subway on Lexington Avenue, I must turn right to reach the corner before I cross. I continue walking up towards the corner looking for a very definite cue, which is the Nedick's stand. This is easy to detect because of the odour of hot frankfurters. I take two more steps forward and then turn left to cross Lexington. Walking on 42nd Street across Third Avenue I follow the method of trying to keep myself a certain distance from the kerb and when I feel that I am reaching the end of the block I swing wide to the left so that I may avoid the Third Avenue El stairs which I know to be there. I proceed to cross Third Avenue with assistance or with my own cues and I remember that somewhere in the middle of the block and very close to the kerb extending inward for a few feet there is an obstacle which is about three feet high, and on several occasions I have found myself hitting this with great force, giving me temporary pain in my midsection. This obstacle I have managed to avoid through memory.'

Thus, maintenance of general orientation depends on finding a succession of landmarks. These may be linked together by such mnemonic devices as step-counting where the route is exacting. Reference points are used also in the detailed operations of walking in a straight line at a constant distance from the kerb. The variety of cues described as useful for landmark

identifications is a tribute to the ingenuity of the traveller, but equally, it is an index of the paucity of information available.

Moreover, not all objects reveal their position by sound or smell. Obstacle avoidance is a second task to which constant attention must be given, a task of such importance that it is often considered almost synonymous with independent travel.

Evidently priority is assigned to a hazard on the basis of how severe might be the physical harm, and only secondarily on how often it occurs. For example, missing the edge of a platform, which may be classed as an encounter with a negative obstacle, ranks high in the list. But obstacles of a less hazardous nature can also be vexatious. Even the possibility of collision with a dust bin or a fire hydrant may slow progress to a laggard's pace. Indeed, freedom to walk at a normal rate would be a major boon to the blind.

In brief, success in travelling alone is largely a matter of locating and identifying objects of the outdoor environment. Some can be heard and thus give warning or serve as landmarks. Others lie in wait, silent and inflexible.

Existing aids

The requirements to be met by a guidance aid are, in the main, that it permits one to walk at a normal pace without undue risk. Obviously a device for this purpose must be easily portable, reliable in operation, and not too conspicuous. Its primary function, however, which is to detect obstacles, requires more careful analysis before design specification can be formulated. A useful point of view proposed by C. M. Witcher in a study of this sort divides the forward area into three zones: an outer 'awareness' region, a middle 'attention' region within which objects may require a decision to change course, and an inner 'avoidance' region, where action is imperative. Appropriate widths of the two inner zones were estimated at about four feet each, on the basis of a normal rate of walking. Figures of this sort help to determine the kind of range information which an ideal guidance device should provide.

The three aids which the blind have now are dog, cane and

obstacle sense. All have their merits as well as their limitations. The effectiveness of the Seeing Eye dog depends chiefly on rapport between dog and master. This, like the finest of human friendships, is a rare thing, and explains in part why the number of guide dogs in use in the United States is less than fifteen hundred, although there are some thirty to fifty thousand of the able-bodied blind. The cane, in skilled hands, can be an instrument of delicacy and precision. Its length of course is limited and it must explore at a rate which will not annoy the user or antagonize bystanders.

However, most of the blind who travel independently do not rely exclusively on dog or cane. A few abjure them altogether, depending instead on an uncanny 'sixth sense' by which they can detect most sizeable objects at distances of several feet. This faculty has been variously explained in such semi-mystical terms as facial vision, pressure sense or more generally, obstacle sense. It appears, however, to be strictly auditory in nature, involving only unusual skill in the interpretation of faint echoes returned from nearby objects.

The gift of obstacle sense appears to require special insight as well as careful listening. This is borne out by individual accounts of rapid and complete mastery of the skill after years without it. If this insight could be achieved through special training, many more of the able-bodied blind might be helped to relative independence of action without resort to instrumental aids. Some promising beginnings have been made, but much remains to be done in formulating effective training procedures. Obstacle sense is not, however, the final answer. Even those who are most skilful encounter many tasks and situations with which, for lack of data, they cannot cope adequately.

Dog, cane and obstacle sense - strange tools, nowadays, for gathering information! Many now consider how our fabulous new techniques might be used in building devices to give the blind greater independence of travel. An adequate account of these efforts would be too extensive for inclusion here. Besides, the subject has been fully covered in a recent book on blindness published under the joint sponsorship of the National Research

Council and the Veterans Administration (*Blindness: Modern Approaches to the Unseen Environment*. P. A. Zahl, Editor, Princeton University Press, 1950). We can, at most, mention a few of the more recent undertakings before turning to a consideration of the devices themselves.

EXPERIMENTAL DEVICES

The most ambitious of the group efforts was that of the Committee on Sensory Devices, initiated in 1944 by Vannevar Bush as part of his wartime Office of Scientific Research and Development. This was a programme of basic research on the psychological and engineering principles involved in building guidance aids, reading machines, and other devices for blinded service men. In approach, as in initial scale of effort, it was unique, with major emphasis on the human engineering aspects of the problem rather than gadgetry. Perhaps the principal lesson drawn by the committee lies in a heightened awareness of the controlling rôle which human factors must play in the design of such instruments. Thus, as Dr George W. Corner, then chairman of the committee, wrote in the volume, *Blindness*, 'One thing (that) has surely been gained ... is the realization by physicists, engineers, and mechanical inventors that when a machine is to act upon a man there are always going to be biological and psychological limitations that outweigh all the mechanical difficulties.' Indeed, several of the guidance devices developed as a part of the programme operated quite satisfactorily as mechanisms, but still failed to be of much assistance to blind users. The committee is continuing its work as an organ of the National Research Council and with assistance from the W. K. Kellogg Foundation, though now on the reduced scale befitting a war orphan. Also, some of the guidance projects started or assisted by the committee are being continued at the Franklin Institute, the American Foundation for the Blind, and the Haskins Laboratories.

In a parallel programme, the Signal Corps Engineering Laboratories undertook the development of an optical guidance device, and collaborative arrangements for testing it were made

with the Committee on Sensory Devices. Eventually, twenty-five units were engineered and produced by the Radio Corporation of America. Field tests with these units are now under way at Haverford College under the auspices of the Veterans Administration. Although both Army and Navy had extensive rehabilitation programmes for blinded servicemen, these did not take up the problem of developing devices for guidance.

In England a Sensory Devices Committee was formed, somewhat along the lines of its American counterpart, to coordinate the development work of various groups, including St Dunstan's Experimental and Research Department, the National Institute for the Blind, and the National Physical Laboratory. Several guidance devices were built and tested shortly after the end of the war. In Canada, also, the National Research Council undertook a programme of research, including the further development of one of the devices initiated in the U.S.A.

It has, unfortunately, been necessary to describe most of these endeavours in the past tense. There are two main reasons for this: in some cases, at least, financial support was withdrawn as men and governments tried to forget the havoc of war; and, in addition, the lack of immediate success in building *useful* as contrasted with *operative* devices has been discouraging. Clearly, the problem is more complex than it seemed, and in ways which elude the engineer.

For this reason, in examining a sample collection of the guidance devices developed during the past five or six years, our purpose will be to discover where these devices have failed, and what lessons may be learned for the future. Almost all the guidance devices which have been proposed thus far are conceptual descendants of the cane; that is, they are intended to permit the location of obstacles by manual searching with an immaterial probe such as a beam of sound or light. The natural 'feel' of the cane is replaced by some other signal, auditory or tactile, which must convey the information that an obstacle has been located and that it is at a certain distance.

Supersonic methods of obstacle detection offer the advantage that range information is obtainable directly from the time of

flight of a pulsed signal generated by the device. A guidance aid utilizing this property was developed for the Committee on Sensory Devices by Slaymaker, Meeker and Larsen of the Stromberg-Carlson Company. Two magnetostrictive transducers were used, one to transmit a two-millisecond pulse at thirty-two kilocycles, and the other to receive echoes from any nearby objects. The transducers were mounted in parabolic horns about four inches in diameter which gave directional reception and a narrow transmitted beam, 6.5 degrees wide at the half-power points. The circuits were arranged to operate on the first echo only, thus restricting attention to the nearest object at which the horns were pointed. Information was passed from device to user by feeding the received pulses into earphones or into a tactile stimulator. A first rough model weighed about eight pounds, and was carried on a shoulder strap. The horns were mounted side by side on a handle so that they could be used like a flashlight to explore the surroundings. This handle also carried the tactile stimulator, a vibrating stylus on which a finger could be placed.

Experience with this device was typical of that obtained with a number of other supersonic guidance aids. It was sensitive enough to detect objects as small as a pencil or as flimsy as a silk handkerchief at distances of several feet. For larger objects, a maximum usable range of twenty-five to fifty feet was possible, but was not used. In fact the blind subjects who tested the device preferred that no signal should be given unless an object was nearer than about ten feet. The appearance of a signal then served to warn them of an object near enough to require attention and yet far enough to permit easy avoidance. Range judgments were crude, since the total scale of pulse rates was only five to thirty per second, an inflexible limitation inherent in the circuit. The best tactile presentation would have required rates of about twenty to two hundred.

Use of the device was enormously complicated by specular effects. Many surfaces behave like mirrors at supersonic frequencies, with the result that a smooth wall may fail to give any detectable echo whatever unless the horns are pointed directly

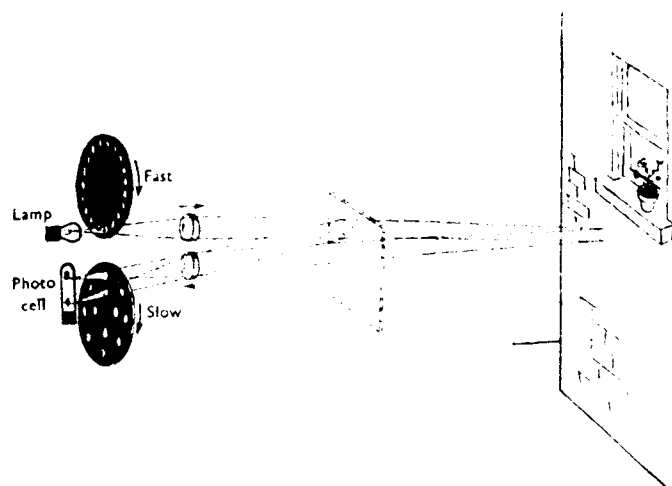


Fig. 6. (a) Automatic triangulation in the Signal Corps optical device gives a signal in which the number of pulses per second gives information on the range. The lower the beat, the closer the obstacle.

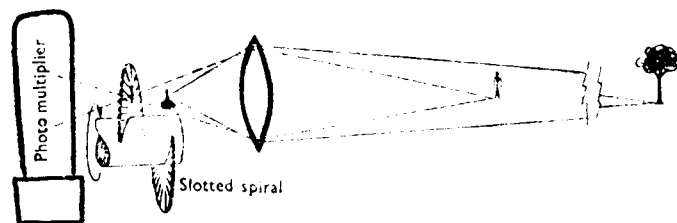


Fig. 6. (b) OPTAR — Optical Automatic Ranging — is what Kallmann calls his optical guidance device. It uses ambient light and derives its range information by searching in depth for image structure.

An alternate approach, now under investigation at the Franklin Institute, is the use of ultraviolet light of wavelengths shorter than those remaining in sunlight after its passage through the atmosphere.

It would be premature to judge the performance of the Signal

Corps optical device until systematic tests have been completed with the fully engineered models. The greatly reduced size and weight of these units will facilitate searching, and the added provision of vibratory presentation of the signals will free the ears for other duties.

A general comparison of optical and supersonic systems must be based partly on theory and partly on experience with comparatively crude devices. Each system has its own virtues and shortcomings, but on balance they all seem to be of comparable merit.

Although optical and supersonic devices which employ a projected beam of energy have received major attention, there are a number of other possible approaches worthy of notice. Optical devices dependent on ambient illumination were described as early as 1912 by Fournier d'Albe and as recently as 1950 by H. E. Kallmann. The d'Albe device used selenium cells in a bridge circuit, with unbalance indicated by a buzzing sound in a telephone receiver. With it windows and doors could be found, but not much else. A modern version, designed to simulate the primitive eye of insects, was proposed by Lashley. In appearance and manner of use it resembled a flashlight, although of course it was used to collect light rather than to emit it. The audible signal from the device was a steady tone so long as the incoming light did not change in intensity. However, scanning across a dark to light boundary caused a momentary rise in pitch, or conversely, a decrease in pitch if the change were from light to dark. Outlines could be traced with moderate ease but interpretation proved difficult. Information about the distance of objects was not available directly; it could be inferred from apparent size only when the object could be recognized.

Kallmann's device (Fig. 6b), on the other hand, is designed primarily for ranging, and it accomplishes this result in a very ingenious manner: the image formed by a lens exists in depth as well as in area perpendicular to the axis, and it can be explored in all three dimensions by a light chopper of appropriate shape. Thus, audible signals can be generated from bright areas of the

image in such a way that the time of occurrence, or the pitch, of these tones will correspond to the distance of the object. The signals closely resemble those of the frequency-modulated supersonic device and have some of the same disadvantages. On the other hand, Kallmann's device has the very important virtue that it can be made much lighter and smaller than those devices which must provide power and components for transmitting a beam of light or of supersonic energy.

Audible sounds for echo location have been employed in numerous devices ranging in complexity from steel heel-plates to stereophonic hearing aids. One of the most recent sonic devices was developed by Witcher at Haskins Laboratories and, later, at the American Foundation for the Blind. Witcher used a directional horn, small enough to be manipulated easily like a flashlight, which projected a rapid series of high-pitched clicks. Echoes from such objects as benches, cars and trees were readily detectable at distances of eight to twelve feet, though smaller objects were often not detected. The clicking sounds did not seem to attract undue attention. The directivity of the horn, which gave a beam width of about 16° at 12 kilocycles, allowed easy scanning. In addition, the directional indications obtained by searching were confirmed by binaural localization of the apparent source of the echoes, so that the signals seemed natural and easy to use in avoiding collisions with sizeable objects. Ambient noise and specular effects were, as expected, more troublesome than with supersonic devices, and range information was not provided directly. On the other hand, the sonic device was comparatively small and light, and did not interfere with normal use of the ears. Some experimental trials at St Dunstan's with a somewhat similar audio-click device and with supersonic beam devices tended to favour the sonic device, without however establishing its utility in an absolute sense.

THE CRUX OF THE MATTER

It is precisely the achievement of practical utility which is so elusive. All of the devices which have been mentioned, and many more besides, supply some information not otherwise available

to a blind person. To be sure, none of them merits complete reliance in all situations, notably in detecting a step down, and yet a few of these devices could provide enough information about most situations to permit safe and rapid movements. They could, that is, if the information were readily transferable from the instrument to its user. Devices, like Seeing Eye dogs, would be ever so much more helpful if only they could talk!

Here is the gap which remains to be bridged. The techniques required are, in the main, those of psychology rather than of engineering. Complex as some aspects of the problem undoubtedly are, the central questions can be put in simple terms: how should information be organized and presented in order that it may be most readily perceived? How long a period of learning will be required for the effective use of a device, assuming that the information which it provides is adequate and well organized?

Proficiency is certainly not to be expected until use of the device has become thoroughly automatic, and conscious analysis of its signals is no longer necessary. Ideally, the device must seem to give direct information about the external world, its signals being perceived as attributes of the objects located there without reference to the functioning of the device as an intermediary. For example, long practice will enable one to 'feel' with the tip of a cane rather than with the fingers which grasp its handle. Similarly, the high-pitched clicks from Witcher's device seem occasionally to be coming from the obstacle itself. By contrast, the signals from most devices appear to be localized at the ear-phone or the vibrating handle of the instrument; they fail to convey an impression of objects distributed in space, very likely because they differ from the cues normally involved in space perception.

The difficulties of the blind in dealing with space concepts serve to emphasize the unique role which vision ordinarily plays in the perception of spatial relations. Yet even vision does not yield these results without long practice. A striking example is furnished by those individuals, blind from congenital cataract, who have had their vision restored as adults. At first they are

aware only of colours and vague forms. The names of colours can be learned within a few days, but weeks of training may pass before such simple shapes as squares and triangles can be identified without resort to counting the corners. Other data also point to the conclusion that normal visual perception of objects and spatial relations, which seems so simple and immediate, is actually the result of arduous learning.

If so great a learning task is involved in attaining proficiency with an 'ideal' guidance device, then perhaps some of the existing devices would prove to be quite usable if adequate training were given. Certainly none of them has yet been subjected to such extensive trials. Fortunately, the experiment is about to be made. Thorough field trials, extending those made by the Signal Corps on its optical device, are to be conducted by T. A. Benham at Haverford College. Tests of this sort are feasible only when a device has been well engineered and at least a few trouble-free units are available. Even then the task is immense. These trials should go far towards discovering whether the discouraging results from early tests were due to a wholly inadequate appraisal of the learning problem or to deficiencies of the device, particularly with respect to the presentation of information. And, even though the tests employ only one specific type of equipment, the results should be broadly applicable in this respect to the whole class of probe devices.

Field trials alone cannot wholly dispose of the problem of how best to present information. Even good results from training might conceivably have been achieved more easily with improved signals. Also, the wide range of possible signal presentations calls for simpler and more analytic procedures. For example, the choice of the sensory channel to be used as a substitute for vision involves many psychological factors amenable to study in the laboratory. If the ears must be left free for their usual functions, how can information be conveyed most effectively by the skin senses? Some preliminary experiments by Jerome and Proshansky at Haskins Laboratories suggest that direct electrical stimulation may be quite good, with the proper choice of electrodes, frequency, and waveform. Such signals, although

not unpleasant, command attention. Will they distract attention from auditory cues, and, if so, to a greater or lesser degree than would audible signals from a bone-conduction receiver?

There are still unanswered questions in another field. Manual scanning is only one of several ways in which the surroundings can be explored. Is it the best method? Mechanical simplicity and the 'natural' way in which directional indications are conveyed to the user are evidently virtues. But experience, so far as it has gone, seems to show that this sort of point-by-point, sequential information is very difficult to integrate into a unitary impression of the surroundings. Is mental integration of this sort a skill that can be learned, or is it inherently impossible? Automatic scanning, alone or in combination with binaural presentation, is frequently proposed as a way of providing information in more manageable form. The additional instrumentation might indeed be justified if it could be shown that the psychological assumptions were sound. Other proposals envisage an autoscanning device which presents a small relief map for tactile exploration. The analogy with Braille, which many blind persons read with ease and rapidity, is encouraging, though a number of psychological factors remain obscure. Some clarification may come from studies now under way at the Massachusetts Institute of Technology, using a simulated device.

From all this it appears that the problem of the guidance device – even though it involves such diverse factors as the travel needs of the blind, the vagaries of physical phenomena, and the obtuseness of the human mind – is reducible to two specific research programmes on which useful progress can now be made. Both are primarily psychological. One programme concerns the amount of learning required for the efficient use of a typical probe type device, and the limit of performance attainable with it. Definitive answers may be expected from field tests with the Signal Corps optical device. The other programme comprises the exploration of a number of basic psychological factors involved in the organization and transmission of information when ease and speed of perception is the goal. Very little work is under way on this problem.

Emphasis on the psychological phase does not, of course, imply that the engineering solutions are completely adequate, but only that the results of field trials with one device are needed to justify further engineering effort on other probe types. Likewise, additional psychological data are essential for the design of more complex devices.

So much for immediate problems. Probe devices have monopolized the discussion for the very practical reason that they offer the best prospect of achieving a limited goal within a reasonable time. However, there are more exciting prospects than merely helping a man avoid obstacles. Perhaps a little speculation is not too dangerous.

Actual restoration of sight by direct stimulation of the optic nerve or the visual cortex is almost certainly an illusory hope. To be sure, bright flashes can be caused by electric shocks, provided the optic nerve is intact. However, in the greater number of cases of blindness which cannot be treated surgically the optic nerve undergoes degeneration and is not excitable. Even when stimulation is possible, the visual phenomena are diffuse and give no impression of shape.

An alternate approach is to provide patterned information via the auditory channel so that the blind can 'hear' a scene in the same sense that sighted persons see it – not piecemeal, but as a pattern of objects arranged in space. This is not perhaps so fanciful as it may appear. The underlying assumptions are that the ear can deal skilfully with patterned information, and that there exists an audio-visual transformation by which distinctive shapes in visual space can be converted into equally distinctive patterns in the auditory domain.

The transformation of coordinates may, in fact, be fairly simple. The 'pictures' produced by the sound spectrograph are enough, as visual patterns, to be read by a practised eye, though not with quite the facility that the corresponding sounds are recognized by ear. Conversely, pictures can be turned into identifiable sounds by means of a pattern playback, an instrument with functions reciprocal to those of the spectrograph.

A comparable instrument, operating on a simple two-dimen-

sional image of the environment, would yield audible patterns with the dimensions of frequency and time. To the extent that these sound patterns can be identified mentally with the corresponding objects, the user of the instrument would indeed 'hear' the scene in front of him.

Such a guidance device should have capabilities far greater than those of a probe type obstacle locator. It might in fact provide a substitute for vision, though doubtless a rather crude one. But can such a device be built? Probably it can, with no great difficulty. The real question – a psychological one of enormous complexity – is whether or not a man can learn to use such a device. The answer to this, until much more has been learned about auditory perception, must remain highly speculative.

*(Reprinted by courtesy of Physics Today from its
July 1950 issue)*

FIFTY YEARS OF PHYSICS

PROFESSOR MAX BORN, F.R.S.

No other half century in the history of physics has witnessed so revolutionary a transformation in our ideas of the physical universe as the one through which we have just passed. We have seen not only a vast extension of actual knowledge, but a profound revision of basic concepts and principles. From this gigantic material those parts are here selected which most strikingly illustrate the contrast between the ideas held at the beginning and those held at the end of the period.

SPACE AND TIME

In 1900 Newton's concepts of space and time were still accepted. They imply a restricted relativity, *i.e.* the mechanical equivalence of an infinite number of 'inertial systems' of reference moving with constant relative velocity. However, the propagation of light (electromagnetic waves) through interstellar space was believed to demand a substantial carrier. Thus in electrodynamics Lorentz's assumption of an 'ether absolutely at rest' (1892) seemed to be unavoidable.

Experimental evidence for the non-observability of absolute motion had been already accumulated in the previous century, *e.g.* through the experiment of Michelson and Morley. The theory was developed by Poincaré, Lorentz, FitzGerald and others. Einstein in 1905 reduced their results to a simple argument: the conception of absolute simultaneity of events at different places has no physical meaning because the velocity of the fastest signals (light) is the same for all observers, irrespective of their motion. By using different scales for space and time in different inertial systems, relativity can be preserved both in mechanics and electrodynamics. The adequate mathematical treatment of this theory is due to Minkowski (1907); space and

time are merged into a four-dimensional extension, where every point represents an 'event', and where a generalization of ordinary Euclidean geometry holds. The most important consequence of relativity is Einstein's law of the equivalence of mass (m) and energy (E), expressed by the equation $E = mc^2$, c being the velocity of light. First regarded as a result of great philosophical interest, it later turned out to have immense practical implications (Nuclear Physics, see below).

In 1915 Einstein extended relativity to accelerated systems, guided by the simple fact that all bodies in vacuo fall with the same acceleration. He found the adequate mathematics in a 4-dimensional generalization of Riemann's geometry of 'curved' spaces and obtained a field theory of gravitation where Newton's law is only a first approximation. Its greatest success was the prediction of the deflexion of light from stars by the sun, which was observed during the total eclipse of 1918.

The general theory of relativity provided the foundation of a rational cosmology and cosmogony, of which in 1900 there was hardly a trace. From the observational side this development was stimulated by Hubble's discovery of the 'expanding universe,' *i.e.*, of the fact that the so-called nebulae, which are in fact distant galaxies like our own, are moving away with velocities proportional to their distances. A slight modification of Einstein's equation, first suggested by Friedman (1922), led to a solution representing a closed expanding universe (Lemaître, Robertson Eddington, 1927). This theory stimulated a vast number of investigations which have, in the past fifty years, widened our astronomical horizon more than all previous centuries.

CONTINUOUS MATTER

In 1900 the bulk of physical research was still working with the concept of continuous matter, though 'atomistics' was already on the march. The methods of the continuum have survived to our day, for practical applications in hydrodynamics, electricity, thermodynamics and electrodynamics, and their progress and success is spectacular enough. One has only to remember that in 1900 the internal combustion engine was in its infancy, the

ceiling of the atmosphere – a complex of ionized layers called the ionosphere.

The scientific applications of very short electric waves are of great diversity. By observing selective absorption of radar waves, due to resonance with atomic periods (vibrations of atoms in the absorbing substance), the dynamical structure of molecules has been explored (Cleeton and Williams, 1934) and even the 'spins' (rotations) of atomic nuclei measured (Rabi, 1938). By observing the arrival of the reflection of a radar signal by a distant object the distance of the moon has been measured (U.S. Signal Corps, 1948) and meteor trails detected in full daylight (Hey and Stewart, 1946). Especially important have been the developments in the new science of radio-astronomy in which radio waves emitted by the sun and the stars are examined. Sunspots have been found to be powerful emitters of radio waves in the metre band (Appleton and Hey, 1946) while the detection of spontaneous radio emissions from the Milky Way (Jansky, 1931) provides us with the record distance of radio travel.

ATOMISTICS

The most striking difference between physics in 1900 and 1950 is the complete victory of atomistics. The speculations of the ancient Greek philosophers and the dreams of the alchemists have come true.

By 1900 the atomistic hypothesis had proved its value in chemistry. The elements were arranged in a periodic system according to atomic weight A , from hydrogen ($A = 1$) up to uranium ($A = 238$), with 92 places almost all occupied by known atoms. In physics the atomistic idea was useful in the kinetic theory of gases, and began to spread to other branches. About 1882, Gibbs developed a mathematical method of great power, called statistical mechanics, to deal with systems of a great number of particles.

As early as 1894 J. J. Thomson had recognized the atomic structure of electricity. He found the 'electron' to be a constituent of all atoms, and made the first crude determinations

of its charge, which was later (1917) accurately measured by Millikan.

Still there were in 1900 distinguished scholars who denied the existence of atoms. To-day the physical reality of the atom is beyond doubt, but its name ('indivisible') is no longer appropriate. The atom is built up of two kinds of elementary particles:

- (1) the nucleon which, when electrically charged (always positive) is called proton, otherwise neutron.
- (2) the electron, about 1,800 times lighter and negatively charged (though positive electrons, or positrons, can be artificially produced).

A number of nucleons, N neutrons and Z protons, form a densely packed cluster, the nucleus of the atom, of tiny dimensions (a millionth of a millionth part of a millimetre). Around the nucleus Z electrons are moving, like the planets around the sun, in orbits whose diameters are about 10,000 times larger than that of a nucleus. All chemical and almost all physical properties depend only on the charge number Z , and as N may vary for a given Z , there may be several atoms, 'isotopes', of the same chemical type but different 'mass number' $A = N + Z$. Chemical elements are mixtures of isotopes. This planetary model was the result of long experimental and theoretical research.

Decisive evidence for the reality of atoms was given by Einstein (1904) and Smoluchowski (1906) through their interpretation of the Brownian movement of particles suspended in a fluid as an effect of statistical fluctuations. Using Einstein's formula Perrin derived from his observations (1909) the first reliable value of the number of atoms in a given weight of matter.

Much more information was obtained by the study of various forms of radiation. Röntgen's X-rays opened this period in 1895 and were immediately followed (1896) by Becquerel's discovery of the radio-activity of uranium. In 1898 the Curies isolated the elements radium and thorium, which produced enormous quantities of energy, apparently from nothing. This

puzzle was solved by the brilliant researches of Rutherford and his school (from 1902). He found that the radiation consisted of two main parts: α -rays, which turned out to be helium nuclei (1908), and β -rays, which are fast electrons. A third type of radiation, γ -rays, found by Villard (1900), were later recognized as short electromagnetic waves, like X-rays.

The atomistic character of the α - and β -radiation became obvious when methods for counting fast particles were developed. Rutherford obtained his first results with the help of scintillations seen on a screen covered by zinc sulphide (Crookes, 1903); then came the Geiger counter which registers a particle by an electric discharge. Here, as in many other fields, the possibility of amplifying tiny currents was a decisive factor. The simple electronic valve or diode invented by Fleming in 1904 was developed for amplification and other purposes (triodes, pentodes) by de Forest (1907) and Langmuir (1915).

An experimental technique of the greatest importance, enabling us not only to count but actually to see the tracks of particles, was C. T. R. Wilson's 'cloud chamber' filled with supersaturated vapour which condenses to small droplets along the path of the particle. Blackett invented (1937) a kind of trigger arrangement with counters, in such a way that a photograph is taken only if a particle passes the instrument. Thus the efficiency was immensely improved. Also in 1937 Blau and Wurmbacher discovered that particles passing through a photographic plate produce a microscopic track. Through improvement of the emulsions this has become a most efficient method for studying atomic processes.

With rather primitive instruments Rutherford and Soddy (1900) analysed the process of radioactive disintegration and found that it consists in a series of transformations of one atom into another. Thus the belief in the invariability of the chemical elements was shattered. At the same time ample proof for the existence of isotopes was found amongst the radio-active elements (e.g. all three series end in different lead isotopes). Later, in 1913, J. J. Thomson discovered the first example of

isotopy amongst ordinary elements (neon), by electromagnetic deflection of charged atoms. This method was refined by Aston (1919) in his mass-spectrograph which made very accurate mass determination possible. The masses of all elements turned out to be very nearly integral multiples of the mass of the hydrogen atom, a revival of Prout's hypothesis (1815).

The internal structure of atoms was explored by observing their effect (absorption, scattering) on different kinds of radiation. Lenard found in 1903 that for fast electrons the space occupied by an atom is almost empty. Rutherford obtained (1911) much more significant results by using α -rays; in fact by accurate measurement of the scattering he gave convincing proof for the 'planetary atom' described above and determined the nuclear charge which attracts the electrons and keeps them in their orbits. These results were soon confirmed by Moseley (1913) through observations on X-ray spectra, which depend on the number of electrons.

Apart from this fundamental research in the structure of the atom the application of atomistics to the properties of matter in bulk made great strides. Thus Langevin (1905) gave an explanation of paramagnetism in terms of molecular magnets, and Debye (1912) transferred this idea to the dielectric constant which he expressed in terms of molecular dipoles. Similar methods were successful for understanding the interaction of light and matter, namely absorption, refraction, dispersion and rotary power, in particular the dependence of these phenomena on temperature and external electric and magnetic fields. The study of the scattering of light, first investigated by Tyndall (1868) and explained by Rayleigh (1871) revealed the shape (anisotropy) of molecules (Gans 1912, Cabannes 1921). The statistical methods to deal with great numbers of molecules were greatly improved by Darwin and Fowler (1922).

The problem arose to derive the atomic constants used in these theories from a model of the atom. But the attempts to use the planetary model encountered formidable difficulties, mainly due to the fact that a Newtonian system does not possess the stability of actual atomic structures.

THE QUANTUM OF ENERGY

The solution of these difficulties came from a quite different series of investigations and was much more radical than expected. It meant nothing less than the replacement of classical mechanics, with its strict determinism, by a new atomic mechanics which is essentially statistical and indeterministic.

An example of a process where deterministic description seemed to be inadequate is radio-active decay. It is not possible to predict the moment when a certain radium atom will disintegrate, though the average life of a great number of atoms is perfectly determined (v. Schweidler, 1905). This situation seemed at first a gap in our causal knowledge, but turned out to be of a fundamental character.

It was from the study of radiant heat that the new mechanics started. In 1900 Max Planck had convinced himself that the observed spectrum of black bodies could not be accounted for by classical mechanics but by the strange assumption of finite quanta of energy ϵ , which are proportional to the frequency ν , $\epsilon = h\nu$.

The physical world received this idea with great scepticism. The wave theory of light was well established by innumerable experiments on interference and diffraction. The wave length could be measured with extreme accuracy; for instance, the line spectra of gases had been studied and regularities discovered, for hydrogen as early as 1885 by Balmer, later also for other atoms (from 1900 by Rydberg, Paschen and Runge, Ritz).

The splitting of spectral lines by a magnetic field discovered by Zeeman as early as 1896, was investigated with powerful instruments and revealed amazingly harmonious patterns. The meaning of these regularities remained obscure; but as they could be expressed in terms of wavelength and frequency, nobody doubted the wave theory of light.

The nature of X-rays was controversial. Selective absorption and polarization discovered by Barkla (1909) indicated wave structure. W. H. Bragg found (1910) evidence for corpuscular structure, while Walter and Pohl obtained (1912) diffraction from which Sommerfeld estimated the wave length. This dispute

was settled in favour of the waves when Laue and his collaborators found in 1912 the diffraction of X-rays by crystals, demonstrating at the same time the lattice structure of crystals.

In the hands of W. H. and W. L. Bragg this method opened a new chapter of crystallography.

Yet the corpuscular idea was not dead and grew in weight. Einstein took it up and showed that significant features concerning the ejection of electrons from metals by light could be explained in terms of Planck's quanta (theory of the photoelectric effect, 1905). Two years later (1907) he applied the quantum theory to the thermal properties of molecules and crystals, and predicted a strange behaviour of the specific heat of solids at low temperatures. This was soon confirmed by experimental investigations made by Nernst and his school. On this basis a detailed atomic theory of crystals was later developed (Debye 1912, Born & Karman 1912, Ewald 1912, Madelung 1918).

THE QUANTUM THEORY OF THE ATOM

Our fifty years' period is, in regard to quantum theory, clearly divided into four almost equal sections. The second section began when in 1913 Niels Bohr applied the quantum hypothesis to Rutherford's planetary model of the atom. This was a great success as it solved at one blow the riddle of atomic stability, and explained the mysterious spectral series, and some features of the periodic system. Many of Bohr's predictions were soon confirmed by experiment (Franck and Hertz, 1914) and the theory extended in several directions. The 'spin' of the electron was introduced by Uhlenbeck and Goudsmit (1925), and an important 'exclusion principle' for Bohr's orbits was discovered by Pauli (1924). This enabled Bohr himself to complete his interpretation of the periodic system of elements in terms of electronic orbits started in 1922, and resulted in the discovery of one of the 'missing' elements, hafnium (Coster and Hevesy, 1922).

Even the most startling consequences of Bohr's theory, as for instance concerning the orientation of atoms in magnetic fields (Sommerfeld, 1916) were found in agreement with observation

Important results can be obtained by very simple models, e.g., by treating the nucleus as something like an electrically charged liquid drop with surface tension (Weizsäcker, 1925; Bohr, 1935). Thus it is found that there is a tendency of the light nuclei to fuse, of the heavy ones to disintegrate; hence all elements, except those in the middle of the periodic table (iron) are in principle unstable. But reaction velocities are, under terrestrial conditions, so extremely slow that nothing happens. It is, however, different in the interior of stars; Bethe showed in 1938 that one can account for the heat developed in the sun and the stars by a nuclear reaction, the fusion of four hydrogen nuclei to form a helium nucleus. The opposite phenomenon, the fission of the heavy nucleus of uranium into almost equal parts, was discovered by Hahn and Strassmann in 1938. This process is initiated by the capture of a neutron and followed by the emission of several neutrons. Thus a self-supporting chain reaction can be obtained, by which enormous energies are released.

It is general knowledge how this discovery, under the pressure of war, led to the construction of a nuclear reactor or 'pile' (Fermi, 1942) and finally to the production of the atomic bomb. This is not the place to enlarge on the technological problems connected with this development, nor on its economic and political implications; the issues are so formidable that their discussion would need another article.

Peaceful science, not only physics but also chemistry, biology, and medicine have greatly profited from the products of the pile. The remaining few gaps in the periodic table of elements have been filled and four trans-uranic elements found, amongst them fissionable nuclei. Innumerable new isotopes of known elements have been produced. Some of these can be used as 'tracers' in chemical and biological research, others as a substitute for the expensive radium in the treatment of cancer and other diseases.

MESONS

The last quarter of our half-century was again opened by a fundamental discovery in quantum theory, concerning the nature of the nuclear forces. These differ, by their short range of action,

from the electro-magnetic forces which keep the electrons in their orbits. There exists a generalisation of Maxwell's equations (Proca, 1936) which has such short-range solutions. By studying other solutions representing waves Yukawa was led in 1935 to predict a new type of particle, later called meson, which is in the same relation to the new field as light quanta (photons) to the electro-magnetic field. Its mass could be calculated from the range of forces and was found to be 300 electron masses. Soon the existence of mesons was experimentally confirmed, first in cosmic rays (Anderson and Neddermeyer, 1936), later with the help of a cyclotron in California (1948). The method of photographic tracks (p. 52) has, in the hands of Powell (from 1940) produced a wealth of new results, e.g., the existence of two kinds of electrically charged mesons, one 300, the other 200 times heavier than the electron: the first kind spontaneously decays into the second (plus a neutral particle). It is probable that still more types of mesons exist.

These discoveries open quite new vistas for the future. The electro-magnetic field which for a long time has dominated physics will very likely be only one of many fields, each associated with a type of particle, and the fundamental problem will be to establish the relations of all these entities and to unite them into one theory, not excluding gravitation.

CONCLUSION

Surveying this brief account of half a century we find two remarkable facts: The fundamental - or metaphysical - concepts concerning space and time, matter and motion, cause and effect, which physics has inherited from a previous period, have not withstood the onslaught of new experiences and have had to be replaced by different, even opposite ideas. On the other hand, the actual physical theories, though strongly modified and extended, have never been quite discarded: the old ones are always preserved as limiting cases in the new ones. Thus in the midst of turbulent happenings and in spite of an incredibly widened horizon of facts and theories the continuity of physical research has been perfectly preserved.

[*Note by Editor.* – Some of the subjects touched on in this review have been more fully covered in past issues of *Science News*. For accounts of hydrodynamics and viscosity see *Science News* 8, p. 91 and 17, p. 137. For aerodynamics, see 7, p. 23 and 18, p. 44. Ultrasonic vibrations have been discussed in 7 p. 48 and 9, p. 88. Thermodynamics is treated in 18, p. 21; the absolute zero in 10, p. 71 and 17, p. 123. Radar and meteor trails have received several mentions (e.g. 5, p. 28) and radio-astronomy is described in 4, p. 53. *Science News* 2 was devoted to 'Atomistics', while nuclear physics was also reviewed in 6, p. 62, and meson research in 16, p. 9 and 18, p. 86.]

This article was presented as a lecture to the Royal Society of Edinburgh on 23 October, 1950. A shortened version appeared in Scientific American, September 1950.

STUDYING PLANTS WITH X-RAYS

THE advance of biology in all its many branches depends to a large extent on the applications of advances made in physics and chemistry. It is sad to think how little this truism has been accepted in scientific practice; and the way in which X-rays have been used in research since their discovery in 1895 illustrates how seriously limited the outlook of zoologists and botanists can be. Almost from the beginning X-rays were employed by surgeons to aid in the diagnosis of fractures, and with the invention of the radiopaque 'barium meal' the shadows of stomach ulcers and cancers began to be photographed. X-rays of the heart and chest came to give valuable medical information, particularly when abscesses or the inflammation of tuberculosis cast unusual shadows in the X-ray beam. Other parts of the body were made visible by feeding or injecting iodine-containing substances, for iodine is opaque to X-rays. The gall bladder's function could be studied, and the kidney, and the shape of the urinary bladder, and the continuity of the canal in the vertebrae of the spine, where lies the spinal cord of nerve tissue. Substances could be injected into blood vessels to display the circulation and the course of arteries and veins.

What use did zoologists make of all this? A little, a kind of spill-over from the work of their medical colleagues through the common channel of physiological experiment on mammals. And the botanists? Nothing at all: too remote from medicine, they left the mystery of X-rays alone, just as for so long they left the mysteries of biochemistry and of physics.

However, an important step was taken three years ago by an eminent medical radiologist, unfortunately since deceased, with a colleague who was interested in botanical problems, and in the *British Journal of Radiology* for November, 1948, appeared

a paper by Dr A. E. Barclay and Mr Donald Leatherdale describing how they had accidentally discovered strange 'spots' in the leaves of many plants (see Inset, 10-12). They used 'soft' X-rays, that is rays of low intensity and low penetrating power produced by low voltages; and they found shadows from the leaves of many plants, indicating accumulations of some unknown materials. In the Mermaid rose and in *Prunus* the large spots lay along the course of the leaf veins, and they deduced that they were of high atomic weight, perhaps mineral deposits. In the potato and tomato on the other hand the spots were predominantly in intervenous spaces, were 300 - 500 μ across and gave softer shadows suggestive of lower atomic weight substances. In *Berberis*, strangely enough, no spots were ever found. Studies carried out through one season suggested that the accumulations of material which cast these X-ray shadows are largest and most marked in the spring, shrink during the summer, and are gone completely by autumn. Here then is a subject for further research, a mystery which may prove the door to important discoveries. Yet, simple as it is, it has had to wait twenty years and more for the genius of Barclay. (Some of his work, incidentally, has already been described and illustrated in *Science News* 10, where Professor K. J. Franklin described the work of the Oxford School on the circulation in the kidney. See especially pp. 102-7.)

Barclay and Leatherdale were really studying ways of showing up and studying the vascular system of plants - the special tubular tissues up which water is carried from the roots, and along which various food stuffs such as the sugar synthesized in the leaves can be carried: the xylem and phloem. They found that a saturated solution of lead acetate will rise in a cut stem and show up the vascular channels on X-ray. Later they found that they could make visible a good deal of plant anatomy without recourse to any special agents which might, like lead acetate, be artificial and poisonous.

Mr Donald Leatherdale writes:

Subsequent to the publication of the paper by Dr A. E. Barclay and myself on a botanical use of the technique of

radiography, some work was done on the development of plant galls.

One of the disadvantages of studying internal development by more orthodox methods is that a specimen must be grossly mutilated by dissection or microtome sectioning to establish its pattern. But using this radiological approach it has proved possible to radiograph a single specimen at various intervals of time: thus the development of an individual plant gall may be described, rather than having to form a composite description from several specimens.

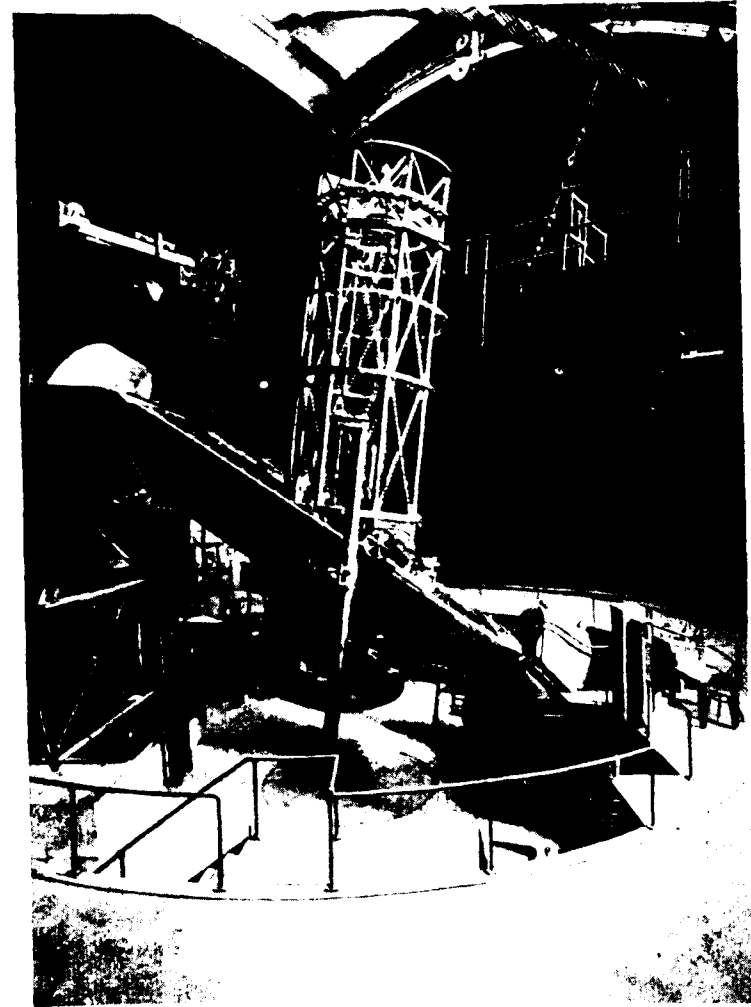
The relationship between host plant and gall was the object of our experiments, with particular reference to their inter-related vascular systems. The use of 'soft' X-rays shows these systems without the necessity of employing radiopaque contrast media. It will be appreciated that only the smaller species of plant gall could be used, as larger growths (such as the common oak apple, oak marble gall, and the 'robin's pincushion' of certain wild roses) were too thick for detail to be resolved from the enlarged radiograph.

The best series of results was obtained from a common leaf gall on the white willow, caused by the sawfly *Pontania proxima* Lepel. The twig bearing the galled leaf was grown in a nutrient solution, and at intervals of ten days the gall was radiographed in identical positions. Microradiographs from these radiographs show the vascular tissues of leaf and gall, and the growth of these tissues in the specimen may be visualized.

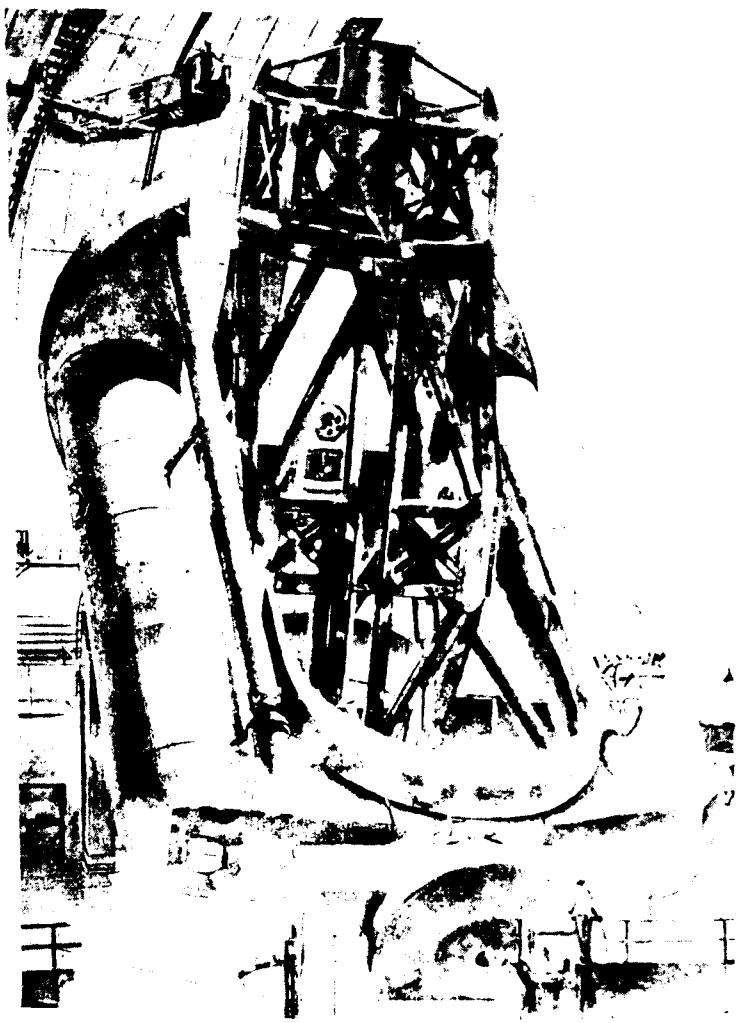
These experiments were in the nature of trial runs, to prove to ourselves that the technique was suitable for the type of work. There is much further work to be done along these lines, both with the multitude of galls now known, and with the radiopaque bodies described earlier. With regard to the latter, it can now definitely be stated that the 'spots' are most prolific during the period of active leaf growth. Later in the year their numbers diminish, or they may even be altogether absent.

Unfortunately we now no longer have Dr Barclay with us, but the technical detail of the methods used by him with such success at the Nuffield Institute of Medical Research will shortly

be published in his last book, *Micro-arteriography and other Radiological Methods Employed in Biological Research* (Oxford: Blackwell Scientific Publications; and Springfield, Illinois: Charles C. Thomas).



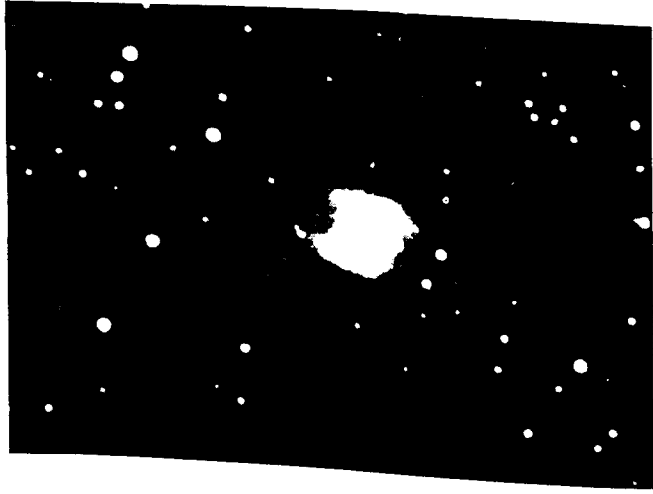
1. The 100 inch telescope. The rectangular frame turns towards or away from the observer for westward and eastward movements; the tube turns left and right for north and south movements. Northwards movement is limited by the shape of the frame. (Mount Wilson Observatory photograph.)



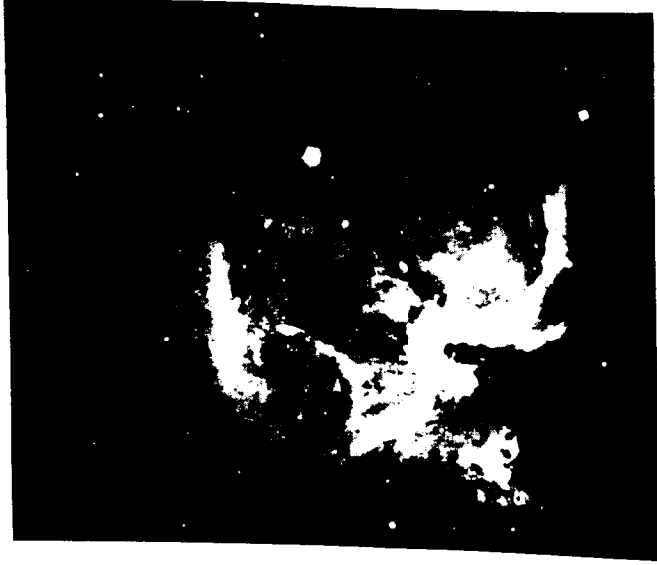
2. Mount Palomar Observatory. The 200 inch telescope showing horseshoe north bearing at top and observer about to enter the central observing carriage. (Drawing by Russell W. Porter.)



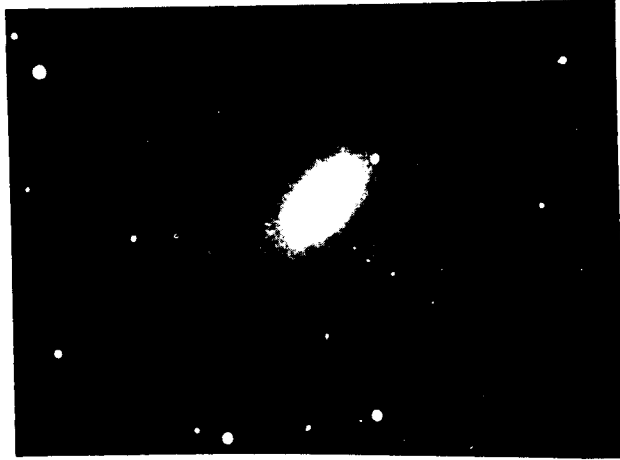
3. The Milky Way in Cepheus. (Yerkes Observatory Photograph.)



4. A planetary nebula in the Southern constellation Norma.



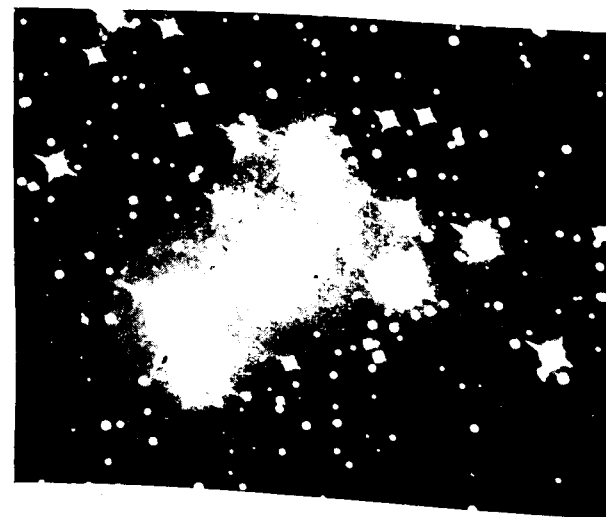
5. The Great Nebula in Orion. (*Mount Wilson Observatory Photograph.*)



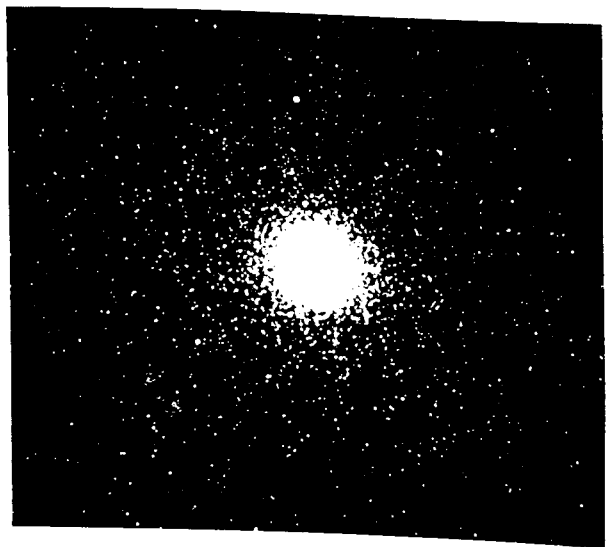
6. The elliptical nebula NGC 5102. On the original print the outer parts are just resolved into stars.



7. The spiral nebula NGC 6744. The nucleus closely resembles an elliptical nebula.

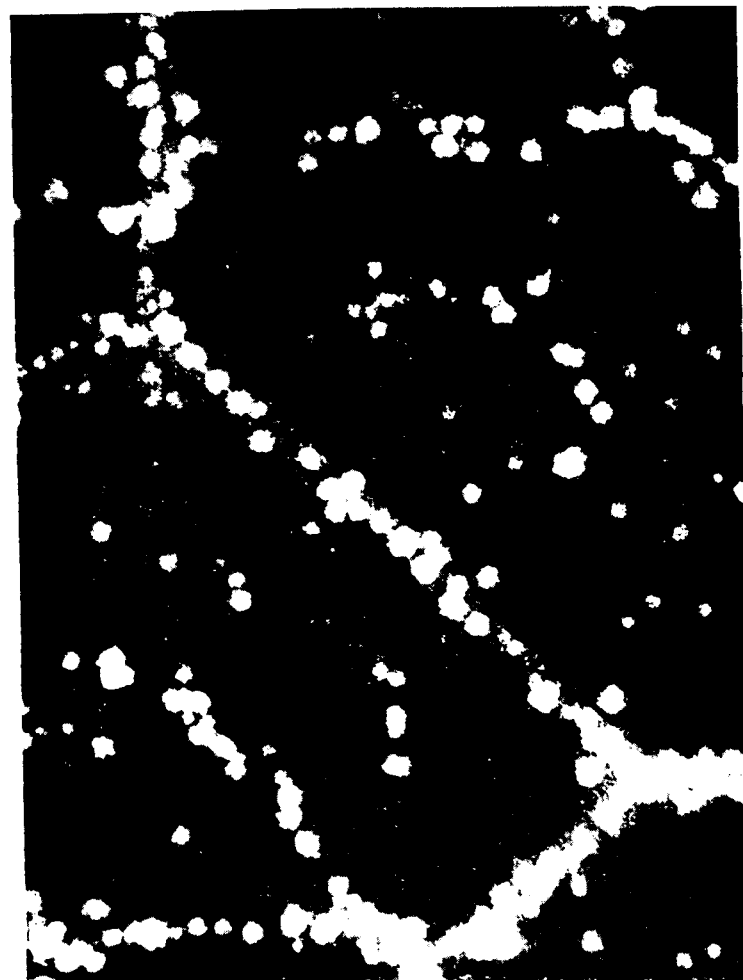


8. The open cluster NGC 6231. The radial streaks are a spurious telescope effect.

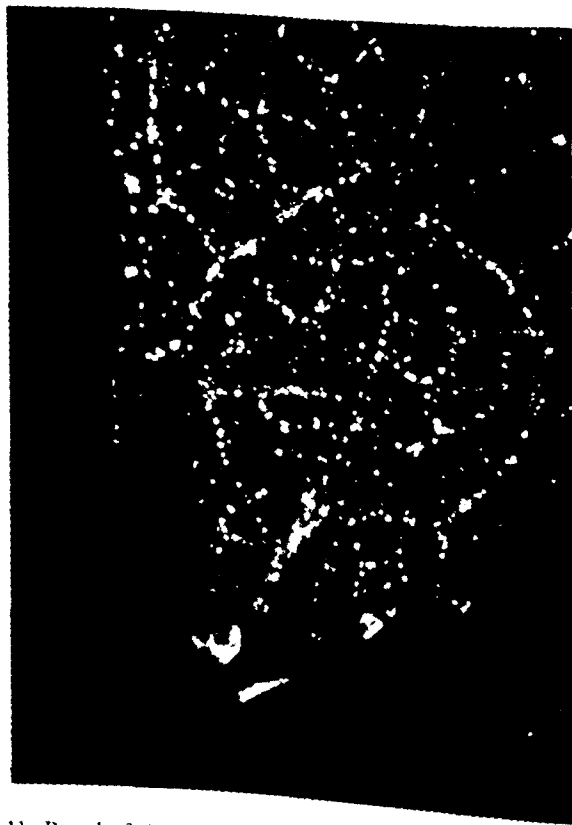


9. The globular cluster 47 Tucanae.
Illustrations 4 and 6-8 are Radcliffe Observatory Photographs by David S. Evans; 9 by A. D. Thackeray.

STUDYING PLANTS WITH X-RAYS



10. Rose leaf, 1942. Shows presence of spots in or around the veins.
(By courtesy of the British Journal of Radiology)

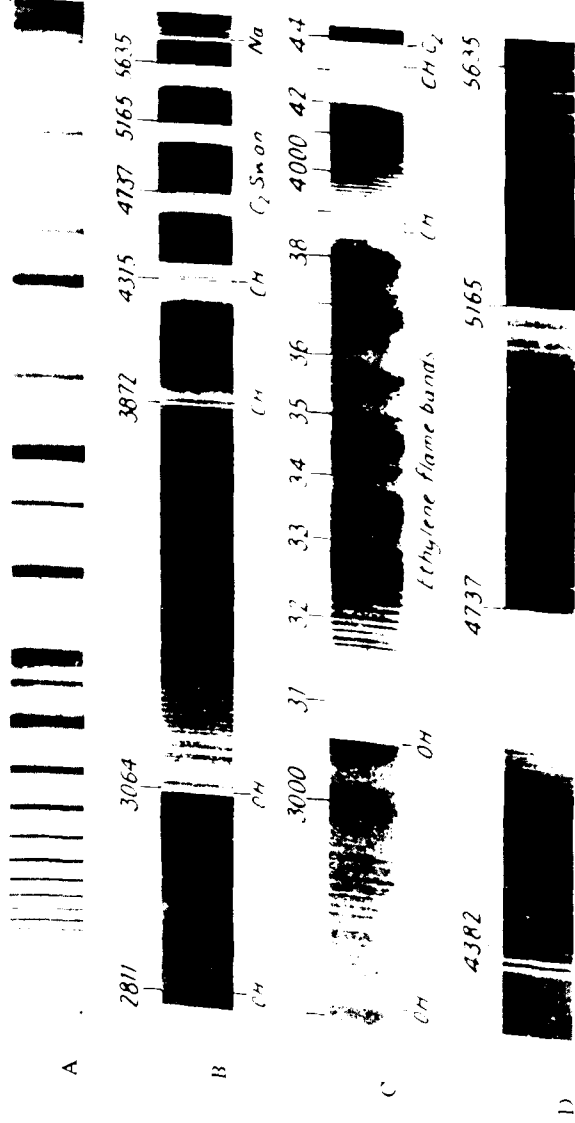


11. Rose leaf, demonstrating constant magnitude of the spots,
at 240 approx.
(By courtesy of the British Journal of Radiology)



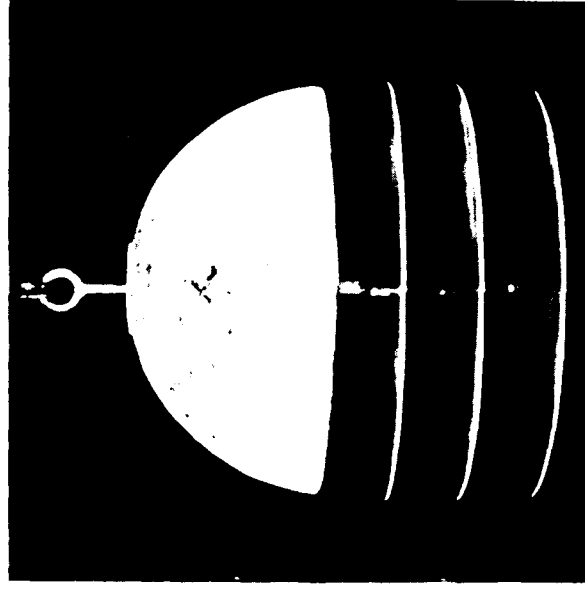
ELUSIVE CHEMICALS

13. Typical spectra of atoms and free radicals.



A. The Balmer spectrum of the hydrogen atom in absorption as seen in the spectrum of a star.
 B. and C. Emission spectra of free radicals in the Bunsen flame and the flame of ethylene. The figures above the spectra are the wavelengths in Angstrom units.
 D. The spectrum of the free radical C₂ produced by an electrical discharge. (Reproduced by courtesy of Drs Loefer and Mohler and the Reinhold Publishing Co. for spectrum C₂ and of Dr Graydon for the remainder.)

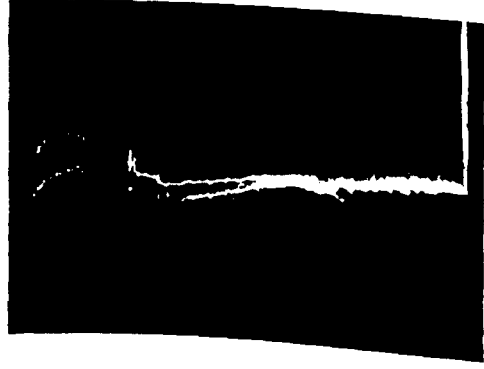
CONTROLLED CORROSION



14. Magnesium Alloy Anode for the protection of pipelines. The principle of sacrificial protection was discovered by an Englishman, Sir Humphry Davy.

15. Magnesium Alloy Anode for the protection of structures which stand in sea-water. This anode weighs 200 lb.; the plates help to 'boost' the protective current.

Both photographs by courtesy of F. A. Hughes & Co. Ltd.



16. Across a 150 cm. gap between a positive point and an earthed plane.



17. Across a 100 cm. gap between a negative point and an earthed plane.



18. Still photo of lightning discharge to ground and within a cloud.

16 and 17 are from photographs obtained with a moving film camera of the development of a spark.

All photographs reproduced with permission from Reports on the Progress of Physics.

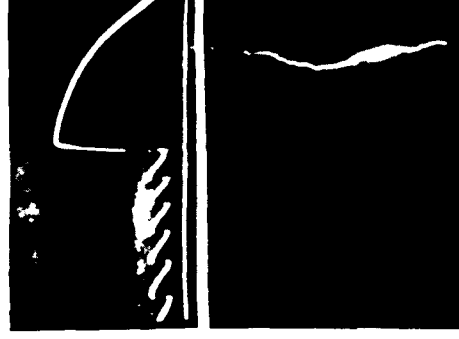
SPARK DISCHARGE



19. A photo showing ground streamers developing upwards. (Reproduced with permission from the Journal of the Franklin Institute - A. B. McLaughlin (1939).)



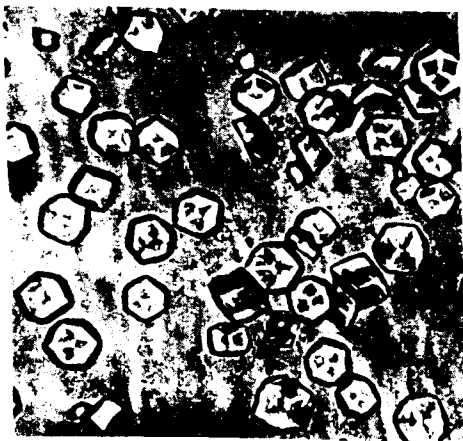
20. Photo, obtained with a Boys camera, of the development of a stepped leader stroke.



21. Multiple strokes in a 63 cm. positive point-to-plane discharge with oscillogram of the voltage shown in upper part of picture. (Photos 20 and 21 reproduced with permission from Proceedings of the Royal Society.)

HORMONES AND CARBOHYDRATE METABOLISM

Microphotographs of hormone crystals



22. Insulin. (*D. A. Scott, Endocrinology, 1939, 25, 437; courtesy of the author and the editor.*)



23. Corticosterone. (*T. Reichstein, Helv. Chim. Acta, 1937, 20, 953; courtesy of the author and the editor.*)



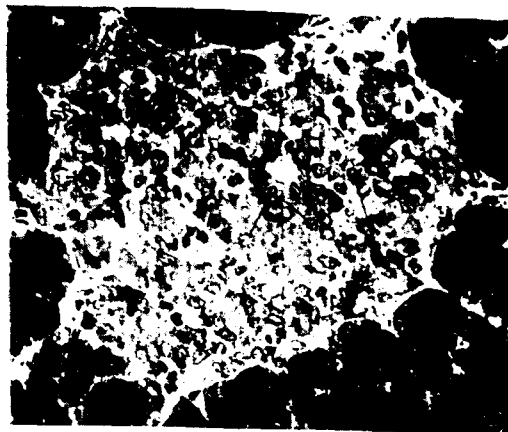
24. 11-dehydro-17-hydroxycorticosterone. (*Courtesy of Professor E. C. Kendall.*)



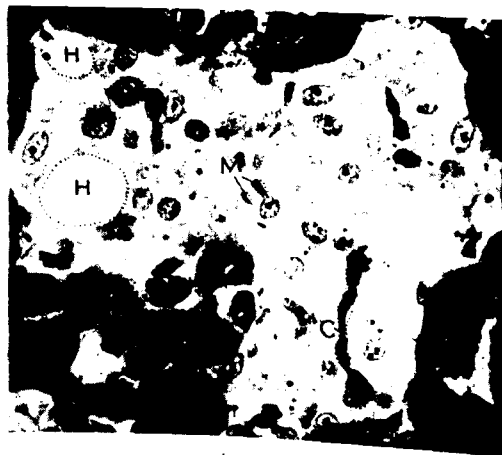
25. Growth hormone. (*C. H. Li, H. M. Evans, & M. E. Simpson, Science, 1948, 108, 624; courtesy of Dr Li and the editor.*)

ELUSIVE CHEMICALS

GEORGE PORTER



26. Islet of Langerhans in the pancreas of a normal dog. Note the grey tone of the islet as a whole associated with the presence of cytoplasmic material ('granules') concerned in insulin production.



27. Islet of Langerhans in the pancreas of a pituitary-treated dog which had developed diabetic symptoms. Note the paleness of the islet, resulting from loss of 'granules'.

- α typical α -cell.
- β typical β -cell.
- C blood capillary.
- H β -cell undergoing 'hydropic degeneration' (accumulation of vacuoles in cytoplasm).
- M β -cell undergoing mitosis (i.e. dividing in two).

(K. C. Richardson, Proc. Roy. Soc. 1940, 128 B, 153; courtesy of the author and the editor).

THE main concern of the chemist in the past has been to prepare and study the properties of as wide a range of substances as could be isolated, and more recently he has also been interested in the way in which the reactions used for these preparations proceed. As a result of this process of probing into the finer aspects of chemical change a vast new group of chemical substances is being discovered which may well be as numerous as those already known. This does not mean that the number of bottles in the chemist's store will be doubled, because this new class of chemical has one property which distinguishes it from the usual run of substances, a very great reactivity and consequent short lifetime. The majority of such substances known at present do not exist for more than a short fraction of a second, which explains why they have been overlooked until comparatively recently.

It seems reasonable to ask why, if such substances can never be isolated, so many chemists are busy at present finding out all they can about *free radicals*, as these short-lived chemicals are usually called. Their importance lies in the controlling influence they have on the way a chemical reaction goes. Chemical equations of the type



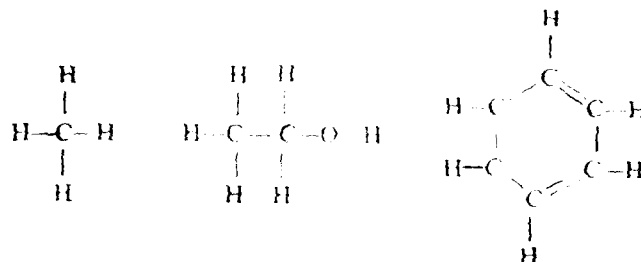
tell us that two molecules of hydrogen (H_2) will combine with one molecule of oxygen (O_2) to give two molecules of water (H_2O). I wonder whether it has occurred to the reader to ask how in fact the molecules manage to rearrange themselves in this way. The first guess would probably be that three molecules, two of hydrogen and one of oxygen, come together in just the right positions so that a split of the bond between the two atoms of the oxygen molecule is all that is necessary to produce the

two water molecules; and in fact some reactions do proceed in this sort of way. But apart from the fact that with more complicated reactions it is usually impossible to write down any reasonable intermediate configuration of this kind, there is a very serious objection to this simple idea in reactions such as this one. It is fairly easy to calculate how many simultaneous collisions of three molecules can occur in a given time and it is found that the number is much too small, even if every such collision is effective, to explain the very rapid and even explosive reaction which can take place between hydrogen and oxygen. In trying to explain reactions of this kind it has been necessary to assume that while the reaction is taking place there are present, as well as the stable molecules themselves, short-lived intermediate substances such as free atoms of hydrogen and free radicals like OH. This assumption was made before any direct evidence of their free existence had been obtained, and much of our knowledge of their chemical behaviour has been derived in this way. More recently direct methods have been perfected for detecting these transient chemical substances, and a whole new branch of chemistry has been opened up.

HISTORY OF THE IDEA OF A FREE RADICAL.

Since the days of Lavoisier the term 'radical' has been used to describe a grouping of atoms which occurs as part of a molecule and is transferred as a whole in a chemical reaction rather as though it were a single atom. Many of the early chemists believed strongly in the free existence of radicals and claimed to have isolated them. In the early part of the nineteenth century the ammonium (NH_4) and cyanogen (CN) radicals were well known examples and Bunsen thought he had isolated free cacodyl $\text{As}(\text{CH}_3)_2$, while Frankland reported the isolation of free methyl CH_3 . In these and similar cases it was always the 'compound radical', which is a stable molecule formed when two such radicals combine, which had been prepared; Bunsen had in fact prepared cacodyl, which is $(\text{CH}_3)_2\text{AsAs}(\text{CH}_3)_2$, and Frankland's free methyl was actually ethane C_2H_6 . It was only when the idea of the stable existence of free radicals was

discarded that the immense structure of organic chemistry could be erected, for it was built on the foundation of the idea of complete valency saturation. The valency of an atom is the number of bonds which it is able to form with other atoms, and as the structure of more and more molecules was determined it was found that carbon always had a valency of four, hydrogen of one and oxygen of two, although the bond might be double as in the case of the oxygen molecule $\text{O}=\text{O}$. In no case was it found possible to prepare a molecule unless it had all these possible bonds in use by combination between the atoms. Thus the following molecules were found to be quite stable:



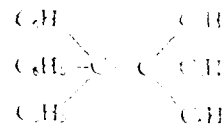
methane

ethyl alcohol

benzene

but the radicals CH_3 , C_2H_5 , OH , C_6H_5 etc. which occur as part of these molecules could apparently have no free existence. In view of the remarkable success of this theory in organic chemistry it is not surprising that the idea of the existence of radicals in the free state was rapidly dropped, so that when Gomberg really did prepare a free radical in 1900 the chemical world was astonished and rather sceptical.

Gomberg was trying to prepare hexaphenyl ethane, which is an ethane molecule in which all the hydrogen atoms have been replaced by phenyl (C_6H_5) groups, and therefore has the formula



are also found to be highly reactive, but to have a lifetime rather longer than might at first have been expected, for the same reason as atomic hydrogen. Free atoms can also be made by shining a light on the molecule, the light energy in this case being the bond breaker, and it was in this way that one of the first clear demonstrations of their existence was given. When chlorine is illuminated with blue light in the presence of hydrogen a very rapid reaction takes place which may be explosive, and hydrogen chloride is formed. For each photon of light which is absorbed by a chlorine molecule as many as a million molecules of hydrogen chloride are produced, and to explain this remarkable effect Nernst, in 1916, proposed his theory of chain reactions. The chain in this case is started by the two free chlorine atoms formed from a chlorine molecule in the original dissociation by light, and continues by producing many HCl molecules before two chlorine atoms (or two hydrogen atoms) eventually recombine and stop the chain (see *Science News* I, p. 93). Although the evidence for free atoms is in this case indirect the reasoning was powerful enough to gain rapid acceptance.

SHORT-LIVED FREE RADICALS

It was not until 1929 that the simple free radicals were shown to be capable of free existence. The apparatus used by Paneth and Hofeditz for this purpose was as simple as it was powerful, and consisted mainly of a long tube through which was rapidly pumped the vapour of lead tetramethyl $Pb(CH_3)_4$. When this tube was heated at some point by a Bunsen burner the vapour was decomposed and lead was deposited on the cool part of the tube, just beyond the flame, in the form of a thin metallic mirror. The tube was now heated at another point upstream from this mirror and a new mirror was formed in the same way as before, but the old mirror downstream was rapidly eaten away by some very reactive material formed in the decomposition of the lead tetramethyl. The final product leaving the tube was simply ethane, which is quite unreactive towards metals of this kind, and it was clear that it was free methyl radicals, produced in the decomposition occurring at the heated part of the tube,

which were removing the mirror. By making lead mirrors of a standard size at different distances along the tube it was possible to show that the number of radicals decreased rapidly with time, the mirror ten inches from the flame taking about ten times as long to disappear as one very near to the flame. Knowing the speed at which the gas was flowing through the tube it was calculated that the average lifetime of a methyl radical in the tube before it reacted was about one hundredth of a second. At last the real answer had been found to the old controversy of whether radicals such as methyl could exist in the free state, and as is often the case in arguments of this kind both sides were right; methyl was quite stable physically and could exist in the free state, but on the other hand it was so reactive chemically that it was only one hundredth of a second before it disappeared.

The free ethyl radical C_2H_5 was also identified by this method, and the 'mirror technique' has been widely used as a test for radicals of this kind in all sorts of reactions. Most organic molecules break up, when heated, into free radicals which can be detected by the removal of metal mirrors, though it is not always easy to say exactly what radical it is which is doing the trick, because the analysis of the very small amounts of the compound formed by the radical with the metal presents many problems. The method has also been used to show the presence of free radicals when molecules are decomposed by light, a bright lamp in place of the flame being the only modification necessary. In this way some of the bigger radicals can be detected which do not appear when heat is used to decompose the molecule, because the heat tends to break up the larger radicals as well, such radicals being phenyl C_6H_5 , tertiary butyl $C(CH_3)_3$, acetyl CH_3CO and benzoyl C_6H_5CO .

As with atoms we have had to rely to a great extent on indirect evidence for our information about free radicals, and an early example of this kind of work is that of Norrish on the breaking up by light, or photochemical decomposition, of ketones. Acetone $CH_3-CO-CH_3$ is such a ketone, and is decomposed by ultraviolet light to give the gases carbon monoxide CO and ethane C_2H_6 . In the same way diethyl ketone decomposes

according to the equation: (light) $C_3H_8-CO-C_2H_5 \longrightarrow CO + C_4H_{10}$.

Now the question arises whether on being excited by the light the molecule just reorganizes itself to give these products, or whether it first splits up into free radicals which recombine to give the hydrocarbons C_3H_8 or C_4H_{10} , and the final products give us no clue to the answer. The solution is easily found, however, if we use a mixed ketone, such as methyl ethyl ketone $C_2H_5-CO-CH_3$, because in the first case only one hydrocarbon, C_3H_8 , will be obtained. In fact Norrish found three hydrocarbons, C_3H_8 , C_3H_6 , and C_4H_{10} , in roughly equal amounts, which is just what would be expected if the ketone first splits up into methyl and ethyl radicals, which then recombine to form the final products.

A vast amount of work of this kind has been done, but it is rather like standing outside a theatre and trying to guess the name of the play from the faces of the people coming out. If one had some means of seeing the radicals and atoms themselves the study of their reactions would be greatly simplified, and one of the nearest approaches to this ideal which is being developed uses the spectroscopic method of detection.

THE SPECTROSCOPY OF TRANSIENT SUBSTANCES

Most substances, whether atoms, molecules or free radicals, when excited by an electrical discharge or by heat, emit light, which for each substance is different and quite characteristic and is known as its emission spectrum. Similarly when white light is passed through a substance certain wavelengths (narrow bands of colour) are removed and a similarly characteristic absorption spectrum is obtained. Examples of all these types of spectra are shown in Inset, 13, and it will be seen that once the atom or radical responsible for such a spectrum is identified the spectrum will in future experiments provide a diagnosis of the most certain kind. The wavelengths of the many lines in such a spectrum, which can be measured very accurately, also give us much detailed information about the structure of the free radicals; for example, from the spectrum shown of the C_2

radical it is possible to measure the distance between the two carbon atoms as well as the energy which would be required to split the bond between them.

Historically the first evidence of the existence of free hydrogen atoms was spectroscopic, the theory being worked out by Niels Bohr in 1913 to explain the series of lines noticed by Balmer when an electrical discharge is passed through hydrogen, and the emitted light examined spectroscopically. Bohr showed very conclusively that the lines were those of atomic and not molecular hydrogen, and at the same time founded the theory of spectroscopy. This father of all spectra, the Balmer series, is shown in Inset, 13(a) as it appears in the spectrum of a star. Many of the spectra found in the laboratory appear also in the sun, stars and comets; in fact in a few cases atoms and radicals have been studied in this way before they were known on the earth at all. One of the lines noticed by Fraunhofer over a hundred years ago in the spectrum of the sun is now recognized as that of the free radical CH.

The Bohr theory of the hydrogen atom was closely followed by the interpretation of other spectra, many of which were found to be the spectra of molecules, but the molecules identified looked very peculiar to the chemists of thirty years ago, some of the commonest which occurred in flames and discharges being OH, CH, CN, C_2 , NH, etc. It may now be considered fortunate that the very molecules which occur most readily in spectra are the free radicals which are so difficult to study by ordinary chemical methods. Over one hundred free radicals made up of two atoms only have now been found in this way and a great deal has been learned about their structure. Some of them, which occur in flames, are known to play a vital part in the reactions taking place in the flame - OH being an example - but others, such as C_2 and CH, may be formed simply by thermal decomposition of the fuel. The mere appearance of a spectrum in cases like this does not give us enough information to say what part the radical is playing in the reactions taking place.

Attempts are now being made to use the very direct and precise method of spectroscopy to follow free radicals in ordinary

chemical reactions over the very short periods of time during which they exist in the free state. In these experiments the absorption spectrum of the radicals is used to follow their reactions after they have been rapidly produced in a long tube, either by means of the electrical discharge or by photochemical decomposition. The first of these methods, which uses the electrical discharge to prepare the free radicals, was developed by Oldenberg, who has used it to carry out some very intensive studies on the properties of the OH radical produced by an electrical discharge through water vapour. The discharge is passed for only about one hundredth of a second, and it dissociates part of the water into free radicals and atoms; a fraction of a second later, before the radicals have had time to react, a shutter is opened which allows a bright light to pass through the vessel containing the radicals and to record their spectrum on a photographic plate. In order to get a good exposure it is necessary to repeat this procedure thousands of times, but in this way very small amounts of the OH radical, as low as one part in ten million, can be detected. By altering the time interval between the discharge and the opening of the shutter a series of snapshots of the radical over the period of its reaction can be obtained, and it was found that it could be followed for as long as a quarter of a second after the discharge, showing that once again a third body is necessary to carry away the excess energy before recombination can take place. As a result of these experiments, carried out over the past ten years, our knowledge of the OH radical now compares favourably with what we know about many of the more stable molecules. A few other radicals have been studied in the same way, but the method is suitable only for a limited number of such radicals which survive the violent conditions in an electrical discharge.

Light is a very useful molecule-smasher, and more kinds of free radicals can be made by photochemical decomposition than in any other way; unfortunately, however, even the brightest lamps known do not produce enough of these radicals to make the spectroscopic method possible. This difficulty has been overcome in an apparatus designed by the author, which takes

advantage of the fact that there is no point in illuminating the molecules for longer than a fraction of a second, because after this time the radicals are disappearing as rapidly as they are formed. The light used is therefore a flash lasting only one thousandth of a second, and in this time an enormous amount of energy can be dissipated by discharging a very large condenser across the lamp. The flash produced is a million times brighter than the ordinary electric light bulb, so it is not surprising that it has been found possible to dissociate many substances almost completely to atoms and free radicals; in fact the photochemical method is now capable of giving a higher concentration of radicals than the other methods, as well as a greater variety. There are many uses for these very intense flashes in experiments of this kind; for example in this apparatus a second flash is used to photograph the spectrum so that only one snapshot is necessary, instead of several thousand when an ordinary light and shutter are used. The free radicals produced are studied in the same way as before, by taking a series of snapshots at different time intervals after the radicals are formed, and lifetimes varying from as long as a minute for CS₂, produced by decomposing carbon disulphide, to less than a thousandth of a second for CH₃CO, produced from diacetyl, have been observed. Sometimes free radicals are found in the spectra when other methods indicate that there is no reaction; for example when chlorine is illuminated in the presence of oxygen nothing apparently happens but the spectrum shows that ClO radicals are formed which are present for a few thousandths of a second and then react to give chlorine and oxygen again. There are probably many other reactions and short-lived molecules like these which would for ever remain undetected by the more usual chemical experiments which take seconds or minutes to perform.

FREE RADICALS IN INDUSTRY

There is no sale for free radicals as such; even the most jet-propelled of delivery services could not handle these perishable goods; their importance in commerce lies in the directing influence they have on the mechanism of industrial processes.

The cracking of the higher hydrocarbons to give useful fuels like petrol involves first the breaking-up of the larger molecules into free radicals and then the recombination of these radicals to the smaller molecules required. Then again when this fuel is burned the whole mechanism of the combustion, or reaction with oxygen, consists of a number of steps nearly every one of which is a free radical reaction. The petroleum engineer would like to know very much more about the chemistry of these intermediates in order to control better the processes he directs.

The manufacture of plastics is another industry which depends on free radicals for its livelihood. The growing polymer in this type of reaction is actually a growing free radical which continues to grow until it meets another free radical and so ends the chain (see *Science News* 3, p. 156). To start the process a free radical must be produced in some way, for example by adding the catalyst benzoyl peroxide which decomposes easily to give a phenyl radical, and the properties of the final polymer are determined to a large extent by the number and kind of free radicals used for this purpose.

Very few chemical industries can get along without using these labile molecules somewhere in their process, and the modern chemist is no longer startled by a chemical formula which disobeys all the classical rules of valency.

FURTHER READING

Modern Aspects of Inorganic Chemistry. Ch. 4. Emeleus and Anderson. (Routledge)

The Chemistry of Free Radicals. Waters. (O.U.P.)

Kinetics of Chemical Change. Hinshelwood. (O.U.P.)

Photochemistry. Rollefson and Burton. (Prentice Hall)

Spectroscopy and Combustion Theory. Gaydon. (Chapman and Hall)

The following papers give details of the methods discussed:

Wood. *Philosophical Magazine*. Vol. 44 (1922), p. 538.

Paneth and Lautsch. *J. Chemical Society*. 1935, p. 380.

Oldenberg. Series of papers in the *J. Chemical Physics* between 1935-41.

Porter. *Proceedings of the Royal Society*. Vol. 200 (1950), p. 284.

RESEARCH REPORT

A. W. HASLETT

AMOEBAL TRANSPLANTS

THE technique of micro-manipulation, developed to a new pitch of precision through the work of Pierre de Fonbrune at the Institut Pasteur at Garches, has made possible many experiments which could not before have been undertaken. One of the most spectacular is the removal from an amoeba of its cell nucleus, and the later replacement of this by a different nucleus, transplanted from a second amoeba. This was first described by Dr de Fonbrune, and his collaborator Dr J. Commandon, in 1939, and has also been illustrated in a film. An extension of this experiment, of potentially wide interest, has been carried out lately by Dr. I. J. Lorch of the Chester Beatty Research Institute, the Royal Cancer Hospital, and Professor J. F. Danielli of the Department of Zoology, King's College, London. This was on the same lines as Dr de Fonbrune's original work in France, but with the important difference that transplants have been from one species of amoeba into another. The result in one case has been the creation of what appears to be a new strain of amoeba, maintained by repeated division and intermediate in form between the original two species. There is thus evidence that, in amoebae at least, the cell plasma as well as the nucleus affects the observable properties of the cell - these including the size of nucleus, and the patterns of external outline shown by the amoeba as a whole. It is the kind of work which needs to be repeated and extended, as the authors point out, but as a record of experiment and results is of interest for its own sake at the present time.

The species used were *Amoeba proteus* and *Amoeba discoides*. Both can be grown in mass cultures from single individuals, and they can be readily distinguished. *A. discoides* has more serrated outlines than *A. proteus*, and its nuclei are smaller. The nuclei of

both are irregular in shape, and measurements were in all cases of the largest diameter. Nuclear size is naturally smallest after division, and increases up to the next division, so that measurements must be made on a considerable number of individuals to obtain figures which are significant. Those for *A. discoides* ranged from 30.4 to 35.6 microns (thousandth-millimetre) and for *A. proteus* from 36 to 46 microns. These figures were found to be characteristic of the strains used, and where mass cultures were grown from individuals were independent of the size of nucleus in the individual amoeba from which the culture was grown.

Removal of the nucleus results in a slowing down and inco-ordination of internal movements. In Dr de Fonbrune's description, there are 'mouvements anarchiques qui se ralentissent progressivement.' After replacement of the nucleus by transplantation it was found in the London experiments that 'normal appearance and ability to move' may be recovered in a few seconds, though 'several hours may elapse before recovery is complete in the case of some animals.' Recovery, in this sense, is described as 'reactivation'. It was achieved in about the same proportion, whether transplantation was between amoebae of the same or of different species. But the number of animals which afterwards divided was considerably reduced when transplantation was inter-species. With amoebae of the same species, normal movement and appearance were restored in about 90 per cent of cases, and in about 65 per cent mass cultures were obtained. With transplantations between different species, there was a variation in results according to the species which supplied the nucleus.

Out of sixty cases in which a nucleus from *A. discoides* was transplanted into the cell plasma of *A. proteus*, fifty-one were 'reactivated', but of these only twenty-two divided, and no one of these gave a mass culture. The largest diameters of twelve of these nuclei were measured immediately before transfer, and again 24 hours later. The average before transfer was 33 microns, which was the same as the species average; but after transfer was 39 microns, which was outside the normal range for *A. discoides*,

but within that for *A. proteus* into which the nuclei had been transferred. The opposite transplantation - nucleus of *A. proteus* into cell plasma of *A. discoides* - was made in sixty-one cases. Of these, forty-five were 'reactivated', but only three divided afterwards. On the other hand, one of those which did divide gave a mass culture which was maintained for longer than a year. From the two which divided, but did not give a mass culture, measurements were made on thirteen individuals which were their progeny by division. The average for the largest nuclear diameters remained within the normal range for *A. proteus* although slightly reduced. The change was in the direction of *A. discoides*, but may not have been significant. In the unique case which gave a mass culture, the range of diameters was practically identical with that for *A. discoides*, into which the transplantation had been made. External outlines were studied in the same culture, from tracings of moving individuals - seen in projection. Different observers were given drawings of these outlines, together with outlines of normal individuals of both species. They varied in their classification, some placing the hybrid outlines as *proteus*, others as *discoides*, and others again in a group on their own. It seems a reasonable conclusion, therefore, that the forms found were, in fact, intermediate. Finally, neither in size of nucleus nor in general appearance has there been any recognised change during a year's observations.

Lorch and Danielli, *Nature*, 1950, **66**, 329.

GROWTH CONTROL IN PLANTS

A long-term investigation of fruit tree hormones (auxins) was begun at the East Malling Research Station near Maidstone in 1946, in conjunction with the Research Institute of Plant Physiology of the Imperial College of Science and Technology. The most recent result, recorded in preliminary form in the annual report of the station for 1949, is the extraction of a natural growth-inhibiting substance, which acts in opposition to the growth-promoting hormone.

In earlier work at East Malling, essentially the same method was applied to vegetative shoots of apple and plum as had been

used by F. W. Went at Utrecht in 1927 in a series of experiments which provided the first complete proof that growth-promoting substances were present in developing plant tissues. Went's experiments were on a pure line of oats. He used the coleoptile of the seed – the sheath protecting the plumule or shoot within it – both as the source and the indicator of the growth-promoting substance. He cut off the tips of coleoptiles, as the source, and placed them in rows on agar plates. The tips were then removed and the plates cut up into corresponding sections. To show the presence of the growth substance in the agar, he applied sections of agar to the stumps from which the tips had been cut, some centrally, and others to one side – the whole experiment being carried out either in the dark or in a red light. When the agar section was applied to one side of a stump, there was a curvature of growth in a direction away from the covered side. The interpretation was that the growth-substance had passed from the severed tip into the agar, and from the agar into the stump, and that growth was greatest on that side of the stump into which the growth substance had passed. Because of the small amounts in which growth substances are present, measurement of the curvature produced in oat coleoptiles has remained as the standard method for the determination of plant growth hormones – and it was the means, incidentally, by which the activity of synthetic growth substances was first established and measured.

Experiments during the 1946 and 1947 seasons at East Malling followed essentially the same methods in both respects. The result was to confirm, in general, that wherever there was extension of the shoot, there also a release of auxin could be demonstrated. But in detail, some of the effects found were quite complicated, and a number of questions were raised to which no decisive answers could be given. One was about the source of the auxin; another about its ultimate fate, as the growth season drew to a close. There were indications, on the first, that the auxin came from the stem tissues proper. But on the second, it could be said only that auxin persisted for longer than active growth, and in the end it seemed just to disappear, or at least to become unavailable for extraction by the agar method.

In the more recent work, now reported, auxin has been extracted also with ether, and in this way it has been shown that 'non-transportable' auxin may be present which is not shown by the method of agar extraction. In this form – or under these conditions – auxin was found to persist throughout the dormant period in shoots of Myrobalan B plum, and it could be extracted from the greater part of the shoot at any stage. But in apple shoots of the Crab C stock, auxin was found only in the basal region during the dormant period, and even there only up to early December. It was also by the ether extraction method that the presence of the growth-inhibiting substance, already mentioned, was first confirmed; and an inhibitor, presumably the same substance, has been extracted from apple leaves as well as from shoots.

Hatcher. *Report East Malling Research Station* (1948), pp. 113-16.
Vyvyan. *Ibid.* (1950), p. 34.

MUSCLE EXPERIMENTS

Physical experiments on muscle are carried out at a number of different levels, according to the object in view and the interests of the experimenter. At one extreme, there is basic research on the properties of muscle as such. Experiments of this kind are usually carried out on frog muscle, and the experimental unit is commonly a single muscular twitch. Their object is to discover the cycle of operations by which chemical energy is translated into mechanical work; or, in other words, to understand the working of muscles as engines. In an intermediate category are experiments in which the performance of a single muscle is studied in sustained contraction. Finally, there is the functional type of experiment in which the object is to observe the use made of groups of muscles under natural conditions. The following note brings together some examples of recent research at these three levels.

In work on the single muscular twitch, Professor A. V. Hill, of University College, London, has for some years been recording with increasing accuracy the relationship in time between the beginning of muscular contraction and that of the release of heat

from experiments on cats which might have seemed of doubtful relevance. With the spine bent, there is a critical position beyond which the spinal muscles are inhibited from activity; and a connection was suggested with the tendency of spinal discs (normally lying between the vertebrae) to slip from position when a heavy weight is thus lifted. In sitting, measurements of the same kind show less activity in the forward slouched position, which is unconsciously adopted in fatigue, compared with the upright position, whether with the back supported or otherwise, which is conventionally regarded as more correct.

Hill. *Proc. Roy. Soc., B*, 1950, **137**, 268; *Nature*, 1950, **166**, 415.

Floyd and Silver. *J. Anatomy*, 1950, **84**, 132.

OCEANS AND CLIMATE

The difficulty in studying climatic changes by the classical method of the advance and retreat of glaciers is to compare the record of one region with that of another. Areas of glaciation are of limited extent, and between them are continental regions which must be spanned by less certain methods, as well as the oceans which until lately could be spanned by no other method except a jump. The limitation has been from lack of information, and not from choice: for a region of the ocean bed which has been undisturbed apart from the slow deposition of sediment provides ideal material in principle for the analysis of whatever information can be extracted from the sediment.

Material for examination, covering the required depth within the ocean bed, has lately become available from the piston core sampler designed by Dr B. Kullenberg in Sweden and used during the Swedish Deep-Sea Expedition of 1947-8, led by Dr Hans Pettersson of Göteborg, with Dr Kullenberg as deputy leader. With this equipment, cores of up to about 70 ft. length can be recovered from the ocean bed at the greatest depths; and there has been renewed interest in the possibility of obtaining a continuous record of surface ocean climate from the character of sediments deposited on the sea bed at different periods.

Changes in temperature, shown by these cores, have been estimated by two methods. The first was developed by Dr

F. B. Phleger of the Woods Hole Oceanographical Institution, Massachusetts, and later re-assessed and modified by Mr C. D. Ovey of the British Museum (Natural History). It consists in making population counts, by species, of Foraminifera, small single-celled organisms which live in the surface layers, and then sink to the bottom, where their 'tests' or skeletons accumulate as sediment (*Science News* **17**, pp. 117-18). The second method, developed by Dr J. D. H. Wiseman, also of the British Museum, depends on chemical measurements of the amount of carbonate contributed by the Foraminifera to different levels of the core. This was first described at the centenary meeting of the Royal Meteorological Society in 1948, and gave results which in general agreed well with those given by the Foraminifera method based on species counts. Its basis is that the higher the temperature in the surface layers, the greater the mass of Foraminifera tests, and therefore of carbonate, which is deposited.

Dating, however, has remained speculative in the absence of a check by a radioactivity method applied to the same core. An alternative procedure, believed to give a short-cut to dating in a core from an undisturbed area remote from land, is now stated by Dr Wiseman to have been worked out from a core obtained from a depth of 2,379 fathoms in the equatorial Atlantic by the Swedish Deep-sea Expedition. Chemical and physical tests, still proceeding, are said to suggest, first, that the core consists essentially only of clay and the remains of Foraminifera; and, second, that the rate at which clay was deposited was substantially uniform. On this basis the time-scale for the core has been fixed by the known last period of greatest warmth at about 3,000 B.C. - the so-called climatic optimum - and tentatively applied to give approximate dates for earlier climatic changes. The first date quoted is about 117,000 B.C., when there was 'a distinct but sharp minimum temperature.' The next principal maximum of temperature is given as 78,000 B.C., followed by a lesser minimum at 68,000 B.C. From this period, temperature is thought to have risen until about 43,000 B.C. Then, after remaining essentially constant for 16,000 years, there was a third but lesser minimum at about 23,000 B.C. There was

then a general, but not uniform, rise until the optimum about 3,000 B.C. already quoted. It is emphasized by Dr Wiseman that the dates given should be regarded as provisional at the present stage.

Wiseman and Ovey. *Proc. Geol. Ass.*, 1950, 61, 28.

Wiseman. *The Times*, 1950, September 22.

LOW TEMPERATURE PHYSICS

A footnote can now be added to the paragraph given under the same heading in *Science News* 17 (pp. 123-6). In this paragraph some recent measurements were recorded of the speed of 'second sound' - the transmission of heat as a form of wave disturbance through helium II at very low temperatures; and the connection was illustrated between these measurements and theories of helium II, 'a liquid so unusual in its behaviour as to justify the description of a matter in a "fourth state" - neither solid, ordinary liquid, nor gas.' The experiments then described were by J. R. Pellam and R. B. Scott of the United States Bureau of Standards, Washington, and consisted in measurements of the speed of transmission of second sound at lower temperatures than before. They confirmed that there was a minimum speed of transmission of 60.4 ft. per second at a temperature of about 1.1° Absolute, and thereafter showed a smooth rise to a speed of 111 ft. per second at a temperature which, though not determined, was between 0.5° and 0.7° Absolute. This increase in speed of transmission was in agreement with predictions based on a theory developed by Professor L. Landau in Russia, in contrast with the principal alternative theory which predicted the reverse effect.

Further measurements, at still lower temperatures, have now been made by K. R. Atkins and D. V. Osborne in the Royal Society Mond Laboratory, Cambridge - and these, too, support Professor Landau's theory. In the course of two experiments, they made eleven measurements of the speed of transmission of second sound within the temperature range from about 0.4° to about 0.1° Absolute. The results show a continued rise in speed of transmission, but with a tendency to flatten out, as if to a

steady value, as the absolute zero is approached. At the lowest temperature reached - which is subject to revision as regards temperature - the speed of transmission was 152 metres per second, equal to about 500 ft. per second, or more than four times as great as that reached in the Bureau of Standards measurements. According to Professor Landau's theory, the speed of second sound should tend to a predicted ratio to the speed of normal sound as the absolute zero is approached. In figures, the speed of second sound should be $1/\sqrt{3}$ that of normal sound. The latter has not been measured at any lower temperature than 1.5° Absolute but, on the simplest supposition as to what happens in the interval, is taken provisionally to be about 272 metres per second at the absolute zero. This, according to Professor Landau's theory, would give a speed for second sound at the absolute zero of 157 metres per second, compared with the observed figure of 152 metres per second at 0.1° Absolute. There are various loopholes, admittedly, which are pointed out. The speed of normal sound may change in a different way with temperature from that assumed; the speed of second sound may depart from the experimental curve between 0.1° Absolute and the absolute zero; and there is the chance that other theories may be developed which give the same result. But in the meantime, the Cambridge workers sum up, 'the present experimental results must be considered strongly in favour of Landau's method of approach'.

Atkins and Osborne. *Phil. Mag.*, 1950, 41, 1078.

THE SIZE OF PLUTO

Pluto, the outermost of the known planets, has had an ironic history. The irony lies in the fact that it is probably too small in mass by a factor of sixty to account for the perturbations in the orbit of Uranus which led to its discovery. The discrepancy, which before had been suspected, has been confirmed lately by measurements of the diameter of Pluto, made with the 200-inch telescope at Palomar Observatory in California, and a disc meter designed by Dr G. P. Kuiper of Chicago for the more accurate measurement of the diameter of Neptune. The effect

of the latter instrument is to enable the apparent size of a planet, as seen through a telescope, to be matched by eye with that of a disc which can be varied continuously in diameter, brightness, and colour. The measurements on Pluto were made independently by Dr Kuiper and by Dr M. L. Humason of Mount Wilson and Palomar Observatories. They showed its diameter to be about 0.46 that of the earth. With the same average density, this would correspond with a mass equal to 0.1 that of the earth; but, in fact, the densities of the other planets lighter than the earth – Venus, Mars, and Mercury – are less than that of the earth by 10–20 per cent. The predictions of the American astronomer, Lowell, which led to the discovery of Pluto, were made in 1915 and gave it a mass of the order of six times that of the earth. They were based on the perturbations of the orbit of Uranus, after those due to Neptune had been allowed for. Later estimates, based on the apparent action of Pluto in pulling Neptune slightly out of its orbital plane, gave a figure for Pluto's mass which was about five times smaller, but still greater by eight to 10 times than has now been shown probable.

J. Brit. Astronom. Ass., 1950, 50, pp. 237–9 and 260.

LIGHTNING AND THE SPARK DISCHARGE

R. D. CONNOR

It is some 200 years since Franklin proved the electrical nature of lightning, yet it is only in the last 15 years or so that, as a result of much concentrated research, the subject has been clarified enough to allow of a description of the complex processes involved in the discharge. Today many aspects are the subject of conflicting theories and still await a complete description. Fifty years ago Townsend began his classic researches on spark breakdown, and many years passed before the need arose of modifying in part the views then formulated. Recent work has shown the close link between long sparks produced in the laboratory and the lightning discharge, so it is through such studies that an understanding of lightning can be reached.

THE SPARK DISCHARGE

The Townsend Mechanism. Townsend described clearly the sequence of events in a gas between two parallel metal plates

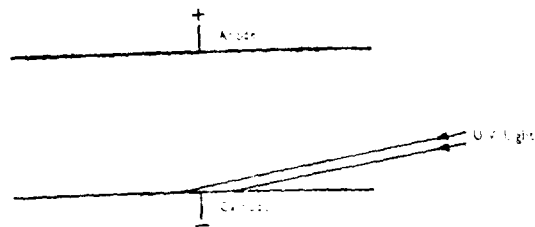


Fig. 7

connected to the opposite terminals of a battery (Fig. 7). A small central area of the negative electrode (the cathode) is illuminated

with ultra-violet light. These high energy photons (particles of light) liberate photoelectrons from the metal, and these electrons will migrate to the positive plate (the anode) under the action of the electric field X . The electric field is the gradient of electrical pressure or voltage in the gap, and here $X = V/d$, where V is the applied voltage and d is the plate separation in cms. For a constant ultra-violet illumination, the current to the anode increases as the field is increased from zero and soon tends to a "saturation" value, i_s (Fig. 8). True saturation means that as many electrons reach the anode per second as are liberated from the cathode per second, a condition rarely attained in practice because of electron diffusion away from the anode, and other complicating factors. Thus the portion BC of Fig. 8 is not quite flat, but is nearly so. At C the current begins to increase rapidly, until, at a field strength given by the point E , the gap breaks down and a spark passes. The explanation of the current increase at C is that, in the higher fields then available, a photoelectron

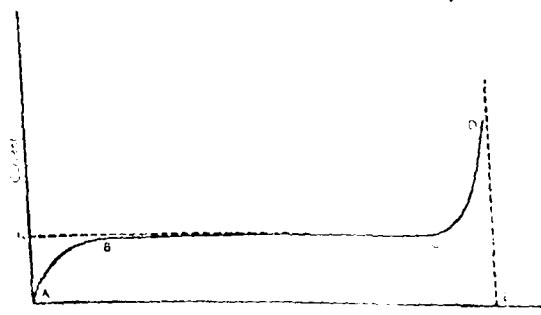


Fig. 8

from the cathode gains enough energy between collisions with gas molecules to liberate electrons by collision from these molecules. As the molecule was electrically neutral before, the removal of a negative electron leaves it with a net positive charge. The molecule is then called a positive ion. The new electrons so produced advance to the anode and by the same process produce further new electrons. This process of ionization by collision is

cumulative, and so an electron avalanche is formed which proceeds to the anode.

If on the average α new electrons are produced by one electron in advancing one cm. in the field, then the current reaching the anode can be shown to be $i = i_s e^{\alpha d}$. . . (1) where e is the base of Napierian logarithms. Now α will depend on X . In fact α/p is a continuous function of x/p , p being the gas pressure measured in mm. of mercury, and X the field strength in volts per cm. The onset of ionization by collision occurs at a characteristic value of x/p for each gas. Thus, this characteristic value is 2 for neon, 5 for argon, 10 for hydrogen, and 20 for air.

α is a statistical quantity, for the number of new electrons produced per cm. by one electron will depend on the number and nature of the collisions it makes with the gas molecules. Average values of α are therefore used.

As the field is increased above that corresponding to the point C (Fig. 8) the current increases exponentially (Eqn. 1), but subsequently, with higher fields, the current increases more rapidly than exponentially. When this occurs, additional electrons are being created by some process other than that mentioned above. The explanation offered for this new effect was that the positive ions left behind in the gap by the electron avalanche would themselves be able to ionize by collision as they moved towards the cathode. The positive ions, being much more massive than the electrons, have a speed about one-hundredth that of the electrons.

On this view positive ions would begin to ionize at a critical value of x/p , and if β new electrons are formed by one positive ion in advancing 1 cm. towards the cathode, the total value of

the current is $i = i_s \frac{\alpha e^{\alpha d}}{\alpha - \beta e^{\alpha d}}$. . . (2) if β is small when com-

pared with α , as is usually the case. Equation (2) reduces to (1) if $\beta=0$ and the current becomes infinite if $\alpha = \beta e^{\alpha d}$. . . (3). This condition was regarded as the criterion for a spark. The equation satisfied the observations, and was accepted until evidence accumulated to show that positive ions could not gain sufficient

energy, in the electric fields employed, to ionize the gas by collision. Further, when the gas pressure was low a small dependence on the cathode material was observed, while α as defined above is essentially controlled by the gas.

However, there are two other processes, either or both of which may be active at one time, depending on the experimental conditions, both of which yield equations very similar in form to (2). For this reason they are referred to as Townsend mechanisms. These are positive ion bombardment of the cathode, and photoelectric effects at the cathode. In the first process, the positive ions on arriving at the cathode strike the metal surface and in so doing have a small probability of liberating an electron from the metal. The liberated electron will then proceed to ionize by collision on its way to the anode. In the second process, if on impact some of the electron's energy is transferred to the gas molecule, the latter is 'excited' and can emit photons in returning to its normal state. Photons are also emitted when a positive ion is neutralized by an electron. These photons are emitted at random in all directions, so some, depending on the geometry of the apparatus, will strike the cathode and will have a small probability of liberating an electron by the photoelectric effect, provided the photons are not absorbed by the gas. These newly produced electrons will ionize in their advance to the anode.

Under these conditions the sparking criterion (Eqn. 3) is equivalent to saying that more than one electron must be generated at the cathode by the positive ions or photons produced in the passage of a single electron and its progeny across the gap. This ensures that succeeding avalanches will increase in size until one sufficiently large causes the spark to occur.

The Streamer Mechanism. Unfortunately for the simplicity of the subject, these Townsend mechanisms are not universally applicable. They apply in cases where the gas pressure is low and the electrode separation small. They are not of fundamental importance at higher pressures and longer gaps. Part of the evidence for this can be stated briefly. Consider a 1 cm. gap in air at atmospheric pressure when the applied voltage is somewhat greater than the minimum necessary to cause sparking. Irradiate

the cathode by a sudden flash of ultra-violet light. If a cathode mechanism were effective at least one electron avalanche would require to cross the gap before the spark could pass. The time necessary for this is about 10^{-7} seconds, yet luminous channels are observed well across the gap in times of the order of 10^{-8} seconds after the initiating flash. The spark is thus under way before the first avalanche has crossed the gap. Under such conditions no dependence on the cathode material is observed, so a new mechanism in which cathode processes are unimportant must replace the Townsend mechanism, when the pressure and gap are large.

The evidence leaves no doubt that for longer gaps and higher pressures photo-ionization of the gas molecules and the subsequent accumulation of positive ions in the gap to produce a space charge are the two factors which control spark breakdown.

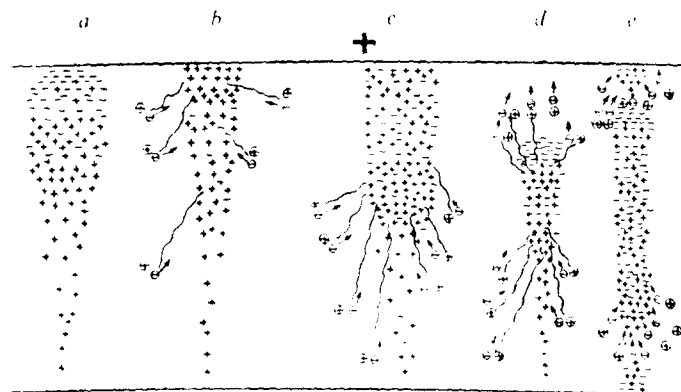


Fig. 9. (Re-drawn by permission from the Journal of Applied Physics.)

The term 'space charge' usually signifies a slowly moving concentrated aggregate of charged particles or ions. The process as envisaged by Meek is as follows. An electron liberated from, or near, the cathode will produce α new electrons per cm. of its path to the anode. The total number of electrons formed in advancing x cm. is $e\alpha^x$, and an equal number of positive ions

will be left behind and can be considered as relatively at rest in the gap as their mobility is small. As the electron avalanche reaches the anode and is absorbed by it, a conical-shaped distribution of positive ions is left (Fig. 9c). Most of the positive ions are to be found close to the anode, and this dense aggregate of positive charge extending from the anode into the gap will, if large enough, attract to itself photo-electrons and neighbouring electron avalanches. The electrons of the captured avalanche change the positive ion space charge into a conducting column with both positive and negative charges in it (Fig. 9b). Photons emitted by the initial avalanche are responsible for the creation of these neighbouring photo-electrons in the gas, and the process continues with succeeding avalanches towards the positive space charge (Fig. 9c). Thus more and more photo-electrons are produced in the gas and more avalanches are attracted to the column as time goes on. The addition of the positive ions of the captured avalanches extends the column towards the cathode. This process is termed positive streamer formation. When the streamer reaches the cathode a highly conducting column now bridges the gap and the electrodes discharge through this channel, producing the visible spark. The speed of the avalanche is about 2×10^7 cm./sec. while the return positive streamer is about ten times as fast. The final discharge is between 100 and 1,000 times more rapid than the avalanche.

Clearly the necessary condition for streamer formation is that the original avalanche should leave behind a sufficiently large positive ion space charge so that neighbouring photo-electrons and their avalanches may be attracted to it. Meek has shown that this is equivalent to saying that the radial electric field due to the positive ion space charge must be of the same order of magnitude as the electric field between the plates.

The problem of the formative time mentioned above can now be solved. If the applied voltage is in excess of the minimum required for spark breakdown, then the initial avalanche grows so quickly that, at some point in the gap, the positive ion space charge can attract other avalanches to it. The space charge grows upwards towards the anode and downwards towards the

cathode simultaneously, as photons are emitted in all directions, and photo-electrons produced in the line of advance are more effective than those formed in other directions. (Fig. 9d and e). The rapid growth of the streamer thus accounts for the short formative times observed.

The Sparking Potential. In measuring the voltage for which a given electrode assembly would break down it has been customary to irradiate the cathode and air in the gap with an ionizing radiation such as ultra-violet light or X-rays. This is to ensure that when the critical voltage is reached, there are enough electrons in the gap to ensure that the spark mechanism proceeds, be it a Townsend or a streamer process. Unless there is at least one electron in the gap, sparking cannot take place, irrespective of how large a voltage is applied to the electrodes. In measuring sparking potentials, it is customary to apply a voltage for an arbitrary time to the electrodes, and if no spark occurs in this interval, the voltage is increased. We define the sparking potential as that voltage for which in 50% of its applications the gap broke down in a spark. If the gap is not irradiated, voltages greater than critical can be applied for long periods to the gap without a spark passing. This delay between the application of the voltage and the passage of the spark is called the time lag, and it ranges from 10^{-9} secs. for irradiated gaps to 30 minutes or more for gaps carefully screened from irradiation. These time lags consist of two main parts. Firstly there is the statistical lag, which is the delay before an electron is produced in the gap at a point from which breakdown can be initiated. Secondly there is the formative time of the spark itself once the electrons have begun their avalanche. Statistical lags of 100 microseconds have been observed in non-irradiated gaps of 1 mm. when impulsive voltages are applied which are 50% greater than that necessary to cause breakdown in the same gap when irradiated. Voltages sixteen times the normal sparking voltage have been applied to non-irradiated gaps for 1 microsecond without breakdown occurring. With ample irradiation no lower limit to the value of the time lag has been found, for with excessive voltages the gap breaks down more rapidly. If the

irradiation is very intense the ionization in the gap produces sufficient space charge to distort the field and a reduction in the sparking potential is observed, so the intensity of the irradiation of the gap must be kept within reasonable limits for concordant results.

From Townsend's sparking criterion it can be shown that the sparking potential depends only on the product of the gas pressure and the electrode spacing. This is Paschen's law. The law is based on the total number of ions present in the gap. Meek's theory is based on ion density and predicts departures from Paschen's law. Such departures are observed. To give one example, the sparking potential for 1 atmosphere pressure and 1 cm. gap is 32 KV., while for 21 atmospheres and a gap of .1 cm. it is about 27 KV.

Corona. If one plane electrode is replaced by a sharp point, such as a needle, the nature of the breakdown is altered. In such a point-to-plane discharge, the field is no longer uniform between the electrodes. The field is very large in the neighbourhood of the point and relatively small in other regions of the gap, particularly if the electrode separation is large. Thus if the point is made the anode, and the voltage across the electrode gap is slowly increased, high fields capable of producing streamers will occur in the neighbourhood of the point, as described above for a plane parallel gap. Streamers will propagate towards, but will not reach, the cathode, because they will be advancing into progressively weaker fields. After advancing so far, the streamers fail to maintain themselves and so cease to advance. Recombination will rapidly obliterate the streamer unless a second streamer, advancing from the point, enters the channel of the first. With increasing voltage, the excitation caused by electron avalanches to the point and the subsequent streamers produces a visible discharge around the point. Thus streamer formation in asymmetrical gaps does not at once lead to a spark, but to a corona round the pointed electrode. Further increases in voltage enable streamers to progress farther and farther towards the cathode, and, as before, spark breakdown occurs when a streamer is able to bridge the gap.

When the polarity is reversed, the mechanism is different, for now electrons are repelled away from the point, and if the field is high enough, ionization by collision will begin. As the electrons move away from the point, not only are they advancing into ever weaker fields, but also they leave behind the positive ions created in the collision process. These two factors slow the electrons down, so that there will be at first a rapid multiplication of electrons, followed by a gradual reduction in their number when multiplication ceases. With slow electrons, there is a likelihood that they will be captured by oxygen molecules in the air to form negative ions, the neutral oxygen molecule having a high affinity for electrons. Thus in the region beyond the positive ion space charge there is formed a negative ion space charge which slowly migrates to the anode. The field near the point is enhanced by the presence of the positive space charge and positive ions are strongly pulled to the point, where some liberate new electrons by bombardment, and these new electrons will rapidly proceed outwards from the point, ionizing as they go, until they too are slowed down under the retarding action of the weaker field and the positive and negative space charges. As this process continues with increasing voltage, the space charges increase, the field near the point increases and the new electrons are able to penetrate to increasing distances before ceasing to ionize. In the neighbourhood of the point the gas will become excited and photo-ionization of the gas occurs. A corona begins to be visible around the point and, although luminous streamers develop outwards from the point, it will be clear from the space charge distribution that breakdown cannot proceed all the way to the anode. What does occur is that the high concentration of negative ions near the anode creates a field large enough to permit the formation of an upward-moving positive streamer. Breakdown occurs when the downward-descending negative streamers from the point meet this positive one. The junction takes place in the gap but nearer the point than the plane. Inset, 16 is a photograph of positive point-to-plane breakdown taken with a special camera which will be described later. The streamer is separated on the photograph from the return

stroke and is seen on the left. The return stroke moves up the streamer channel from the plate cathode at the foot of the photograph. Inset, 17 is a similar photograph taken for breakdown when the point is negative. The discharge is seen to be quite different. The downward negative streamer appears, but most of the positive streamer is obliterated by the brilliance which follows their junction. Breakdown occurs for positive points for average fields of the order of 5KV/cm. in long gaps, while for negative points the average fields are much higher, as would be expected.

THE LIGHTNING DISCHARGE

Let it be said now that, despite the vast accumulation of observational data on the subject, workers on the lightning discharge are not all in agreement on the interpretation of the data. Such theory as is given below represents perhaps the views of the majority.

Cloud Charges: The surface of the earth exhibits a net negative charge, and in the atmosphere there is an electric field of such polarity as to repel an electron outwards from the earth's surface. This field exists in the absence of cloud, but when a thunderstorm is overhead it is very often observed that the direction of the field reverses, indicating powerful negative charges in the cloud. The normal field is between 20 and 200 volts per metre, depending on locality. Under a thundercloud, the reversed fields near the surface of the earth can reach values of 100 volts per cm. Recent determinations of the fields by aircraft within clouds have shown that in clouds producing rain with little convection, the field is small, less than 40 volts/cm. The fields in normal stable clouds without precipitation are generally less than 10 volts/cm., and flights through thunderclouds have shown that, prior to discharge, fields of at least 3,400 volts/cm. exist, but it is not known how much reliance should be placed on data obtained in a metal aircraft, as the presence of the aeroplane will very seriously distort the field. Considerable variation in the field is found on traversing the cloud. The largest fields, together with the most rapid variations,

occur in the freezing region of the cloud, and large fields are generally confined to the clouds themselves. Sounding balloons have revealed a general charge distribution as shown in Fig. 10, the arrows giving the direction of the air movements. In all thunderclouds there is a positive charge near the top of the cloud where the temperature may be about -20°C . Lower down, where the temperature is between -10°C . and 0°C ., a negative charge exists, while even lower, in the region of the storm centre, are localized regions of positive charge. The temperature there is above the freezing point.

Many attempts have been made to explain how raindrops falling through rapidly ascending air currents can generate the electrical charges found in thunderclouds. It has been shown experimentally that the break up of large water drops into smaller ones results in the drops acquiring a positive charge, while the air carries away negative ions or spray. C. T. R. Wilson has advanced a theory which has widespread acceptance. In this, small cloud droplets carried to the cloud top by the up-draught are considered positively charged, while large raindrops are negatively charged and are held in the cloud base by up-draught and the electrostatic attraction of the upper positive charge. A neutral drop falling in the mid region of the cloud will have an induced negative charge on its upper surface and a similar positive charge on its lower surface, and will thus attract and absorb negative ions in the course of its fall, thereby gaining a net negative charge. The theory shows that if the drop is smaller than a critical size its slow rate of fall in the cloud will cause it to collect a net positive charge.

The larger negative drop may be held in the cloud base as described above or may fall to the ground. Beneath the negative cloud base there is an up-current of positive ions produced by point discharge from trees, bushes, grass, tall buildings, lightning conductors, etc. A negative drop falling through such an up-current is likely not only to be neutralized but to acquire a net positive charge. In this way the observation that positively charged rain predominates under thunderclouds is explained. An alternative view is that the rain carries down the charge of

the originating cloud region and, as the storm centre gives the heaviest rain, the preponderance of positive rain is again explained (Fig. 10). In the upper regions of the cloud the precipitation is in the form of ice crystals, so if any charges are produced in this, a major portion of the cloud, they cannot be accounted for on a water drop theory. Recent experiments show that by causing water drops to impinge on ice in a cold chamber, the ice becomes negatively charged. The residue of the drops which fall from the ice carries a positive charge. These results, coupled with the aircraft results given above, indicate that both water drops and ice crystals are likely to be effective in the production of electrical charges in thunderclouds.

The lengths of lightning strokes vary from a few hundred metres to 2 or 3 kilometres, and the potential difference between cloud and earth would appear to be frequently in the range 100-1,000 million volts. The charge transfer between cloud and earth is on the average 20 coulombs, although as little as 0.1

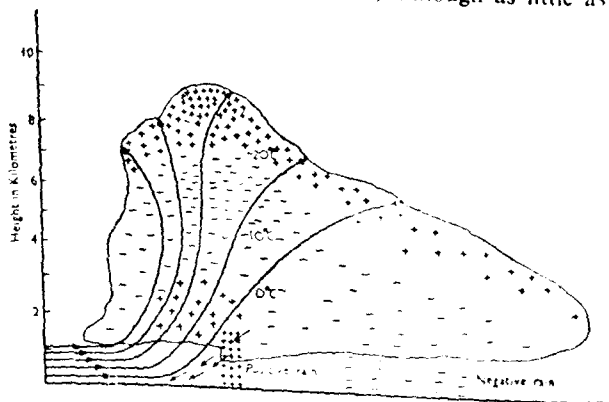


Fig. 10. (Re-drawn by permission from Proceedings of the Royal Society.)

and as much as 200 coulombs have been recorded. One coulomb is the amount of electrical charge transferred by the flow of 1 amp. along a wire for 1 second.

As will appear later, the lightning flash occupies an extremely short time, so that to transfer even these modest charges a very

high current must flow. A peak current of 20,000 amps. is common, while 220,000 amps. have been observed. While lightning outstrips the laboratory in voltage and length of spark, the laboratory can hold its own where current is concerned. In recent work at Liverpool, currents of half a million amps. were employed in spark studies.

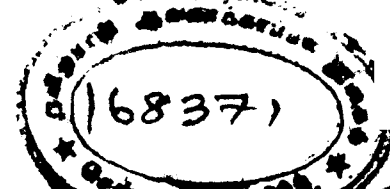
The energy from the discharge to ground of 20 coulombs initially at a potential of 100 million volts is nearly 280 kilowatt-hours, and a rough estimate shows that, for the earth as a whole, 100 lightning flashes occur per second. For England, where lightning is not so common as in other parts of the world, a recent survey gives six strokes per square mile per annum. The rapid release of energy in the channel creates a temperature of ten to fifteen thousand degrees centigrade, and the rapid expansion of the air at an initial rate of 10^5 cm./sec. is the principal cause of thunder.

The lightning discharge has been likened to the discharge of an enormous condenser of which the charged region of the cloud forms one plate and the earth the other. This analogy is not good, for the discharge of a condenser is oscillatory, whereas by far the greater bulk of all observations indicate a unidirectional discharge. Occasionally, a few isolated results occur which might signify an oscillatory discharge for a particular flash, but usually the observation is open to other interpretations.

Duration and Nature. Lightning and its associated thunder is not in any way the cause of the storm. Rather they are the results of the meteorological processes at work involving rapidly moving up-currents of warm moist air.

The lightning discharge has been observed to occur between cloud and ground, within a cloud, between clouds, and from cloud to air, the latter being termed air discharges. Inset, 18 is a still photograph showing the first two types of discharge.

Recent observations show that 50% of the lightning flashes examined had a total duration of about 0.1 sec. or more, and 5% had a total duration of 0.75 sec. or more. On one occasion the duration was 1.53 secs. The term 'total duration' is used here, because a lightning stroke, although it may appear to the eye



to be a single stroke, is very often composed of several rapidly succeeding strokes. The high-speed photographic methods described below are able to resolve the individual flashes, and as many as 42 have been observed. In 50% of a batch of photographs, the lightning stroke was seen to consist of 2 or more individual flashes, and 5% consisted of 10 or more. The time intervals between the individual flashes were measured. In 50% of the cases it was 0.06 sec. or greater; in 5% the interval was 0.3 sec. or greater.

Cloud to ground discharges are more easily photographed than other types, but this does not mean that such discharges are more frequent. A recent determination in this country showed cloud discharges to be about as frequent as ground discharges, but earlier work in South Africa showed cloud discharges to be ten times more frequent. Discharges within a cloud or between clouds have more individual flashes, recurring more rapidly, and having a shorter total duration, than discharges between cloud and ground. Discharges from negatively charged regions in clouds to the earth are more common than discharges from positive regions. In the tropics, the ratio is about 17 to 1 in favour of the former, but in more temperate zones the ratio is about 3 to 1. For the earth as a whole, 90% of the lightning strokes examined are from negative clouds, except in mountainous regions.

High Speed Photography. A still photograph does not reveal the development of the discharge. For this a camera of the Boys type is needed. This consists in essentials of a rotating drum of film and a fixed optical system (Fig. 11). A luminous object moving uniformly from *A* to *B* would trace out the lines *ab* and *a'b'*, on the film if this were stationary. If the film drum rotates as shown, the lines traced out are *ac* and *a'e'*, the displacement *bc* depending on the speed of the luminous object, the speed of the rotation being fixed. In one investigation the drum was rotated at 3,000 revs. per min., equivalent to a linear film speed of 140 ft./sec., hence the large resolving power of these cameras, but often the photographs obtained are difficult to interpret.

The Mechanism of the Discharge. Using data from many

sources, it appears that lightning proceeds as follows. Localized high fields in the cloud reach such a magnitude as to maintain and propagate streamers. The action of water drops will be important here, for it has been shown in the laboratory that at fields of

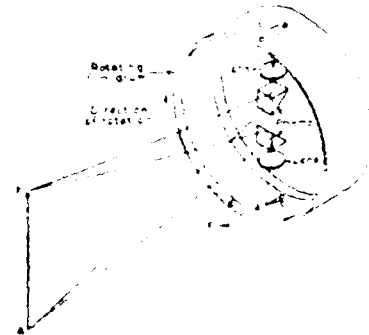


Fig. 11. Boys moving film camera. (Reproduced with permission from the Journal of the Franklin Institute - K. B. McEachron, 1939.)

8 KV/cm., large drops will be deformed and will appear pointed towards the two opposing charges. From these points a visible glow or corona can be seen, which is more marked for the water point, which is charged positively by induction. The drops produce a fine spray from these points, and recent work in the University of California has shown the efficacy of these spray droplets in maintaining corona from water drops. Thus, breakdown in the presence of water drops sets in long before the 30 KV/cm. needed for plane parallel gaps is reached. The streamer will not cease once it bridges the gap between the two localized charges but will extend probably from both ends, the lower end proceeding towards the ground. It is not necessary to have breakdown fields existing throughout the whole cloud-ground distance in order to permit a streamer to pass. Just prior to the passage of lightning, fields of 2,700 V/cm. have been observed at the earth and it is to be expected that during the descent of the streamer these fields will increase. Part of this will be due to the field of the descending streamer itself. Thus a streamer may find

itself in fields capable of maintaining its growth, and it advances towards the earth in a series of separate steps, the individual steps being of the order of 10 metres in length. This is called the stepped leader and is of such intensity as to leave a faint record on photographic film. When the leader is near the earth a streamer rises from the earth to meet the descending leader and a brilliant flash, the return stroke, proceeds from the earth to the cloud. These earth streamers are very short if the lightning is occurring in open country, and are rarely photographed. One of the few photographs in existence is reproduced in Inset, 19. While the average speed of descent of the stepped leader is 2×10^7 cm./sec., it does



Fig. 12. Diagram of a stepped leader stroke showing the individual steps of the leader. (Reproduced with permission from the Proceedings of the Royal Society.)

not proceed uniformly, but each individual step takes place jerkily and rapidly, the actual speed of each advance being of the order of 5×10^9 cm./sec. Each step follows the path of the preceding step and extends the channel by some 10 metres or so. When the stepped leader reaches the ground or the upward moving earth streamers, the return stroke proceeds up the

pre-ionized channel with a speed about half that of the velocity of light, i.e., about 1.5×10^{10} cm./sec. Its passage is not resolved by the camera, even though the speed may fall by a factor of ten as it moves away from the ground. The peak current flows during the return stroke and from 1% to 30% of the atoms in the channel will be ionized, so intense is the discharge. Inset, 20 is a Boys camera photograph showing the downward-stepped development of the leader, and Fig. 12 is a clearer sketch of a similar photo showing the development against a time scale. The return stroke is here shown as a heavy black line, indicating that the arc-like discharge which followed the bridging of the earth-cloud gap by the return stroke lasted some 100 micro-seconds.

Very shortly after the passage of the return stroke a new leader may come from the cloud, and follow the same channel to earth, and engender a second return stroke. As this leader is moving along an ionized channel it is not stepped, but moves continuously with a speed of about 2×10^9 cm./sec. These are called dart leaders. Further dart leaders and return strokes can occur in rapid succession, this giving rise to the multiplicity of the lightning stroke already mentioned. The upper portion of Fig. 13 is a sketch of the process from the descent of the stepped leader to the succeeding dart and return strokes, as would be seen on a rotating film. Inset, 21 shows very clearly the successive components of a long spark generated in the laboratory with a synchronized oscillogram of the voltage.

Several reasons have been advanced for the multiplicity of the lightning discharge. One is that the channel may extend to new charge centres in the cloud, or that leaders may develop from other charged localities to the existing one. More probably, the recurrence may be due to the recharging of the cloud. This would account for the frequent regularity in the time intervals between succeeding return strokes.

The time intervals between succeeding steps of the first leader are remarkable in their uniformity. Many lie close to 50 micro-seconds and nearly all that have been observed lie in the range 30 - 100 micro-seconds. Theoretical arguments have been

advanced to account for this regularity, which invoke recombination processes in the leader channel and the existence of a hypothetical pilot leader which precedes the stepped leader. It is considered likely that the primary discharge from a cloud is a pilot leader, which moves more or less uniformly towards the earth with a speed of 2×10^7 cm./sec. After the pilot leader tip has moved about 10 metres in a time of about 50 microseconds, that portion of the channel near the cloud will have undergone considerable recombination. Its resistance will increase. As current is still flowing into the streamer tip, a considerable voltage will develop across this resistance, which finally causes breakdown to occur across it. A new brighter discharge leaves the cloud and travels down the pre-ionized channel of the pilot leader with a velocity of about 5×10^8 cm./sec. This new discharge is the stepped leader. It rapidly overtakes the pilot streamer and stops when it reaches it, while the pilot streamer continues its journey. Some 50 microseconds later recombination will again cause an increased resistance in the channel and breakdown will occur again. A new discharge travels the 20 metres to the tip of the pilot streamer and stops there, to appear as the second step on the photograph of the stepped leader. The process continues.

The pilot streamer does not appear on any photograph yet examined, and calculations indicate that its ion density would be insufficient to create an impression on a rapidly moving film. Recently a novel technique has revealed the presence of ionized corona channels right across a long gap in the laboratory, while the photographable leader is only a short way across the gap and is following the existing corona channels. The theory of the pilot leader explains many difficulties of the lightning discharge and it may well be similar in nature to the almost invisible corona streamers mentioned above.

These considerations apply to a discharge leaving a negative region in the cloud. From what has been said earlier no difficulty occurs in envisaging streamers from positive regions of cloud.

From laboratory and field observation it is certain that branching of a lightning stroke occurs in the direction of

Lightning and the Spark Discharge

propagation and is independent of polarity. The stepped leader and first return stroke may exhibit branching but succeeding strokes do so very rarely (Fig. 13).

Tall Buildings. Lightning strokes to tall buildings, particularly the Empire State building in New York, have been intensively studied. In the vast majority of discharges examined the cloud has been negatively charged, and upward stepped leaders, which sometimes displayed upward branching, were very common. The initial stepped leader in this case is not followed by a return stroke from the cloud. On entering the cloud the luminosity of the leader continues to be recorded on the photograph for times up to one-tenth of a second. The condition is similar to a low current arc, and is called a continuing stroke. Thereafter suc-

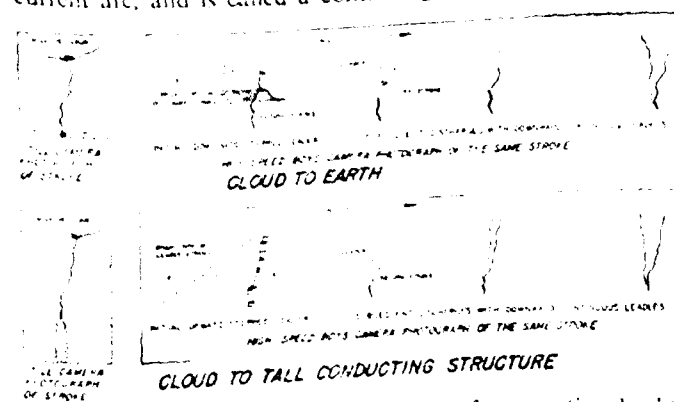


Fig. 13. Schematic diagram showing discharges from negative cloud to substantially flat terrain and discharges from negative cloud to tall structure such as Empire State Building. In a small number of cases the downward step leader type has been observed to the Empire State Building. (Reproduced with permission from the Journal of the Franklin Institute - K. B. McEachron, 1939.)

ceeding flashes in the same channel are created by a downward developing leader stroke, followed by a return stroke from the building. The process is illustrated in the lower section of Fig. 13. A probable explanation for the absence of a return stroke from

the cloud is that sufficient charge is not concentrated at that part of the cloud, and therefore is not immediately available for the production of a downward return stroke. If the return stroke depends on the availability of charge at the end of the leader channel, it explains also the observation that discharges from cloud to air do not give a return stroke either. The discharge to a tall building is similar in nature to positive point-to-plane breakdown with the removal of the return stroke (Inset, 16). It may be that a downward developing streamer from the cloud is in action, as well as the upward streamer from the building. This is not seen in the majority of cases, but this might be due to the leader being obscured by cloud.

Lightning is the common territory of the worker on atmospheric electricity and the worker on the spark discharge. Continuing co-operation between these two groups may finally yield the complete elucidation of the phenomenon which we lack to-day.

CONTROLLED CORROSION

F. A. FOX

RUSTING of iron and steel has been a source of worry to engineers and an expense to the community for a very long time, and a great many ways of meeting this problem have been evolved. Until recently these have usually depended on putting some form of covering on the surface of the metal and so protecting it more or less mechanically from the destructive influences. Painting, electro-plating, and bitumen coating are familiar examples of the protective methods we are forced to adopt.

In spite of these ordinary methods of protection, which in the aggregate are very costly, it still happens that certain kinds of steel structures do not last well; for example it is officially estimated that the annual cost of replacing corroded water mains in England and Wales alone is £5 million. Failures of this kind are due mainly to mechanical breakage of the substance protecting the surface – the paint film or the coating. One might argue that the problem could be avoided by making critical structures in stainless steel and so relying on the intrinsic properties of the steel to resist the attack. This would be very agreeable if it were practicable, but it is not so for a variety of reasons, chiefly that the use of stainless steel would be prohibitively expensive, even when one takes into account the recurring replacement necessary for ordinary iron and steel.

A method of protection for certain types of steel structure is, however, coming into prominence, which has the effect of making the steel 'stainless', although it does not affect its composition nor cover it with any mechanically applied layer. This is the method of galvanic protection. This way of protecting steel is made possible by the self-same factors which give rise to the corrosion, and makes use of the same electro-chemical effects.

In order to appreciate how this protective method works let

us consider very briefly what happens when a piece of steel corrodes. For corrosion of the kind we have in mind to take place at all, it is necessary for the surface of the metal to be exposed to the action of some liquid solution; this can be a relatively strong solution like sea water, a dilute one like rain water, or may consist even of dampness in some surrounding medium like soil. The metal surface, either because of local slight differences in composition or because of local differences in the solution on it (the 'electrolyte') assumes different characteristics at different points, with different tendencies to go into solution in the liquid. At the more reactive ('anodic') spots the metal may be thought of as splitting up into positively charged ions which enter the solution and electrons which move to other areas of the metal, giving these ('cathodic') areas a negative charge. The positive ions migrate in the solution and there encounter negatively-charged ions belonging to the electrolyte. The two sorts of ion combine to form a corrosion product. The electrolyte having by this part of the process lost the negative ions, a corresponding number of positive ions remain. These may be, for example, hydrogen ions or metallic ions (like sodium) which may have been in the electrolyte. These positive ions migrate to the negatively-charged cathodic parts of the metal and are there discharged by absorption of electrons. This is (basically) a continuing process, though sometimes certain side effects may interfere with it and slow it or stop it. The metal thus continues to be eaten away at the anodic area. The movement of electrons mentioned above constitutes a flow of electric current, which by our ordinary convention we usually regard as moving in a direction opposite to that of the electrons. A current, therefore, leaves the steel at the anodic spot, traverses the electrolyte, and re-enters the metal at the cathodic area. Depending on many factors, anodic and cathodic areas may be far apart or can be so close together as to be indistinguishable from each other.

This process of corrosion is thus identified with the passage of current out from all the anodic areas of the steel; if current could in some way be prevented from leaving the metal no

corrosion would occur. The principle of galvanic protection is, therefore, to create electrical conditions which make the *whole* of the steel surface cathodic; this ensures that no outward current flow takes place. This result is achieved by electrically coupling a more active metal with the steel and with the electrolyte; when this is done current flows, as in a sample battery, from the reactive metal through the electrolyte and into the steel. In the face of this inflow, no current can then flow out, no anodic spots can develop and no corrosion can occur. One may consider this condition as the provision of the elements of a large-scale battery; the current generated by this battery action is made to flow into the steel and so swamps the tendency to the formation of minute local batteries within the steel, which is the cause of the corrosion which would otherwise occur. It is obvious that the current flowing from the reactive metal to the steel must be much larger than the corrosion currents which flow in unprotected steel, since the former is due to the effects of two dissimilar metals, while the latter result from small differences in different parts of metal which is basically of uniform composition. The swamping effect is consequently large, and complete protection must follow from the coupling of the reactive metal.

The reactive metal, since it supplies the swamping current, is anodic and consequently is itself corroded, on behalf, so to speak, of the steel. However, this is not of great moment since it can readily be arranged that the sacrificial metal can be renewed when it is completely eaten away.

Various metals offer themselves as candidates for the work of acting as galvanic anodes. The general requirements are that the metal chosen should:

- (a) be strongly anodic to the steel so that its 'battery power' is strong,
- (b) be eaten away not too rapidly; it should have a large electrical capacity per unit of weight,
- (c) be free from any tendency to form a scale or film which might insulate it from the circuit,
- (d) be liable to corrode to a minimum extent on its own account.

Although zinc meets some of these requirements, the metal which fills the bill best is magnesium, and this metal is being increasingly used as a sacrificial anode. Its use in the United States and in Britain is growing quickly, especially for the protection of pipe lines, storage tanks, and telephone and power cables and sheaths.

The use of galvanic protection for pipe lines is particularly apt and helpful. Here the soil in which the pipe is buried acts as the electrolyte and the galvanic anode is also directly coupled by electric cable to the pipe. Long pipe lines such as those carrying oil across desert areas in the Middle East pass through a variety of different soils, some of which are very brackish and liable to attack the pipe at any point where its mechanical protection (bitumen wrapping) has broken down. Such 'aggressive' soil zones are a nightmare to the engineers since they are areas in which costly pipe leakages are always likely to occur. Galvanic anodes provide an elegant answer to the problem since these automatically provide protection at all faults in the coating when they occur and as they occur (Inset, 14, 15). The protective 'swamping' current can enter the pipe only at a discontinuity in the coating, and it is, therefore, naturally distributed to protect those parts of the pipe which stand in most need.

Magnesium galvanic anodes have been supplied to protect parts of a 1,200 mile pipe line across the desert from Haifa to Endor, for water pipe lines in England and Scotland, and for the protection of transformer tanks. In Texas a length of 82 miles of 4-inch gas main has been protected in this way, and steel structures in sea-water, like jetties and pontoons, are also being preserved by magnesium anodes in many parts of the world.

The corrosion of steel can also occur under certain conditions, by a mechanism which is not the usual electrochemical one, as a result of the action of soil bacteria. As a sort of bonus to the useful results that magnesium anodes confer in preventing electrochemical corrosion, it turns out that the use of magnesium anodes raises the pH of the soil to a level at which the bacteria in question - *B. microspira desulphuricans* - do not flourish.

HORMONES AND CARBOHYDRATE METABOLISM

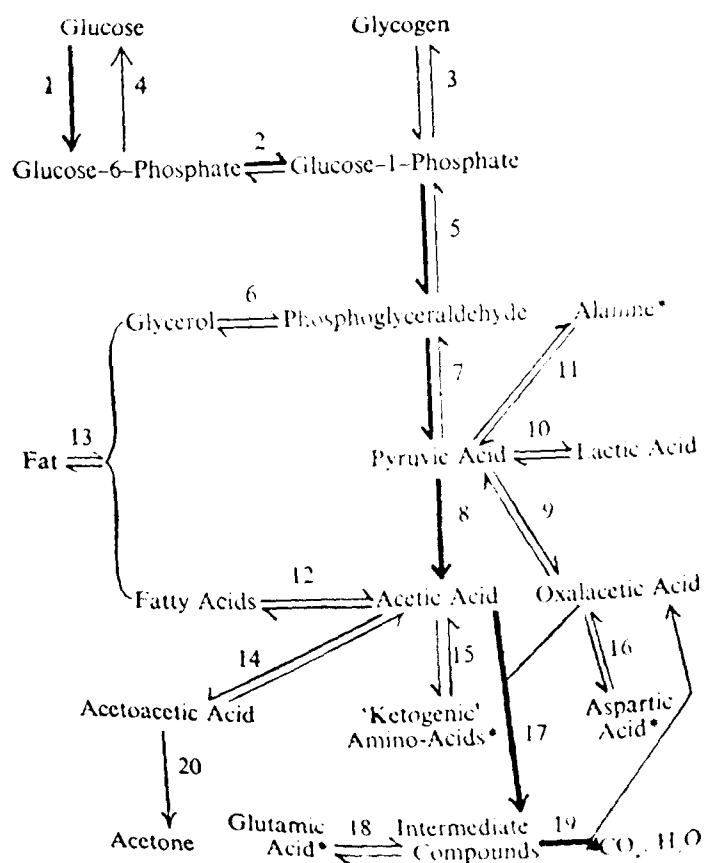
ERIC REID

THE disease *diabetes mellitus* (commonly called 'diabetes') has been known since ancient times. The sufferer excretes an enormous volume of urine which (unlike normal urine) contains a sugar, and the disease is named after these symptoms ('diabetes' = siphon; 'mellitus' = sweet). A reference by a seventeenth-century playwright, Molière, to the sweet taste of the urine in this disease suggests that the diagnostic methods then available to physicians were somewhat limited! Indeed, it was not until the eighteenth century that the disease was clearly distinguished from another disease (*diabetes insipidus*) in which there is a large urine excretion, but no sugar present.

As recently as 30 years ago, *diabetes mellitus* was regarded as a hopeless disease, and even now there is no true cure for it. But to-day it is rarely fatal, since it can be kept under control by injections of the hormone, insulin. As we shall see shortly, the presence of a sugar (glucose) in the urine of diabetic persons is a result of an abnormal increase in the sugar always circulating in the blood. If insulin is injected, the blood sugar level is lowered, and there is no longer any 'spill-over' into the urine.

We must begin with a brief explanation of the term 'hormone'. Since the beginning of this century it has become recognized that the animal body contains a number of ductless glands (see Fig. 14), which produce chemical substances known as 'hormones'. There is a certain resemblance between the function of the ductless glands and of the brain, for both essentially control processes occurring in other parts of the body. The development of the testes and ovaries, and growth in general, are examples of processes which are influenced by ductless glands. The brain controls distant processes by means of nerves, which may be

Not only is glucose not stored as such, but it does not occur free inside cells in appreciable amounts. It enters the cells from the blood in the form of a phosphate ester, glucose-6-phosphate. A number of other intermediate reactions in glucose metabolism involve the formation of phosphate compounds, some of which are indicated in Fig. 15. The nature of the intermediate compounds, and the role played by the compound ATP (adenosine



triphosphate) in the formation of certain phosphate compounds, is described in *Science News* 10, p. 66.

It is important to note that a key reaction in the metabolism of glucose is its conversion to glucose-6-phosphate (reaction 1, Fig. 15). This reaction, which enables glucose to pass from the blood into the tissue cells, involves ATP (acting as a source of phosphate) and the enzyme hexokinase. We may note in passing that the breakdown of carbohydrate is arrested at the pyruvic acid stage if the oxygen supply is deficient (as may happen in an actively contracting muscle). The pyruvic acid is then converted to lactic acid (reaction 10). The formation of lactic acid from glucose or glycogen requires no oxygen, but the energy obtained from this limited breakdown is much less than that obtained by complete oxidative breakdown of the carbohydrate to carbon dioxide and water. Much of the lactic acid formed for instance during violent exercise is oxidized later, when oxygen becomes more plentiful during the subsequent rest period; the rest is built up into carbohydrate again.

Although carbohydrate is the chief fuel of the body, we cannot

Fig. 15. Metabolism of carbohydrate in animal tissues. The main pathway by which glucose is oxidized to provide energy is denoted by heavy arrows. Some important details are not presented in the scheme. In particular,

- (1) some of the reactions are confined to certain tissues: thus, reaction 4 occurs in the liver, but not in the muscles;
- (2) each reaction has a specific catalyst, i.e. an enzyme; thus reaction 1 is catalysed by the enzyme hexokinase;
- (3) ATP must be present to provide phosphate for certain reactions, e.g. reaction 1;
- (4) amino-acids (of which the compounds marked * are examples) can be formed from, or built up into, protein.

Where a reaction is represented with only a single arrow (pointing downwards), the reaction cannot proceed in the opposite direction, in contrast to reactions represented with a double arrow.

Although glucose and glucose-6-phosphate can be converted into each other in the liver, this is not represented by a double arrow, since the two reactions (1 and 4) require different enzymes.

120

Science News 19

glucose into the tissue cells. We do not yet know the exact way it does this. The reaction requires ATP as a source of phosphate, and insulin may act by making more ATP available. But this is probably not the sole explanation.

Insulin not only lowers the blood glucose level when injected into an animal, but may also increase the amount of glycogen in the tissues. How is this brought about? One way depends on a principle known as 'mass action'. The rate of a chemical reaction is increased if the concentration of any of the reacting compounds in the solution is increased, or if that of any of the products is decreased. Thus speeding the hexokinase reaction raises the concentration of glucose-6-phosphate in the cells, and makes the transformation of this compound into glucose-1-phosphate (reaction 2, Fig. 15) proceed faster, and hence speeds also the conversion of the glucose-1-phosphate to glycogen (reaction 3). But recent work suggests that insulin can also *directly* speed up the conversion of glucose-1-phosphate to glycogen.

Insulin also accelerates the conversion of carbohydrate into fat although it could be argued that this effect of insulin may be an indirect result of its effect on the hexokinase reaction). It also stimulates the building up of amino-acids into protein, so that there is less conversion of amino-acids into carbohydrate. Either process would tend to reduce the amount of carbohydrate in the liver, and its output of glucose to the blood (cf. reaction 4, Fig. 15) would be lowered.

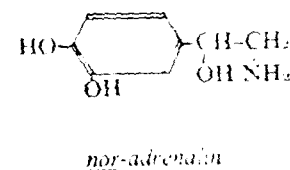
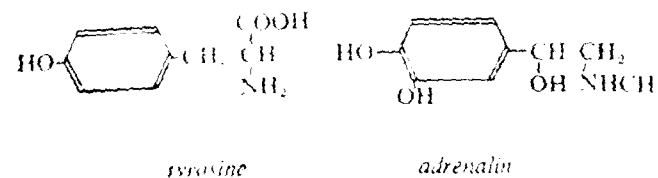
It is evident that administration of insulin to an animal, or to a suitable tissue preparation kept alive in the laboratory, may produce diverse effects, and that it is difficult to decide which effects are primary (due to a direct action of insulin) and which are secondary. At present the situation is confused, rather than clarified, by the discovery that the metabolic pathways of protein, fat, and carbohydrate are interrelated.

Although an insulin preparation injected into an animal lowers the level of glucose in the blood, the initial effect may actually be a slight *increase* in the level. This increase has recently been shown by de Duve and others to be due to a factor, commonly present in insulin as an impurity, which increases the breakdown

of liver glycogen to furnish glucose to the blood (reactions 3, 2, and 4, Fig. 15). Little was it realized by many workers engaged in studying the actions of insulin that their insulin preparations, thought to be pure, in fact contained also a substance with an action opposite to that of insulin! It has been suggested, somewhat speculatively, that this factor is a hormone, and that it originates from the so-called α -cells of the pancreatic islets of Langerhans (see Inset, 26). The results of investigations now in progress may throw light on this.

THE ADRENAL GLANDS

Mention has already been made of the theory that when a person is frightened the adrenal glands secrete a hormone which makes more fuel available to the limb muscles. This fuel is, of course, carbohydrate. A substance called adrenalin has been isolated from extracts of the inner part (medulla) of the adrenal glands, and this substance produces a marked increase in the blood glucose level when injected into the blood of an animal. This increase is the result of an increase in the breakdown of

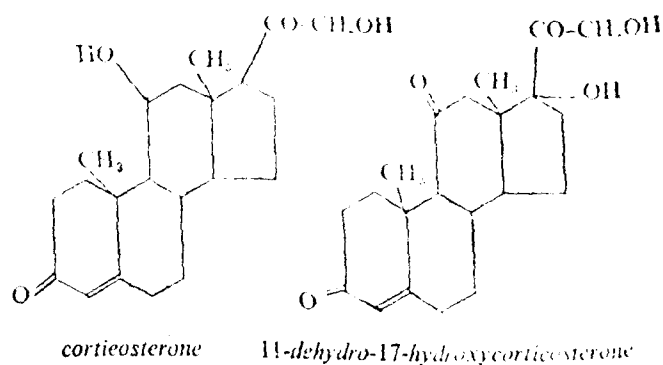


liver glycogen. The extra glucose thus produced can be drawn upon by the muscle cells as an energy source. Adrenalin is a compound with a structure similar to that of the amino-acid tyrosine.

Very recently evidence has been found to suggest that the true hormone which is secreted in the body may be not adrenalin itself, but the related compound *nor*-adrenalin, which can also be isolated from the adrenal glands.

If one examines sections of an adrenal gland under the microscope, one observes a difference in appearance between the outer part (the cortex) and the inner part (the medulla). It has been found that the two regions secrete different types of hormones; those secreted by the cortex having a 'steroid' structure. We have already seen that the adrenal medulla may influence carbohydrate metabolism in a spectacular way. It has become clear in recent years that certain steroid hormones produced by the adrenal cortex are of equal, if not greater, importance in this field.

One such hormone is corticosterone* (Inset, 23), and another is 11-dehydro-17-hydroxy-corticosterone (Inset, 24). The latter will be familiar to many readers, under the less formidable name of 'Cortisone' or 'Compound E', in connection with recent reports that it relieves the condition of rheumatoid arthritis (see *Science News* 15, p. 128).



These hormones influence carbohydrate metabolism in two ways. On the one hand they increase the extent to which protein is broken down (and hence converted to carbohydrate). On the

other hand, they decrease the oxidative breakdown of carbohydrate. Both these actions lead to an increase in the carbohydrate stores of the liver. The accumulation of carbohydrate which results from injection of these hormones may even go to pathological lengths, so that the blood glucose level is raised considerably. There may then be a temporary spill over of glucose into the urine, as occurs in diabetes. If only a low dose of one of these hormones is injected, there may be no rise in the blood glucose level; but it is nevertheless found afterwards that injection of insulin does not produce the usual lowering of the level: the adrenal hormone has in some way prevented the normal insulin action.

As well as conserving carbohydrate, hormones of the adrenal cortex may stimulate the use of fat as an alternative energy source. This may be of particular importance to a starving animal, since if it burned carbohydrate at the same rate as a fed animal, its carbohydrate stores would quickly become exhausted.

THE PITUITARY GLAND

The tiny pituitary gland, situated at the base of the brain, plays a leading role in the hormonal set-up of the body. It is made up of two parts – the anterior and posterior lobes – which, though in close contact, are anatomically and functionally quite distinct. The anterior lobe is the more important of the two. No less than six hormones – all proteins – have now been isolated from the anterior lobe of the pituitary, and the existence of others has been suggested, but not proved. Several of these hormones have a controlling influence on other ductless glands – the thyroid, ovaries, testes, and adrenal cortex.

The hormone which stimulates the adrenal cortex is termed adrenocorticotrophin (ACTH). In view of the fact that adrenal cortical hormones can alter the pattern of carbohydrate metabolism when administered to an animal, it is not surprising that ACTH can also affect it. Recently, J. W. Conn and collaborators in America have investigated the effect of ACTH on human volunteers, and found that it can produce symptoms of diabetes.

Early investigators in this field had to use crude unpurified

anterior pituitary extracts containing a mixture of hormones, since it is only recently that biochemical techniques have been developed for the isolation of pure hormones. B. A. Houssay, H. M. Evans, and other workers showed in 1932 that crude extracts may induce symptoms of diabetes when injected into animals such as the dog. Later, F. G. Young found that dogs treated with an extract of cattle pituitaries for a prolonged period developed *persistent* diabetes – that is, diabetes which continued, and even became more severe, after cessation of treatment (Fig. 16).

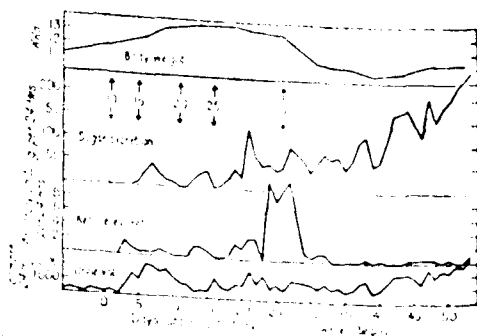


Fig. 16. Effect of pituitary extract on a normal dog. Injections were given once daily. The dose of extract was initially that equivalent to 10g. of anterior pituitary tissue (see first arrow). This dose was later increased (as indicated by arrows), and injections were stopped on the day indicated by the last arrow. Note the appearance of diabetic symptoms 'large urine volume, with sugar (glucose) and "ketones" in the urine' and the persistence of these symptoms after treatment was stopped. (F. G. Young, *Lancet*, 2, 372 (1937) courtesy of the author and the editor.)

The extracts employed in these experiments did not contain much ACTH, so that this hormone could not have been the cause of the diabetes. There was evidence to suggest that the diabetes was rather to be attributed to another hormone known as growth hormone – so called because some animals grow more rapidly when treated with it. American workers have now isolated this hormone as a pure protein (Inset, 25), and it has recently

been shown by Young and collaborators that the pure hormone can induce diabetic symptoms similar to those produced by a crude extract.

Why is a single hormone capable of producing effects as different as normal growth and the disease diabetes? It should be pointed out that the particular effect obtained depends on the test animal employed: the *adult* dog develops diabetes, but the puppy, and the rat (young or adult) merely grow in response to treatment with growth hormone. The clue to these differences is to be found in the pancreas. Pituitary extracts have a stimulating effect on the islets of Langerhans in the pancreas of the rat or the puppy, so that the β -cells of the islets secrete more insulin. On the other hand Inset, 27 shows the typical appearance of an islet of Langerhans in a dog which has just developed diabetes as a result of pituitary treatment. The appearance should be compared with that of a normal islet (Inset, 26). Signs of exhaustion are seen in many of the β -cells of the islet. Some cells are filled with fluid (hydropic degeneration), and many of the cells have lost the granules which are present when insulin is being produced. Some β -cells appear to be functioning even more actively than usual; it is significant that one β -cell in Inset, 27 has been caught in the act of dividing in two. It seems, then, that in the dog the β -cells become overworked as a result of pituitary treatment, and less insulin is produced since many break down under the strain; whereas the β -cells of the puppy or rat are more robust, and do not break down under the stimulating action of pituitary extract, so that these animals do not develop diabetes.

It is likely that the growth-promoting action of the extract in the puppy or rat is largely due to an increase in the amount of insulin produced by the pancreas. If an animal is growing, it needs extra protein as a building-material for the new tissue it is laying down. We have already seen that one action of insulin is to assist in the building-up of protein from amino-acids. Growth would thus be favoured by an increased insulin secretion, as occurs in the puppy or rat given pituitary extract.

To summarize, an immediate result of giving an extract

containing growth hormone to an animal is an increase in the insulin output of the pancreas, and the effect finally obtained – growth or diabetes – depends mainly on the ability of the pancreas to keep on producing. But how does growth hormone bring about an increase in insulin output? Nobody knows, but a clue may be obtained from the work of C. F. Cori and collaborators, who as already mentioned have studied the effect of hormones on hexokinase *in vitro* (i.e. on a preparation of the enzyme extracted from muscle and kept active in the laboratory). Certain pituitary extracts reduced the activity of the enzyme, and thus decreased the conversion of glucose to glucose-6-phosphate. If an extract of the cortex of the adrenal gland was also added, the reduction in activity was even more marked. If, however, insulin was also added, the activity of the enzyme was restored to its original value. The study of the effect of hormones on enzymes is fraught with experimental difficulties, and it is not always easy to interpret the results. Nevertheless, we may soon know more about the ways in which growth hormone, and other hormones, influence enzymes concerned in carbohydrate metabolism.

The metabolic processes of an animal leading a quiet life might proceed in a fairly orderly way if hormonal regulation did not exist. But hormones are particularly important to an animal which is under a stress of some kind, such as fright or starvation, when its carbohydrate stores would run down to a dangerously low level if it were not for an increase in the output of hormones by the adrenal cortex. The pituitary gland produces a hormone (ACTH) which controls the adrenal cortex, and an increased activity of the latter is the sequel to an increased output of ACTH. The change in ACTH output may, in turn, be brought about by a previous increase in the amount of the hormone of the adrenal *medulla* in the blood. The ductless glands influence one another in a way which is difficult to unravel.

It is important to realize that the hormones mentioned in this discussion usually have other physiological actions in addition to their effect on carbohydrate metabolism. We must also remember that the net effect in the living animal, when

functioning naturally, may be different from the findings when each pure hormone is injected and studied singly. Insulin lowers the blood sugar level; adrenalin may raise it: but when both hormones act together (adrenalin helping the transfer of glucose from the glycogen store in the liver into the blood, and insulin the transfer from the blood into muscle) something physiologically more significant takes place than an apparent antagonism – functional co-operation. It is this collaboration of hormones in the living body which makes the scientific analysis of the precise action of each so difficult. So although there is no good evidence that other glands such as the thyroid or posterior pituitary are important in carbohydrate metabolism, research may yet provide some. Likewise little is known about the way the brain controls this metabolism directly: but damage to the hypothalamus may lead to the appearance of symptoms of diabetes.

DIABETES

In the healthy person the amount of glucose circulating in the blood is usually quite constant at about 0.10 per cent. It is true that the level may be higher after a meal, when carbohydrate is passing from the intestine into the blood. If, however, it does rise, the pancreas secretes more insulin and thus helps to restore it to normal. The extra glucose in the blood enters tissue cells, as we have already discussed. Usually it does not pass from the blood into the urine, but it may do so if the concentration of glucose rises above a certain threshold level (approximately 0.16 per cent). This level is seldom exceeded in a healthy person, so that the urine is usually free of glucose.

The insulin-secreting mechanism is somewhat delicate, and it may go wrong in one of two ways. It may break down and be unable to produce enough insulin to meet the needs of the animal. This is essentially what happens in diabetes. On the other hand, rarely, it may run amok and produce more insulin than the animal needs. This condition is known as 'hyper-insulinism'.

If the pancreas is producing too little insulin, as generally occurs in *diabetes mellitus*, the blood glucose level tends to be

much higher than normal – so high that the threshold level is often exceeded and glucose passes into the urine. We have already seen that insulin assists the transfer of glucose from the blood into the tissue cells, and also (directly or indirectly) the conversion of amino-acids to protein and of carbohydrate to fat. If, then, there is a deficiency of insulin, there is not only a piling up of glucose in the blood, but also a tendency for protein and fat to break down more rapidly than they are formed.

Some of the amino-acids formed in the breakdown of protein are converted to carbohydrate. But the carbohydrate merely accumulates in the blood as glucose, since it cannot pass into the tissue cells at the usual rate. Thus, in a diabetic person, carbohydrate is used more slowly, and formed (from protein) more rapidly, than in a normal person. On the other hand, fat is broken down more rapidly than usual, perhaps replacing carbohydrate as the main fuel of the body.

In the diabetic, oxidation of fat to provide energy does not proceed smoothly. The fatty acids formed when fat is broken down are probably converted to acetic acid, which is usually oxidized by the pathways indicated in Fig. 15. For oxidation it is combined with a carrier compound, oxalacetic acid. This acid is shown in Fig. 15 as emerging unchanged from the oxidation reactions, but in actual fact some of it gets lost by the wayside, as it were. The stock of oxalacetic acid in the tissues is normally replenished by a reaction which requires pyruvic acid (reaction 9, Fig. 15). Pyruvic acid is formed by the breakdown of carbohydrate, and may thus be deficient if carbohydrate breakdown is impaired, as in diabetes. Much of the acetic acid formed from fat is then converted instead to acetoacetic acid (reaction 14, Fig. 15), and this may decompose to give acetone (reaction 20). These compounds are known as ketones, and are of little use as a source of energy: in fact, they are quite poisonous in excess.

We can now reconsider the symptoms of *diabetes mellitus* in the light of the foregoing survey. Among the first symptoms to appear is a marked increase in the amount of urine passed. The lining of the urinary system would be irritated if the concentration of glucose in the urine were high. However, the

increase in the volume of urine keeps the concentration down to a tolerable level, but results in a feeling of thirst. The person also feels hungry, and eats more food, but does not put on weight, and in fact may actually get lighter. If tests are carried out on his blood and urine, it is found that the blood glucose level is persistently high and that his urine contains glucose. Abnormally large amounts of ketones may be present in the blood and urine. In severe cases, the smell of acetone may even be noticed in the breath. If the disease runs its natural course (as used to happen before insulin was available), the patient eventually dies in a coma, owing to ketone poisoning. Before this can happen, however, he may succumb to some infectious disease, since he has less resistance than a healthy person.

This was the outlook to which the diabetic patient had to resign himself before the days of insulin treatment. Nowadays diabetes is seldom a fatal disease, although the diabetic person has to live on a carefully controlled diet and take frequent injections of insulin. The amount of insulin needed has to be carefully determined, since it varies from one patient to another. Too much insulin is perhaps more dangerous than too little, since the blood glucose level may fall so low that the patient collapses from lack of glucose in the brain.

If it is indeed a lack of insulin that gives rise to diabetes, what causes this lack of insulin in the first place? Diabetes may develop in some people as a result of an inherited weakness in the insulin-producing mechanism of the pancreas. But many who develop diabetes may not have a hereditary defect, and it is likely that other factors can operate to bring about a breakdown in insulin production.

There are probably several different types of diabetes, with a number of symptoms in common (glucose in the urine, etc.). If a person is found to have these symptoms, a diagnosis of *diabetes mellitus* is made; but this is purely a matter of convenience. A term such as this may be a hindrance rather than a help, if it is not appreciated that the diagnosis considers symptoms as distinct from causes, and that the causes may be manifold. We cannot even safely assume that there is always a

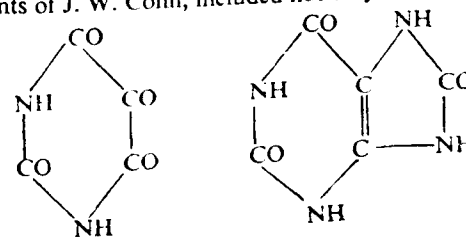
diminished insulin output by the pancreas in diabetes. It is conceivable that the metabolism of the body might alter so as to increase the *need* for insulin in the tissues. If the pancreas could not step up its insulin output correspondingly, there would be a *relative* shortage. For the present, however, we will assume that insulin output does diminish in diabetes, and consider what may cause this diminution.

It will be remembered that diabetes can be produced experimentally by injection of certain hormones, which originate from the adrenal cortex or from the anterior part of the pituitary gland. Diabetes might thus result from over-activity of one of these glands. In particular, it could occur if the pituitary gland produced too much ACTH (which would make the adrenal cortex over-active) or too much growth hormone. There is good evidence that such over-activity may occur in the human and give rise to diabetes. If, for example, the pituitary gland of an adult person produces too much growth hormone, he develops symptoms of acromegaly, such as an enlargement of the bones in the hands and face. Not all persons with acromegaly develop diabetes, but the proportion that do so is higher than that observed in the population as a whole.

We have already considered a possible way in which growth hormone could produce persistent diabetes. Why ACTH should be capable of damaging the pancreas is not known with certainty. However, an interesting theory has recently been put forward, based on the fact that many enzymes contain sulphydryl ($-SH$) groups and lose their activity if these groups become oxidized ($2 (-SH) \rightarrow S-S$). The tissues of the body contain a compound known as glutathione, which itself possesses sulphydryl groups and seems to be responsible for maintaining the sulphydryl groups of enzymes in the reduced (active) state. It is possible that the enzymes responsible for the synthesis of insulin in the β -cells of the pancreas contain sulphydryl groups. If, then, these cells were short of glutathione, the enzymes might become oxidized and be unable to synthesize insulin in sufficient amount for the needs of the body. What could cause such a shortage?

One way in which diabetes can be produced experimentally

is by injecting a compound called alloxan. This compound has a structure similar to that of uric acid and certain other compounds normally present in the body, and it can oxidize the sulphydryl groups of glutathione and of enzymes. It is significant that the effects produced by ACTH in humans, in the experiments of J. W. Conn, included not only a rise in the blood



alloxan

uric acid

glucose level, but also a rise in the level of uric acid and a fall in that of glutathione. The level of glutathione in the β -cells no doubt fell also (although this would be hard to prove), and such a fall might account for a failure of the insulin supply.

Diabetes could thus be the outcome of a somewhat complex series of changes. A temporary over-production of ACTH by the pituitary would rapidly bring about a rise in the blood level of a compound such as alloxan or uric acid, as well as of glucose itself. Glutathione would then become oxidized, and be unable to preserve from oxidation the sulphydryl groups of enzymes responsible for insulin synthesis. The resulting shortage of insulin would lead to the appearance of diabetes, which would persist if the damage to the β -cells were severe.

This theory is far from proved at present, but it will act as a valuable guide to investigation of the causes of diabetes. Medical science has already achieved one triumph in the control of diabetes by insulin. The possibility of a cure being found for diabetes is rather remote, since the β -cells may be irreparably damaged when diabetes has set in. If, however, the changes in the body which precede actual diabetes were better known, a condition of 'potential diabetes' could perhaps be recognized.

It might then be possible to devise treatments whereby the development of actual diabetes could be prevented. This is a fertile field for further research.

FOR FURTHER READING

(Books and reviews marked * are somewhat technical.)

Human Physiology, by Kenneth Walker.

The Physical Basis of Personality, by V. H. Mottram.

These books, issued in the *Pelican* series, include concise accounts of the ductless glands.

Sir Frederick Banting, by Lloyd Stevenson.

A biography which includes an account of the discovery and isolation of insulin.

Dynamic Aspects of Biochemistry, by E. Baldwin.*

A book which is particularly valuable for its outline of metabolic pathways.

The Endocrine Organs in Health and Disease, by H. D. Rolleston.*

A book on the ductless glands which, although out of date, contains interesting historical material.

'The Mechanism of Action of Insulin', by F. G. Young, in *Science Progress*, 1948, No. 141, p. 13.*

'Diabetogenic Action of Pure Anterior Pituitary Growth Hormone', by P. M. Cotes, E. Reid and F. G. Young, in *Nature*, 1949, Vol. 164, p. 209.*

Discussions of the role of hormones in carbohydrate metabolism and diabetes.

'Factors controlling the Development and Progress of Diabetes', by A. Lazarow, in *Physiological Reviews*, 1949, Vol. 29, p. 48.*
A comprehensive review.

'Influence of Hormones on Enzymatic Reactions', by C. F. Gri, in *Lectures, etc., First International Congress of Biochemistry (1950)*.
A stimulating account of recent research.

CORRESPONDENCE

It was, indeed, refreshing news contained in your Editorial of *Science News* 16, that you were extending the scope to include sociological aspects.

As a production engineer and a designer of mass-produced motor-cars, I have never learned so quickly as when I learned about formal traditions and social significance in going over to furniture design. I have been a member of the Institute of Sociology for many years, so I was very interested in learning the limitations to technical progress imposed by these more profound, but no less real, factors.

Conflicts can be seen in many directions, in the factories, on the market, etc., where technical development is trying to alter environments faster than habits can change to accept them – also in many cases because the technical change has sometimes been for its own sake or for novelty's sake and has been rejected.

There is often a regrettable waste of research effort arising from an unguided or misguided application in which economic and social implications have not been carefully considered. This is all the more regrettable because the scientist, if conscious of these other factors, would be able to consider them more impartially than other people and could help to overcome the problems which his technical advancement creates.

In these enlightened days when evolution is an accepted theory, it is a pity that more regard is not paid to the evolution of social habits, conventions and standards – particularly of discriminating tastes regarding intimate social environment by the process of formal tradition. The more close to social situations the greater need for care in furthering technical improvements. Architecture and furniture are two outstanding examples. Unfortunately industrial designers are all too ready to seize on any new material or principle discovered by the scientist and to force alien changes on the appearance of these more intimate articles.

G. E. CLEAVER

SCIENCE AND CULTURE

In the Editorial of *Science News* 16 there was a brief discussion of the relationship of science and culture which raises some extremely interesting questions in one's mind. It was remarked, amongst other things, that while French and history are cultural studies, chemistry and physics are not. *Science as taught*, continued the Editorial, 'deals only with things and abstract relations, while languages and stories inevitably deal with people.' Science, it appears, is not generally regarded as a cultural study, and some constructive suggestions were made towards its improvement as a means of education. In what follows no serious quarrel with the contents of this Editorial really arises, but an attempt is made to deal with the relation of science with culture along more orthodox lines – at least so far as the conception of culture is concerned.

For, of course, the difficulty about any such discussion arises immediately with the meaning we attribute to the two parts of our heading. We have to ask ourselves what these words mean at the present time, not what their dictionary definitions are, for from these the light and shade of modern life may well be absent. In regard to culture no question could well be more elusive, so much are we affected by the assumptions underlying our own point of view, our education and our experience of life. Clive Bell's little book *Civilization*, for example, quite obviously does not yield a conception of culture which would be accepted by a generation later than his own as belonging to the modern world. The experiencing of valuable states of mind, which is his chief theme, belongs to the aestheticism of the twenties, and one can perhaps trace it back to a period of greater achievement in the time of Matthew Arnold, Walter Pater and the stylists of the last century. What any of these writers would have thought about such a rough-and-tumble view of culture as is implied in the *Science News* Editorial it is hard to say. 'Awareness of all that is going on in the world and a self-awareness of oneself as a citizen', although not put forward as any more than something which culture implies, would strike the devotees of 'valuable

states of mind' as much too vigorous – and probably as intrinsically a philistine outlook. For whatever the Editor may rightly say about culture in A.D. 1950 it has in the past always meant something distinct from education and something more than 'a matter of a man's personality and capabilities'. It has meant – and here is a moment for courage on the part of the writer! – a certain coherence between a man's beliefs and actions: an awareness of what ends are worth-while (in the light of what the wisest men have taught) and service of them by the whole man. It has meant at the same time the proving and refining of personality through thought and effort: so that we can accord to only a minority the achievement of a high form of culture. Above all it has meant opening one's mind to the influence of the arts and gaining in this way a release 'but also a bracing' of the emotions, in Herbert Read's phrase. It is clear that the meaning of culture raises questions which bring us near to problems of value and ethics and perhaps of religion, as perhaps Ruskin was the first to make clear. Unfortunately those who have written on the subject have succeeded chiefly in producing a great deal of intellectual fog, and a scientifically-educated person may be excused from a further expression of 'mere opinion.'

If, however, we agree, as I think we must, that culture is inseparable from a man's knowledge and the discrimination he shows in arriving at his beliefs, science plays a far larger part in the problem than we have up to this point allowed, and the question which leaps to one's mind is to know how it is that Western culture has, in essentials, been so little disturbed by the rise of modern science – with all this has meant in the complete transformation of our outlook on the universe and our view of man himself. How is it that this intellectual revolution has not far more profoundly affected the culture of the Western world? The Marxist answer is easily imagined. Rather than have the structure of society disturbed and their little worlds shaken to their foundations, members of a bourgeois civilization, it would be said, prefer to subordinate science to the principles

derived from the older authoritarian tradition. And there may be some truth in it. Professor Waddington's analysis of science, as outlined in *The Scientific Attitude*, was, for example, too destructive for it to be welcomed anywhere as the basis of a new and more scientific form of culture. In the West, or at least in Europe, there is too strong a sense of history and of the sacredness of institutions for a change to occur at all rapidly, and this, I suggest, is after all a very good thing. For the price paid for the rough justice of a revolution exceeds all reckoning, because it is in terms of the value and quality of the life which then becomes possible. However inadequate the older conception of culture may now be in some important respects, it is unavoidable that a change from this 'aristocratic' view to one which is relevant to an equalitarian society must jeopardize culture as we have understood it.

Nevertheless, it seems to be a matter of importance to consider how more of the true scientific outlook may be introduced into the culture of our own age in place of the haphazard and somewhat nihilistic trends of modern thought which are popularly supposed to be 'scientific' but actually may be seen to be nothing of the sort. We have plenty of opportunities of appreciating the evils of the Marxist solution to this problem, for after all in Russia an old-fashioned materialism has been made every bit as authoritative as any of our own teachings and is, in the long run, likely to prove far more destructive of science. But as for ourselves the solution has been not so much found as postponed. The part played by science in our own culture should certainly not depend upon a particular philosophical interpretation authoritatively enforced, but we may well see in science the means of filling the vacuum at the centre of our educational and cultural programmes. Mr Fred Hoyle's broadcasts in this country, whatever their demerits as an illustration of the way in which men of science work (and these are serious), have at least revealed the amount of interest of educated people in what we may call the naturalistic account of the universe. And side by side with cosmology we might place such a study of man as was presented by Sherrington in his Gifford

Lectures of 1937-8. Perhaps, as a contribution to culture, these additions might appear somewhat pungent when considered under the heading of the 'best that has been thought and said', but this only serves to illustrate how inadequate is the criterion of a Matthew Arnold or the aestheticism of a Clive Bell in the middle of this century.

The time to be apologetic about science is indeed long past. As an ingredient of modern culture the subject certainly presents serious difficulties because, as mentioned in the Editorial already quoted, science deals with 'things and abstract relations'. As against this we must protest that any man who is ignorant of the nature of scientific explanations, however well read he may be and however fine his habitual 'states of mind', is not cultured in the modern sense of that word. Broadly speaking the transformation which science has effected in our view of the world in which we live has been to banish explanations which possess a moralizing and edifying quality in favour of those which offer us the truth of observation and measurement. Not since Spinoza shocked and horrified his readers in the seventeenth and eighteenth centuries has the educated world ever been able to bring itself to face an account of events which renders most human prejudices and fears totally irrelevant: to see things as they are, *sub specie aeternitatis*; but this is, in the last resort, the mood of all scientific work. Science shares with the arts a complete disinterestedness towards the multitudinous prejudices which separate men one from another. Some of these prejudices have helped to make civilization possible, as Keith has argued, but if they persist unchecked they may end civilization through the explosive force of the internal stresses they now generate.

Paradoxically enough, the advocates of a more scientific form of culture have unquestionably been forced on to the defensive by the argument that two world wars have occurred in a period of growth of scientific philosophies: *post hoc ergo propter hoc*. Professor Macneile Dixon has complained of the 'deadly dialectic' which destroys all beliefs and codes of conduct; Mr T. S. Eliot with weary superiority says we must be 'very patient' until the time comes for the reactionaries to rebuild

civilization (he does not specify reactionaries). No one seems to have argued that the strife of the modern world results chiefly from the survival of interests and institutions which live on the passions and prejudices of mankind – on the preservation of teachings which obscure the common lot of man on the planet just as they obscure his inevitable governance by law. Nothing short of a full study of man as an organism and his place in nature can equip us to take control of the forces of the modern world, and all that the religious teachings of the past seem to have inculcated needs to be superseded in these respects. These are controversial problems, and the writer would reject all suggestions that science can do the duty of religion or even provide any true basis for ethics. But the commentary of science on man's responsibilities is certainly needed, for all around are arising problems for which traditional teachings have no answers. It is in no spirit of arrogance, certainly, that one would argue that the imagination can, principally though not entirely through science, attain a higher point of view than any which centuries of historical self-consciousness have engendered in human beings, and that it is through this point of view that we may best hope for an eventual *rapprochement* between different cultural groups.

A. E. BILL.

Science Department
Royal Military Academy, Sandhurst

BOOKS RECEIVED

ARE WORKERS HUMAN? by Gordon Rattray Taylor (Falcon Press, 1950), 10s. 6d.

In this book Mr Gordon Rattray Taylor discusses, in non-technical language, the contribution of what he terms 'the new science of human relations' to the problems of modern industry. He is emphatic that most managements still have little understanding of the psychological pressures and frustrations which lead to strikes, restriction of output and general lack of interest in work. He says, 'The paradox of industry is that if you simply aim for higher output, you get neither output nor contentment. If you work for the personal happiness and development of the employee, you get this and output too'. Many recent researches by social scientists in the industrial field have revealed the fundamental importance of the group, particularly the small primary group which is linked by personal ties as well as by the requirements of the work. Social scientists claim that the most effective technique for obtaining higher satisfaction and output is to delegate greater responsibility to primary work groups. Mr Taylor discusses many of the myths and practices of modern industry in the light of these theories. He shows, for example, that motivation cannot be adequately explained in the crude and misleading terms of 'the carrot and the stick' and that large-scale organizations, whether nationalized or not, have peculiar psychological difficulties.

Mr Taylor's book is written simply and vividly and is, perhaps deliberately, highly provocative. It seems intended primarily for managers, and should be very successful in instructing, stimulating and possibly irritating them. Mr Taylor's enthusiasm, however, leads him to make generalizations which are unsupported by adequate evidence, and many social scientists would consider that his claims on their behalf are exaggerated and must await the conclusions of the further researches that are needed in this important field of study.

N. M. D.

A SCIENTIFIC AUTOBIOGRAPHY and other papers by Max Planck (Williams and Norgate Ltd., 1950), 8s. 6d.

This translated volume of the last writings of the great German physicist contains his Scientific Autobiography (one-fifth of the book)

and four papers, all but one – 'The Concept of Causality in Physics' – lectures delivered at various dates, 'Religion and Natural Science' (1937), 'The Meaning and Limits of Exact Science' (1941), and 'Phantom Problems in Science' (1946). As Max Planck was born in 1858, this book is the work of an octogenarian, but of one whose mental vigour clearly remained unimpaired.

It is interesting to learn from *A Scientific Autobiography* of the difficulties and discouragements Planck had to contend against. Theoretical physics was not in his early years recognized as a separate discipline. The lectures he attended were poor and the professors indifferent to him. Their irrefragable opposition to new ideas impressed upon him the view that a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because they eventually die off and a new generation grows up that is familiar with it.

Planck was a philosophic thinker as well as a man of science, and the four papers embody his gradually crystallized and integrated attitude to fundamental problems in both mental spheres. This attitude shows him to be outside the class of scientists who worship science and believe it to be omniscient, able ultimately to explain all human experience satisfactorily. He maintains that natural science is strictly limited to the phenomenological world, that is, the world of objects as it appears to us, mediated through our sense organs and admitting of quantitative expression. All problems of ethics, therefore, are entirely outside its scope. The problem of causality versus free will, which is generally thought to be inside its scope, Planck considers as a 'phantom' problem, that is, it is only a problem in appearance, and seen to be so by realizing that it is a matter of 'different perspectives of interpretation.' The principle of causality must be adhered to, he insists, and is in no wise upset, as is often held mistakenly even by those who ought to know better, by the Heisenberg principle of indeterminacy. Though the will, observed from without, must be determined by motives, nevertheless, observed from within, it is free, as is strikingly shown by our ability to make mental reservations with every word we speak, which is a real freedom experienced at first hand.

Similarly a confusion of viewpoints, Planck contends, is responsible for the supposed conflict between science and religion. Although they have the same goal, namely the recognition of an omnipotent intellect ruling the universe, their starting points and methods are basically different. In religion God is the starting point; in science the starting

point is our sense experiences of the external world and the measurements based upon them. Science operates predominantly with the intellect, religion with sentiment, being founded on a respectful humility before a supreme power mediated to us by symbols. Religion wants man to act, science wants him to learn. Right action falls within the sphere of ethics, and ethics is linked with religion but quite outside science. So religion and science mutually supplement each other instead of being, as is widely supposed, fundamentally at variance.

Planck's arguments and conclusions will certainly not escape criticism from both scientists and philosophers. But the book may be recommended to the general reader as a challenging exposition of vital issues by one of the foremost scientists of our time.

R. W. C.

THE HUMAN SPECIES by Anthony Barnett (Macgibbon and Kee, 1950), 18s.

The author begins by writing 'This book describes some of the contributions that biological knowledge can make to contemporary problems ... it has not been designed as a detached, disinterested account of man, such as a biologist might give of a dung beetle or an earthworm ... Every branch of scientific knowledge has an origin in man's attempts to satisfy his material needs; biology, the science of living things, is most closely linked to the production of food and the prevention of disease.' He discusses in turn the mechanism of heredity and reproduction, the evolution of man, eugenics and sex discrimination, and such topics as food and soil, nutrition, population studies, and public health. The basic idea is good, but 260 pages is too little space in which to do it justice, and it is a pity that the author's political faith too often leads him to argue a case rather than to try to give the facts dispassionately. One may agree in a presentation which shows human biology to have contemporary relevance, without subscribing to a brand of socialism. The photographs are excellent, the diagrams sometimes poor, the price too high.

CONFERENCE ON INDUSTRY AND THE UNIVERSITIES (Federation of British Industries, 1950), 3s.

This is the report of a weekend series of meetings held at the end of 1949 for industrialists and University teachers to exchange viewpoints on the kind of training undergraduates should get to fit them for employment in industry, and on actual and possible jobs suitable for

2

2

[illegible]