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Research Report



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SCIENCE NEWS

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ACKNOWLEDGEMENTS

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Professor H. E. Shortt and Dr P. C. C. Garnham (London School
of Hygiene and Tropical Medicine) (Plate 29 and Figure 9).
We regret that in *Science News* 8 we omitted to mention that Plates
23 and 24 were reproduced from *An Introduction to the Prescribing
and Fitting of Contact Lenses* by Frank Dickinson and K. G. Clifford
Hall, published by Hammond, Hammond and Co. Ltd.

We regret that, owing to shortage of space, the Glossary has had
to be omitted from this issue.

Editorial

ANY scientist casting his eye rapidly down the list of Contents is liable to raise an eyebrow as his gaze meets the title *Telepathy*. Psychological research is still not a respectable subject to the vast majority of laboratory workers, and any journal which offers to take it seriously itself becomes suspect. It is not simply that in the past psychological research has been plagued with charlatans and the worst kind of amateur investigation, but rather that its aims have seemed different from those of natural science, and really rather boring to men studying the phenomena of the Universe like equals of the Creator. Some of it has been tangled up with the attempt to prove the existence of Life after Death, and all of it with the study of human personality, which even under the more neutral name of psychology, is still shunned by some men of science. Accordingly, we felt it necessary to be very cautious. We had to avoid the kind of pseudoscience which conceals large dollops of pure emotion inside a genuine-looking wrapper of scientific method, the sort of thing which convinces the unwary casual reader who takes a great deal on trust. On the other hand we wanted to be fair, to display what had been honestly accomplished in this field of study. We chose *Telepathy* as the subject, because of all the departments of Psychics it is the one most susceptible of simple experimental attack, and one in which advances have certainly been made in the last fifteen years. And we chose the authors because between them they have an enormous experience of psychological research, encyclopaedic knowledge of conjuring, and acutely critical minds. The result is probably as fair and objective as any review of the field can possibly be at the present time.

What else in the Contents is especially noteworthy?
Exploring Jan Mayen by members of the Oxford University

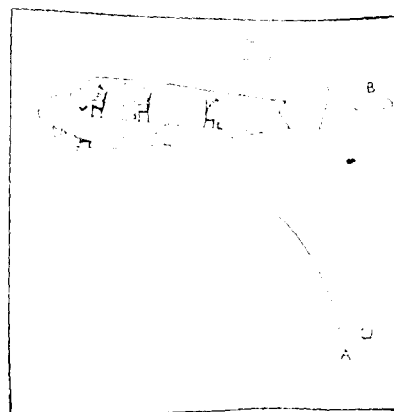


Fig. 1.—Diagram of aircraft in flight showing the position of the 'bird' (A) and alternative mountings (C and B) for the magnetic air detector units.

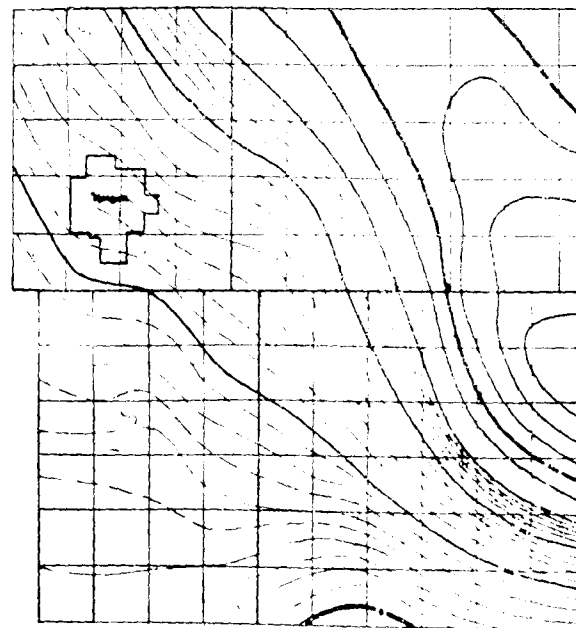
navigational technique: with four cutters acting as wireless stations transmitting radio signals to the aircraft. These signals are recorded alongside the magnetic trace on the same photographic strip so that they can be interpreted to give the position of the aircraft at the time of passing over any magnetic anomaly. The aeroplane flies on a level course up and down parallel lanes over the ocean, automatically recording the magnetic anomalies and their geographical position so that they can be studied at leisure on the ground by experienced geologists, who will decide if the anomaly indicates oil-bearing or associated rocks.

The magnetometer used in this particular survey was developed from M.A.D., the magnetic airborne detector designed during the war for searching for submarines from the air, and the E.F.S. system used in harbours for testing the effectiveness of degaussing equipment aboard ships. Actually the Russians were the first to attempt aerial surveying when they devised a method based on the change of inductance in a coil of wire, due to magnetic anomalies, but this was not sensitive to variations of less than one-

twentieth of the earth's field and is clearly of no use in oil prospecting, although it did help them discover some large iron ore deposits.

On land the magnetic method is the quickest and cheapest for surveying, and this remains true in the air, with the added advantage that small local variations and anomalies are non-effective and eliminated, leaving only the deep structure effects, which are then relatively more pronounced, and it is deep structures which will be connected with oil pools. Even so this initial survey of the Bahamas took six to eight

Fig. 2 (a).—Magnetic Maps from Ground and Airborne Surveys of the Mangum, Oklahoma, area



Total Magnetic Intensity: Observations taken at ground surface
Note the town of Mangum in the upper left-hand quadrant of each map (see also pp. 12-4).

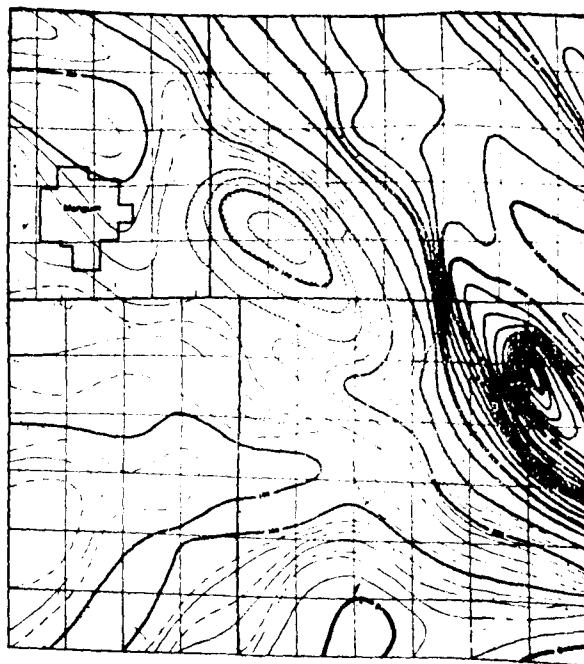


Fig. 2 (b).—Total Magnetic Intensity
Flight level 1,935 ft. above sea level
c. 300 ft. above ground

months, and must be followed later by a tedious careful survey of the most likely areas by gravity or seismic methods.

Aerial prospecting, as distinct from mere aerial photography and pure surveying, is now quite an established practice in America. It has been used over Texas and many parts of the U.S.A., including northern Alaska. Here again, when flying over land it is important to find the exact position of the aircraft and 'split-field' photographs are usually taken as the aeroplane flies over the ground. These are later correlated with accurately known ground surveys

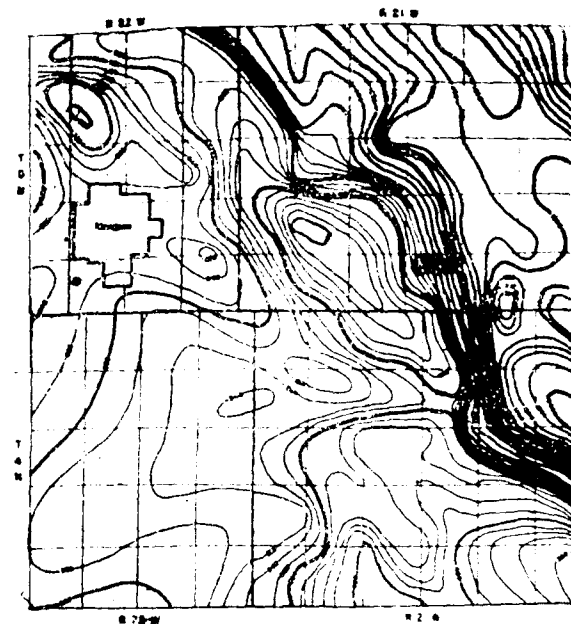


Fig. 2 (c).—Total Magnetic Intensity
Flight level 2,935 ft. above sea level
c. 1,300 ft. above ground

of hills and similar landmarks. Flying at a thousand feet, several hundred miles of survey can be recorded on one continuous strip. Figure 2, A,B,C,D, gives a set of magnetic traverses taken at various heights above the ground over the same strip of ground in Oklahoma. The characteristics can be interpreted geologically and the information gained will be about the major structure of the rocks with increasing depth as the height of the survey increases. Thus the survey at ground level will give the position of any unusual rock structures quite close to the ground surface. That taken by an airborne magnetometer at 300 feet will

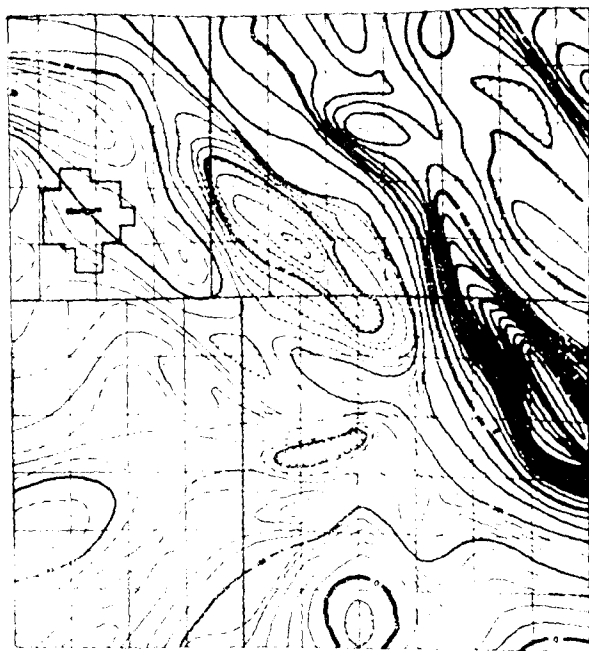


Fig. 2 (d).--Total Magnetic Intensity
Flight level 7,935 ft. above sea level
c. 6,300 ft. above ground

concern major rock structures rather further beneath the surface, i.e., more deeply seated structures as the geologist would say. Similarly the surveys at progressively increasing heights give the general rock structures at increasing depths. With increase in height, however, the absolute value of the anomaly detected will rapidly decrease and the geological interpretation becomes progressively more general and less detailed. The utility of the method is, however, clear since it gives a measure of control of the depth of the rock structures which are being investigated.

Geophysical prospecting, geophysics for short, is a com-

mercial science which has developed so rapidly in the last two decades that it is now by far the most important technique for the discovery of new oil-fields, and uses some of the most precise and sensitive apparatus in science. It often surprises pure physicists when they find out how sensitive these geophysical instruments are. For instance the three types of gravitational instruments, the torsion balance, pendulum, and gravity meter, have all reached their ultimate practical sensitivity. Gravity meters will detect the change in gravitational attraction on raising them from a road surface to the kerb, say about four inches. They can now be made sensitive to vertical positioning to within an inch and no field surveys, in regions where oil may be found, are better than this, so there is no sense in designing more accurate equipment. Torsion balances similarly are so sensitive that the limitation in their use is the practical one of corrections for local terrain gravity attractions caused by slight hillocks, mounds, depressions and embankments.

Eötvös, in the 19th century, and Schlumberger, since

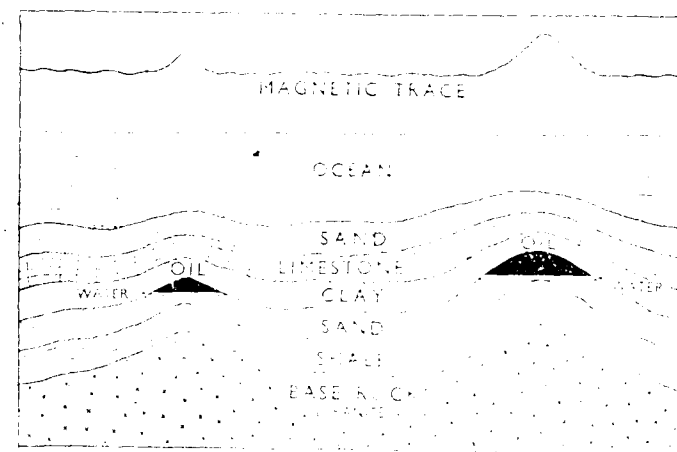


Fig. 3.

some control by varying the type and position of the explosion. The recently introduced radio-active technique (see below) has specialised applications already, and may be more widely used later when thoroughly proven.

These geophysical methods are most powerful when two or more are used in conjunction. Sometimes a rapid method such as the magnetic will be used for the survey and then a sensitive one, such as reflection seismic, for determining the detail in an area. It may also be combined with a relatively ambiguous method, neither of them precise in themselves, but together they cross-eliminate all the possible interpretations except one. A fine example of this was the discovery recently of the extension of the Rand blanket which gave the new Orange Free State gold field. Magnetic and torsion balance surveys in co-operation with skilled geological interpretation gave the clues for this new mine.

Slowly geophysics is extending its applications, and seismic waves are now used in exploring river valleys and buried channels. Typical problems may be finding suitable hard rock on which to place bridge piers or site dam foundations – the huge new dam on the Waikato in New Zealand for instance. If geophysics had plotted the path of the old Mersey river, which probably changed its course near the estuary several thousand years ago, a lot of the troubles encountered when the preliminary tunnel met water-logged sands in the old bed of the river would have been avoided.

A few special minerals and ore body deposits can be located, gold as mentioned above is an example, but at present most of the minerals which might be detected are not sufficiently valuable to pay for costly geophysical methods. Large iron-ore deposits were found by means of magnetometers in Sweden and Russia, but iron ore is relatively abundant, which, combined with its cheapness, means it is rarely sought by geophysicists. Placer or alluvial sand deposits sometimes contain gold, and the sands may be found by magnetic traverses (if they are the so-called

'black sands') or by electrical and gravity traverses, across the old river beds of previous and present-day streams. Galena, graphite and the fine silica sand used in making the best grade optical glass can be detected and distinguished by combining electrical and gravity traverses. Graphite and good quality sand are sufficiently valuable to prospect for them. During the war many minerals were in short supply in the States, even with the increased output, and new sources of chromite and bauxite were sought and found by gravity surveys, the chromite in Cuba and the bauxite in Arkansas. Sulphur is sometimes found in huge masses in the cap rocks just above 'salt domes' along the Gulf coast. Salt domes are a favourite oil cache in that part of the world, usually located by seismic and gravity methods, and it is surprising to realise that it is economically worthwhile to search for such a cheap mineral as sulphur, although, of course, where it is found it occurs in very large quantities relatively pure.

The geophysicists' quest is, however, almost always for oil, and nuclear physics has found a minor application in radio-active well-logging, the latest technique used in looking for oil. Since oil is found only in sedimentary rocks any difference in radio-activity between sandstones, clays, shales and limestones will be a valuable way of distinguishing between them. Common sediments in order of increasing activity are: coal, salt, limestone, sandstone and shale. Shale often contains potassium micas and the salt deposits may also contain potash. In both cases radio-active potassium may be a vital clue in detecting the different strata. Rock layers with uranium or radium will be found as well. All the work is aimed at trying to find the sand strata if there are any, since that is where the oil will be.

The method is very similar to Schlumberger's resistivity logging. A long metal casing or tube contains two Geiger-Müller counters, complete with amplifiers, so that changes in radio-active intensity are magnified, sent up the cables

as electric impulses and recorded at the surface. The metal tube is let down the well on the end of a very long cable and then pulled up by winch at a steady rate, recording the radio-active intensity continuously. 1,500 feet per hour is a common rate for withdrawing the detector and wells down to 12,000 feet have been logged.

Only gamma rays are sufficiently penetrating to pass through the metal well casing and container - almost all wells are lined with metal tubing to prevent the sides collapsing and filling in the well hole. Changes in radio-active intensity give a clear indication of a sand-clay boundary, and this method has advantages over the usual electrical logging since old wells can be explored through transparent casing in order to detect any oil-bearing strata which may have been missed and overlooked when the well was first drilled. Further, where oil or salt in the drilling mud at the bottom of the well make the electrical method useless, radio-active logging is quite unaffected.

It was more recently realised that more information can be got by actively bombarding the rocks with neutrons.

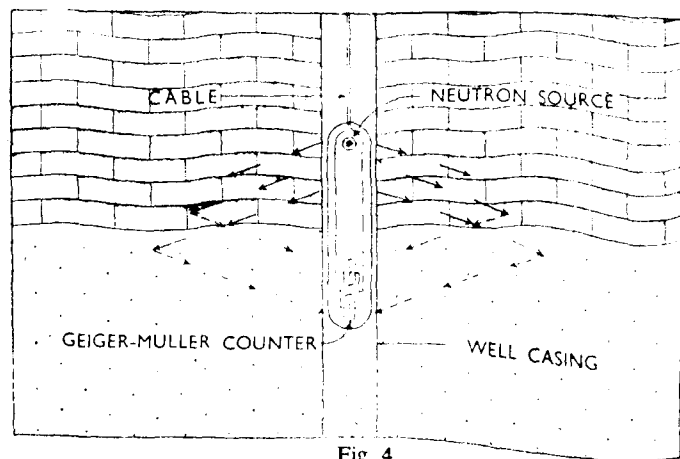


Fig. 4.

This combined with the natural intensities as found above eliminates many of the ambiguities. Indeed the neutron attack is the nearest approach to the direct detection of oil. Fast neutrons are only slowed down appreciably by atoms of approximately the same mass, i.e., hydrogen, which means, in practice, in oil wells, water or oil. When they have slowed down sufficiently the neutrons are captured by atoms in the rock minerals which then become artificially radio-active, and, being unstable, may emit gamma rays which are picked up by the detector. The neutron source, a mixture of radium and beryllium, is at the upper end of the tube and the detector at the bottom so that as the cable is hauled up the detector passes through regions just previously activated by neutrons. Figure 4 is a sketch of the technique. The combination neutron - gamma-ray logs give a distinction between sandstones and limestones, which are hard to distinguish, and in general between porous, liquid-filled regions and those which are non-porous.

The airborne magnetometer and radio-active well-logging are only the latest developments in looking for oil, which is always somewhat of a gamble. No interpretation of geophysical measurements is ever better than a good risk, a guess made with the help of local geology. Since, however, new wells are continuously being found to keep pace with the ever-increasing world consumption of oil, geophysics can well be said to be an efficient and successful young science.

STANDARD TEXT-BOOKS

(but hardly suggested as light reading)

C. A. Heiland. *Geophysical Exploration* (Prentice Hall & Co., 1946),
Jakosky. *Exploration Geophysics* (Times Mirror Press, Los Angeles, 1940).

L. L. Nettleton. *Geophysical Prospecting for Oil* (McGraw Hill & Co., 1940).

Aspects of Bee Behaviour

DR COLIN G. BUTLER

THE organisation of the social life of a colony of honey bees has for generations past intrigued man, and many have been the suggestions made in attempts to explain this phenomenon. Some of the earlier writers, including Virgil, believed that a king bee reigned over the inmates of each hive and directed their labours. It was not, indeed, until 1925 when Rösch published his findings on the division of labour amongst the worker population of a colony of bees that we began – and it was only a beginning – to understand something of the organisation of social life amongst bees.

Rösch showed that every worker bee is able to undertake all the tasks which present themselves to her, following, with advancing age, a definite sequence which is the same for each individual member of the population of a properly balanced colony. He showed that the life of the worker bee in such a colony is divided into three main periods during which she performs the following duties in turn: nursery work, household work, and foraging. The very first duty performed by the young adult bee is to clean out the lately occupied cells of the brood combs so that further larvæ may be reared in them and, at the same time, she also helps to maintain a high and almost constant temperature in the brood nest. When she becomes about three days old she ceases to clean out cells, and from then until about the sixth day of adult life she is primarily concerned with feeding the older larvæ with a mixture of honey and pollen which she takes from the stores of these foods within the hive. During this period she herself consumes large quantities of protein in the form of pollen, and certain glands in her head called the 'brood-food' glands, which

secrete a jelly-like substance very rich in protein, have been increasing in size until by the sixth day of adult life they are fully developed. From the sixth until about the tenth to fifteenth day of adult life, during which period her brood food glands continue to secrete more or less abundantly, she attends to the feeding of the very youngest larvæ which, until they are about three days old and begin to receive a diet of honey and pollen, receive nothing but this special glandular food (Plate 13). By the end of this period of nursing the worker's brood-food glands have once more become greatly reduced in size, and she enters into the second of the main periods of her adult life.

The second period commences on or about the fourteenth day with her first short flight from the hive, the so-called 'play' or first orientation flight. During the course of the next seven days the young bee is responsible for such matters as receiving the nectar that is brought into the hive by the foragers, storing and ripening it, seeing that the pollen brought in is likewise stored properly, general house cleaning, the secretion of wax and any necessary comb building, and, by making further orientation flights, she learns the position of the entrance to her hive, relative to neighbouring objects in the apiary (Plate 14). Such things as other hives, bushes, and even stones, situated within a few yards of the hive, all come to serve as useful landmarks to the homing bee. Towards the end of this period in her life the young bee frequently helps to guard the entrance of her hive against robber bees and wasps.

By the time a bee is three weeks old she has learned to recognise the position of her hive in the apiary and to find it again, and she then embarks upon the third and last period of her life during which she collects water, nectar, pollen (and sometimes a resinous substance called *propolis* which is used for sealing up small spaces within the hive) in the field (Plate 15). During good flying weather in the summer when the field bees are very busy, this final period in a worker bee's life may last for anything up to three weeks.

If at the end of the period during which the young bee is performing her orientation flights, prior to becoming a fully fledged field bee, and is learning the position of her hive relative to neighbouring objects in the apiary she is captured at the hive entrance and released a short distance from her hive, she will find her way home by sight, by recognition of objects in the vicinity of her hive and the position of her hive in relation to them. As soon, however, as she commences to seek nectar and pollen in the field at some distance from the hive, two further senses come into play and assist the young bee to find her way home.

The Forager's Bee-line

Before discussing these senses, let us first see how a bee behaves when she has found a really abundant supply of good-quality food. Let us suppose that a number of bees have found a dish of sugar syrup that we have placed on the ground one hundred yards away from their hive (Plate 16). These bees can be observed to fly straight out of their hive, 'make a bee-line' for the dish of syrup that they have previously found, settle upon it and immediately begin to feed and, as soon as they have filled their honey-stomachs, which will take about half a minute, return by the most direct route to their hive. Here they proceed to regurgitate the syrup that they have collected, passing it with their tongues to those of the household bees that are responsible at the time for the storage and ripening of food brought into the hive. These field bees then leave the hive once more and return to the dish for another load of syrup.

In one of a series of observations made during the summer of 1942 two bees were found to be visiting a dish of syrup (See Plate 16) placed on the ground about 360 yards from their hive. These two bees were each marked with a spot of quick-drying cellulose paint on the dorsal surfaces of their thoraces so that they could be readily recognised not only from all other bees but also from each other, one bee being marked red and the other blue. When this had been done

continuous observation was kept on this dish for just over one hour and the number, duration and time of the visits of these two clearly marked bees to the dish were noted.

During this hour one of these bees paid sixteen visits to the dish and the other fourteen, the average length of time each bee spent on the dish being just over half a minute; the remainder of the time, that is to say the intervals between visits or the time spent each time in flying home, getting rid of the syrup, and flying out to the dish again, averaged about four minutes. In the evening these same bees were still visiting the dish with great regularity and must between them have already made at least 150 round trips, almost certainly without a break, between the hours of 11.26 a.m. (when observation on the dish commenced) and 4.25 p.m. (when it was discontinued for the day). On the following and subsequent days these two bees were still visiting this dish as regularly as ever. It should also be mentioned that in order to reach this dish they had to fly either over or very near many other dishes containing syrup of the same concentration and in the same abundance, and yet they never, so far as could be determined, deviated from their course in order to visit any other dish. It is now known as a result of this and other experiments that honey bees do in fact remain remarkably constant to one particular dish or small group of flowers to which they have somehow become attached, even though this dish or group of flowers may be surrounded by others of apparently equal attraction over which they are forced to fly in order to reach their especially favoured dish or patch of flowers.

It was also observed in the simple experiment that has been described that each of these bees took up a very definite and characteristic stance on the dish. One of the bees always chose a point of feeding on the west side of the experimental dish and the other selected a point on the north side. Neither bee ever moved more than a millimetre or two from her chosen position, and each assumed a characteristic attitude whilst drinking, one drinking from

the side of the dish and the other settling head downwards on the reservoir which supplied the syrup to the dish.

Sensing Direction and Distance

Now it might perhaps be imagined that these two bees that were visiting this dish of syrup with such regularity were finding their way between the dish and the hive by means of sight, by the recognition of various landmarks. Undoubtedly sight, combined with the memory of various prominent objects seen on previous flights, did assist these two bees to find their way home from the dish, but, as already mentioned, Wölf has shown that two other senses, *a sense of direction* and *a sense of distance travelled*, supplement the recognition of landmarks. Let us suppose that we place a dish of sugar syrup *exactly one hundred yards due north* of a fairly strong colony of bees. Sooner or later a few of the bees from this colony find this dish of syrup and begin to make regular journeys between their hive and the dish, transporting the syrup home as quickly as possible. As soon as half a dozen bees have settled down on our dish let us mark each of them with conspicuous spots of white paint so that we may readily recognise them even whilst they are on the wing. The next time that some of these marked bees visit the dish and have settled down to feed we pick up – very gently, so as not to disturb the bees – the dish with the bees still feeding on it, and move it to a point thirty yards due west of the original feeding place. We find that when the bees leave the dish they do not fly in a direct line to their hive as they have been doing previously but instead they fly *exactly one hundred yards due south* and, failing to find their hive in this position, they begin to fly round and round in concentric circles of ever-increasing size until they finally recognise some landmark which enables them to reorientate themselves and find their way home. Similarly, if the dish of syrup with the feeding bees on it is moved to a point due east of the original feeding place, the bees on leaving it fly

due south, rather than south-west, for exactly one hundred yards before they realise that they are lost. The same behaviour is observed if the dish with its feeding bees is moved from its position due north of the hive to a new point just south of the hive. In this case the bees fly in a direction exactly opposite to that which would bring them back to their hive.

To carry this experiment to what appears to be almost an absurdity, the writer once removed the dish from its customary position and placed it on the roof of the hive. Most of the bees on leaving the dish failed to recognise the fact that they were actually on the roof of their home and flew away in search of it. The results of these experiments show very clearly that the honey-bee not only makes use of local landmarks in order to find her way back to her hive, but also possesses knowledge of the direction from the feeding place in which her hive should lie and also of the distance that she has previously flown between her hive and the dish. Thus our experimental bees on leaving the feeding dish in each case flew due south for exactly one hundred yards in order to reach a point at which they expected to find their hive.

Guidance by Smell

In the course of these experiments the observer would have noticed that, although many hours or even several days may have passed before a single bee came near the dish of syrup that had been put out to attract the bees, once one or two bees had found the dish the number of bees visiting it increased rapidly. He may even have been led to wonder whether or not the bee that had first found the dish of syrup was able to convey knowledge of the presence and position of the dish to her sisters. Some writers, unable otherwise to explain the rapidly increasing population, have put forward the theory that the 'finder' bee leads other bees to the source of food either by actually flying along in front of them to it or by laying a trail of

scent between the dish and the hive, or something of a similar nature. Actually as we now know, mainly on account of the work carried out by von Frisch, the finder bee does not leave a trail of scent or anything else to lead further bees to the food. She is, however, fully capable of informing them of the presence and source of a particular kind of nectar or pollen and, furthermore, the direction from the hive in which the flowers in which she has found this food are situated and the approximate distance between them and the hive. When a bee has found some profitable source of food in the field, such as a dish of syrup or some flowers in which a rich supply of pollen or nectar is available, she fills her pollen baskets or honey stomach as the case may be and returns to her hive. She will in all probability enter the hive and move on to one of the nearest combs. Here she proceeds to dance a little dance more or less vigorously. The more profitable the source of food the more vigorously she dances. Some of the younger bees that have just reached foraging age and are near to the dancing bee pay a great deal of attention to her, turn and face her, often follow her movements, and every now and then the dancer feeds to them small quantities of the nectar or pollen that she has collected. These small quantities of nectar or pollen can be shown to contain enough of the perfume of the kind of flower from which they have been collected to inform their recipients of the perfume associated with the flowers from which the nectar or pollen was obtained. Later some of these recipients will leave the hive in their turn in search of this perfume and thus of the flowers from which it and the nectar or pollen were obtained.

Communication by Dancing

The dance itself is somewhat variable, but fundamentally it consists of a series of figures-of-eight repeated at frequent intervals. If the source of food is located only a short distance away from the hive the two loops of the figure-of-eight are superimposed one on top of the other (Fig. 5),

ASPECTS OF BEE BEHAVIOUR

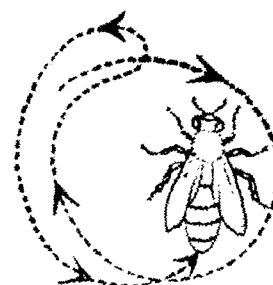


Fig. 5.—A bee is able to communicate to other bees where food is to be found by 'dance language'. This is the pattern she dances when the source of food is relatively near to the hive — the so-called Round Dance of von Frisch. (Figs. 5 and 6 come from von Frisch's paper in *Experientia*.)

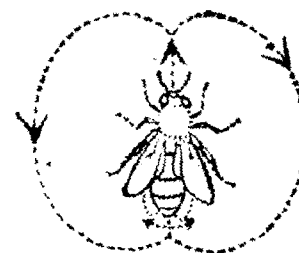


Fig. 6.—As the distance increases, the dance pattern gradually changes until this pattern is reached. Here, in the so-called Wagtail Dance, the bee makes a half-circle to the right, then a straight run during which she waggles her abdomen, and then a half-circle to the left.

but as the distance between the hive and the food becomes greater the two loops of the eight become more and more discrete until, when we reach the stage that the source of food is situated at a distance of about one hundred yards from the hive, a perfect eight with entirely distinct loops is being formed (Fig. 6).

As the distance becomes greater than one hundred yards a straight run of proportionately increasing length is inter-

polated between the two loops of the eight and during the performance of this part of the dance, the straight run, the dancer wags her abdomen rapidly from one side to the other (Fig. 7.) Thus the dancer is able to indicate to her sisters the approximate distance between her hive and the source of food.

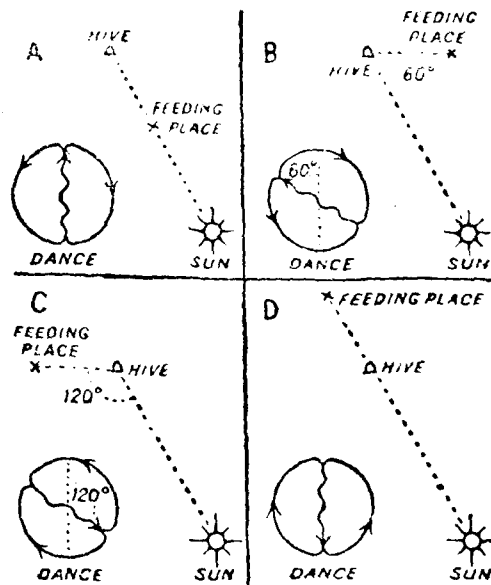


Fig. 7.—How a bee conveys to other bees the direction in which a profitable feeding place lies with respect to the hive. In A, the straight run (shown by wavy line in the diagrams since the bee is wagging her abdomen) is vertically upwards on the comb when the food source lies in the direction of the sun; if the food is in the opposite direction (see D), the straight run is vertically downwards. By varying the angle of the straight run to the vertical the bee can communicate the intermediate directions. (Reproduced by courtesy of the editor of *The Observer*, based on von Frisch's diagram published in *Experientia*.)

Finally it has been shown that the degree of inclination of the straight run, if present, to the vertical is an indication

of the direction in which the source lies relative to the position of the sun. If the straight run is made vertically upwards on the comb then the source of food lies in the direction of the sun at that time; if the run is performed vertically downwards the source of food lies in exactly the opposite direction, and so on. Thus a bee is able to inform her sisters of the richness of a source of food, of the kind of food, that is to say whether it be pollen or nectar; of the perfume of the flowers in which this food is to be found, and of the direction from the hive in which these flowers lie and their distance from the hive!

Division of Labour

Although we know quite a lot about the division of labour amongst the worker bees of a colony before they become field bees, that is, in general, say before they are three weeks old, unfortunately we know very little about the division of labour amongst the field bees themselves. Many observers are convinced that some form of division of labour does exist between the field bees of a colony which ensures, under reasonably favourable circumstances, that all the bees do not go off to collect nectar, resulting in the collection of a surplus of carbohydrate and a shortage of protein. The order, if such exists, in which the several field duties are undertaken by every individual worker bee has not yet been determined with any certainty. One or two observers working with small colonies composed entirely of very young bees have come to the conclusion that, generally speaking, nectar is collected by the younger foragers whilst pollen is collected by the older ones, and water is collected by the youngest foragers of all. The colonies upon which these observations were made were not, of course, properly balanced ones and these results are, therefore, open to question. Indeed Rösch himself was unable to discover any definite sequence of duties performed in the field, and more recent research strongly supports the view that whereas there may be a tendency for the

younger field bees to collect nectar and the older ones pollen, this is little more than a tendency, and the work performed by a field force of a colony of bees at any given time is probably less dependent upon age than upon such other factors as the nutritional requirements of the colony at that time, and, perhaps, the relative availability of nectar and pollen in the field. It is, of course, well known that a certain number of bees collect nectar and pollen simultaneously from the flower of their choice, and that certain flowers contain so much pollen and are constructed in such a way that the visiting bee, even if she should only be desirous of collecting nectar, is compelled to collect on her body a great deal of pollen as well. It is, however, less well known that in certain circumstances a bee will, after combing the pollen off the hairs of her body, instead of transferring this pollen to her pollen baskets for transport back to her hive, deliberately drop the pellet of pollen on to the ground. Such behaviour can frequently be observed amongst bees that are working sunflowers for nectar. There is thus some evidence that whilst for the most part the honey-bee is a creature of habit blindly doing certain things in response to certain stimuli, she is capable on occasion of breaking the general rule and doing the unexpected.

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(Reprinted by courtesy of the Editor of *Discovery*, 244 High Holborn, W.C.1.)

OIL PROSPECTING SEISMOGRAPHY

Explosive charges are set off in holes drilled in the ground, to obtain a record of the speed and character of the resulting vibrations as they are reflected back from successive layers of subterranean rock. Interpretation of the records (see *Science News* 8, page 63) leads to detection of oil-bearing strata.

The following eight plates show the difficulties of ground prospecting in the quiet backwaters and swamps around Lake Arthur, Louisiana. (Plates 1 to 9 by courtesy of the Standard Oil Company, N.J.).



Plate 1. Quarterboats moored under trees draped with Spanish moss constitute a floating base for the entire field party.

Plate 2. Setting off for the day's work. A centrifugal pump with out-board motor head is too heavy for one man.

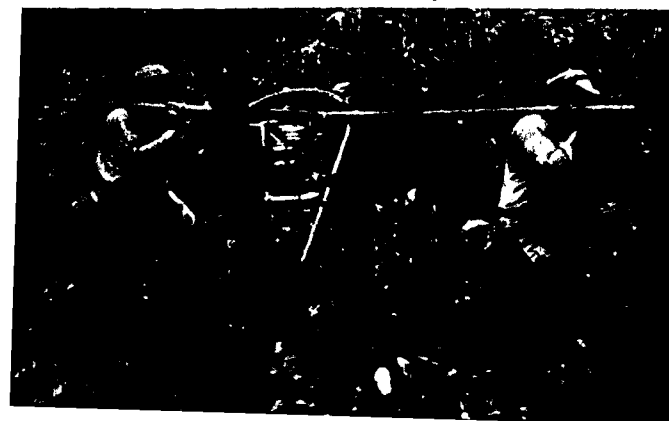


Plate 3. All loads are limited to thirty - five pounds per man, and there are frequent halts for rest. At times the men may sink up to their knees in mud.

Plate 4. A hydraulic drill bores holes as deep as eighty feet to receive the explosive, when the operational site is reached. Water for the drill is pumped from a slush pit, easily blown in the swamp with dynamite, using the pump seen in plates 2 and 5.



Plate 5. Priming the water-pump by pouring water into the intake head, which will then be dropped into the slush pit. The pump, under the hands of the man on the right, drives water through the line in the background to the drill (plate 4).

Plate 6. Meanwhile, the connections on the amplifiers which transmit the impulses from the pick-up microphones in the field to the recorder itself are checked over. The final record is a photograph of galvanometer movements.





Plate 7. A lightproof changing bag is the portable dark room in which film from the recorder is developed immediately after the explosion has been made.

Plate 8. Examining the developed seismic record of the earth vibrations



OIL PROSPECTING MAGNETOMETRY

(See *Advances in Geophysical Prospecting* page 9).

Plate 9. Another way of studying underground rock is by measuring the strength of the earth's magnetic field at different points. Here a ground surveyor is making a measurement of the pull of the rock beneath his feet on a magnet inside the box of his instrument.

Plate 10. A modern improvement is to make the magnetic survey by aeroplane. A twin engine Beechcraft of the U.S. Geological Survey carries a special aerial magnetometer ("Bird") beneath it, like a bomb.

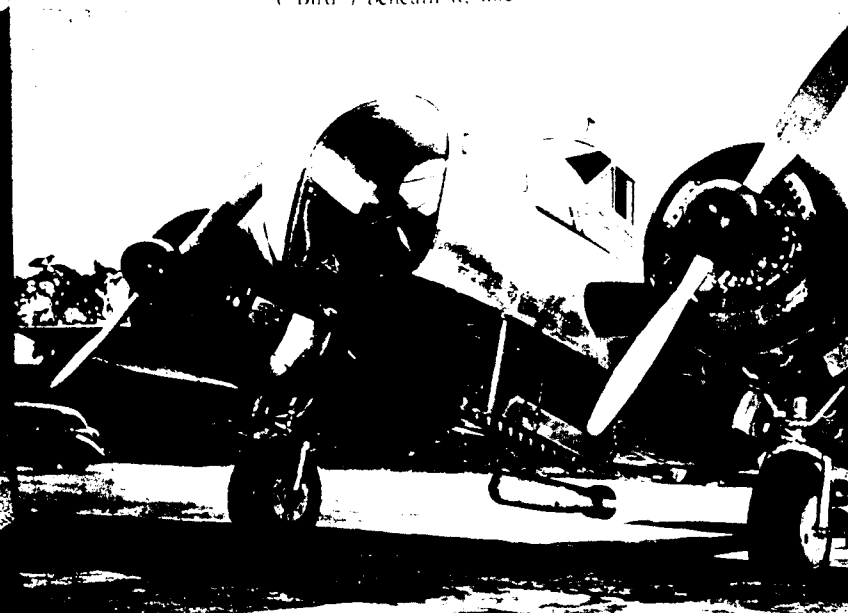




Plate 11. The "Bird" with its nose removed to show the intricate gyro-compass mechanism which orients it in flight

Plate 12. Here is the plane in flight, guided by Shoran stations on anchored ships, with the magnetic detector let out below it. The aircraft takes a circular course around the "drift" station (left) and records its position by reference to the "rate" station (right), while the detector makes a continuous record of the magnetic intensity due to under-lying rock (see maps on page 11). Shoran is a method of navigation by radio. (Plates 10 to 12 by courtesy of *Life* magazine.)



ASPECTS OF BEE BEHAVIOUR

The different functions performed by the worker bee follow a definite sequence, which can be divided into three main periods.

Plate 13. In the first period she carries out nursery duties. This photograph shows nurse bees feeding larvæ curled up in their cells, and older house-hold bees responsible for capping cells containing fully grown larvæ.

Plate 14. The second set of duties can be described as house-hold duties, which include storage of nectar, sealing of cells, and comb-building. Here a worker is tearing down a queen cell.



Plate 15. Finally, the bee 'graduates' to foraging duties. This bee is seeking nectar from plum blossom.

Plate 16. A dish-feeder of the type described on page 24, in which a constant supply of sugar syrup is made available to the experimental bees. (Plates 13 to 16 by courtesy of 'Discovery').

EXPLORING JAN MAYEN



Plate 17. Vogelberg, the site of most of the bird studies, with the Beerenberg volcano behind.

Plate 18. Another view of the Beerenberg, with the North Lagoon at its foot.



Plate 19. A lava flow breaking up; the white specks are lichens. In the foreground, sand collected in a depression bears flowering plants. The snow-covered summit of the 8,000-ft. Beerenberg volcano rises above the mist.



Plate 20. Glaciers at the N.E. end of Jan Mayen; mist banks at sea level and 2,000-ft. Photo taken at 2 a.m., 1½ miles off shore. Few plants grow on the exposed lava.



Plate 21. Typical late snow area. Ice axe marks where plants begin to grow; near top of slope, *Taraxacum*, *Saxifraga* and *Arabis* flower. Note detritus held on snow surface.





Plate 22

Plate 23

Plates 22 to 25 show points 1, 3, 5 and 6 of the late snow area transect. Note the detritus deposited on soil by melting snow in 1; interesting plant growth in 3, 5 and 6 (see text, pages 78 to 80).

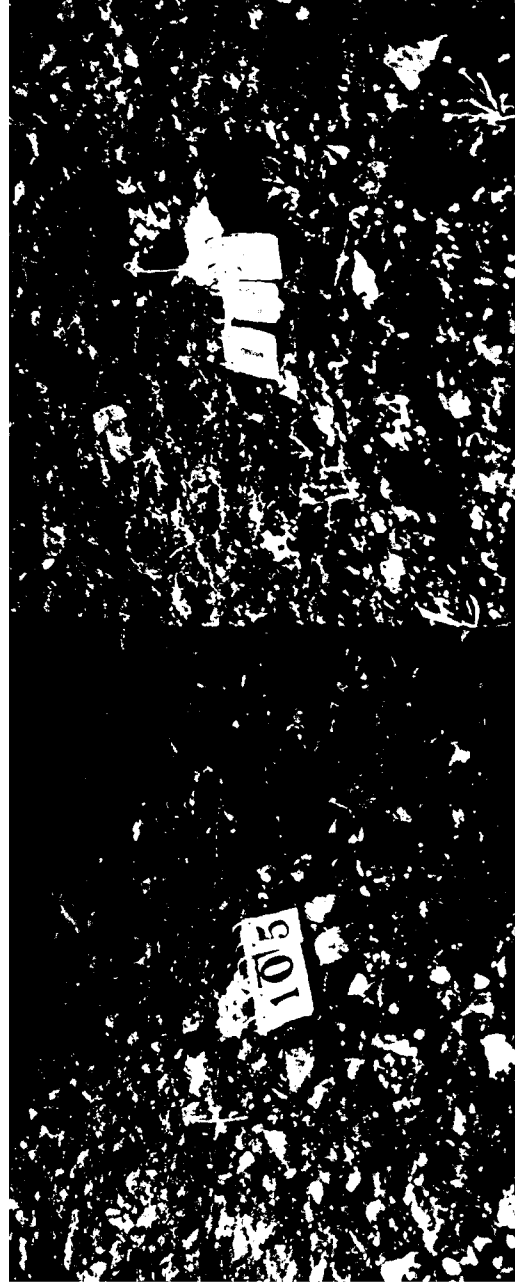


Plate 24

Plate 25

TELEPATHY



Plate 26. Soal and Goldney's experimental set-up for telepathy investigations. The Agent is on the right and the Experimenter controlling the Agent on the left. The Percipient and Experimenter controlling the Percipient sit in an adjoining room.

Plate 27. The Experimenter controlling the Agent sits this side of the screen. She is provided with a sheet of random numbers (b). If the first number is 2, she holds the small card bearing the figure 2 up to the aperture (a), and so on to the end of a series of 50 guesses. The stop-clock was merely used to time the duration of the run.

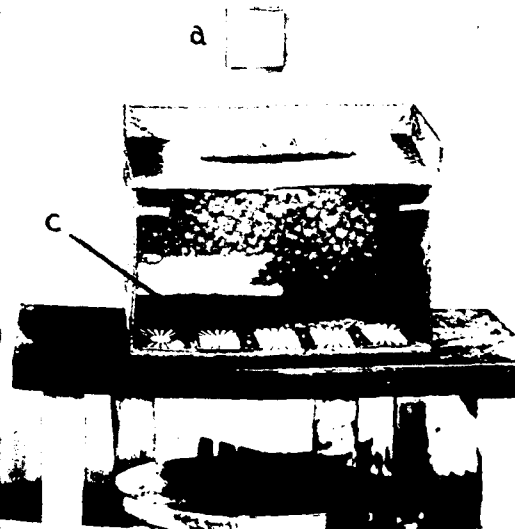
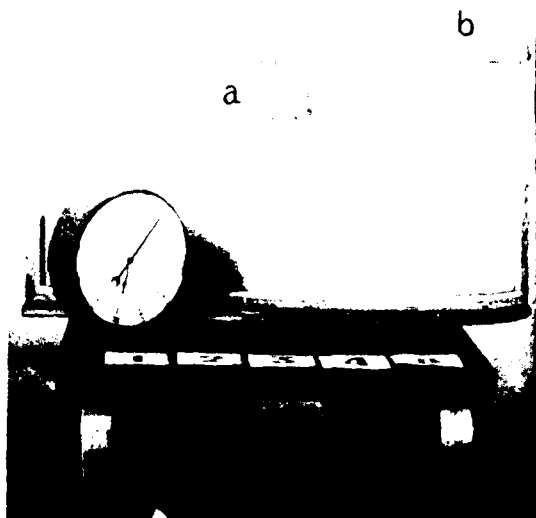
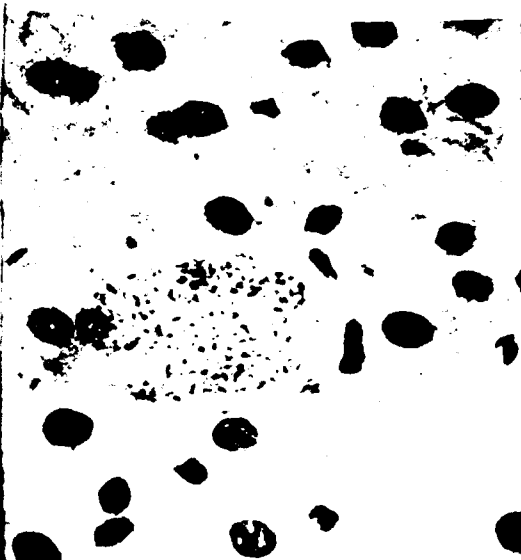


Plate 28. The Agent's side of the screen. The Agent, seeing the figure 2 at the aperture (a) would look at the second card from the left. These cards (c) bear animal symbols and are placed face downwards inside the cardboard box.

RESEARCH REPORT

Plate 29. A section, highly magnified through a microscope, of the liver in the early stages of malaria. All around can be seen normal liver cells packed closely side by side, containing their darkly-stained usually oval nuclei; and in the centre is a tight mass of multiplying malarial parasites, distinguished *inter alia* by their tiny dark nuclei. This is a new phase recently discovered by Professor H. J. Shortt and Dr. P. C. C. Garnham at the London School of Hygiene and Tropical Medicine (see page 53).



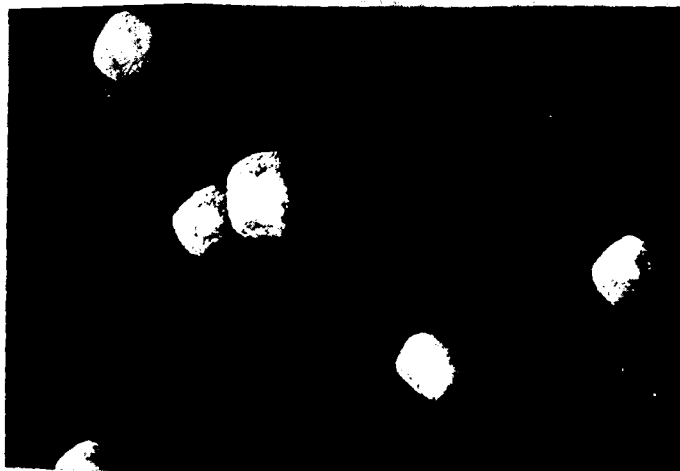


Plate 30. Electron micrograph of vaccinia virus magnified 32,000 times. Note the surface 'bobbles.'

Plate 31. Vaccinia virus after digestion with pepsin. Magnified 32,000 times. Note appearance of collapsed outer membrane and dense intact centre. See page 46.



Telepathy

DR. ERIC J. DINGWALL and DENYS PARSONS

FROM earliest times observations have been made by people living in various stages of culture which seem to suggest that occasionally some persons become aware of facts, events, or impressions which appear to have been obtained neither through the normal channels of sense perception nor by inference. The facts thus acquired may relate to past or present events, but now and then it would seem that knowledge of the future is demonstrated, a phenomenon on which has been reared an immense literature of fortune-telling and prophecy.

It is remarkable what close correspondences exist between reports of experiences of this nature described in Egypt, Greece, Rome and China, centuries before Christ, and those reported right down the Middle Ages to the present day.

The scholars of ancient times discussed these phenomena and attempted to explain them in accordance with their own philosophy. Cicero (B.C. 106-43) wrote a book on divination in which he dealt with the whole problem in a manner which indicated the serious and critical regard which he entertained for the stories current in his time.

Even after the decline of the witchcraft epidemics, interest in the subject was kept alive by students who were still trying in vain to fit paranormal phenomena into a framework of thought clearly not destined to receive them. Thus it was not till late in the eighteenth century that men began a serious attempt to apply experimental method. Not surprisingly, the early experiments were unsystematic and showed that those conducting them had little appreciation of the sources of error and of the possibilities of mal-observation and fraud.

With the rise of modern spiritualism in 1848, however, the interest of the learned world was aroused and some of the bolder intellects conducted experiments of a telepathic nature on subjects in the normal state and in hypnotic trance. In 1882 a determined attack on the problem was formulated. In that year the Society for Psychical Research was founded to conduct a scientific investigation into all phenomena which were *prima facie* inexplicable by the laws known to physical science. Its earliest task was a systematic attempt to investigate the alleged transmission of thoughts from one mind to another by means apparently independent of the organs of sense. The results of these experiments were held to confirm the reality of 'thought transference,' but the experimental conditions did not approach the standard expected for similar experiments to-day.

Nevertheless, the early experimenters reached one important conclusion – that 'thought transference' was too narrow a term to describe the kind of results which were obtained. This led F. W. H. Myers to suggest the word 'telepathy' for the communication of impressions of every kind from one mind to another independently of the recognised sensory channels, and 'telaesthesia' for the *direct* cognition of objects or conditions, *i.e.*, by means apparently independent of the senses and under circumstances in which no other mind could be suggested as the source of the information.

Besides the early experimental efforts there were the usual cases of apparent telepathy encountered by people in their everyday lives. The Society paid a good deal of attention to these so-called 'spontaneous' cases, a large collection of which was published in 1886 under the title, *Phantasms of the Living*. These cases, if veridical, showed that the telepathic or telaesthetic process, in conveying an image, impression or idea to a percipient, is liable to generate secondary reactions of various kinds – for example, the idea of a wine-glass might reach the percipient as an egg-cup, thus indicating some degree of distortion and faulty

interpretation on the part of the percipient, or possibly the sender or 'agent' as he is called. Such distortion is often observed in modern experimental work and obviously adds to the difficulties of evaluation. Occasionally we find records of persons at the receiving end of an urgent 'message', getting a vague feeling of uneasiness, being driven to some compulsive action, or in more complex cases experiencing hallucinations ranging from the simplest visual or auditory phenomena to more highly developed types such as full-form phantasms. Such phantasms when externalised are sometimes built up to such a degree that they are mistaken for real people, but there is strong evidence that they are none the less subjective, as of course are the more common hallucinations of psycho-pathological origin.

The following case is typical. The percipient's brother, an airman, had been shot down in France on the 19th March, 1917. She herself was in India. 'My brother,' she says, 'appeared to me on the 19th March, 1917. At the time I was either sewing or talking to my baby ... I had a very strong feeling I must turn round; on doing so, I saw my brother, Eldred W. Bowyer-Bower. Thinking he was alive and had been sent out to India, I was simply delighted to see him, and turned round quickly to put baby in a safe place on the bed, so that I could go on talking to my brother; then turned again and put my hand out to him, when I found he was not there. I thought he was only joking, so I called him and looked everywhere I could think of looking. It was only when I could not find him I became very frightened and had the awful fear that he might be dead ... Two weeks later I saw in the paper he was missing.'*

Although many of the spontaneous cases exhibit a wealth of evidential detail, there is probably no case which cannot be explained by normal means, if no limit be set to the counterhypotheses of chance coincidence, fraud, collusion, lapse of memory, malobservation, etc., taken singly or in combination. Nevertheless the number of cases which can

* *Proceedings of the S.P.R.*, 1923, xxxiii pp. 170 ff.

reasonably be classed as of fair quality is considerable, and the *a priori* improbability of a telepathic interpretation is perhaps somewhat decreased as a result of experimental work under rigorous conditions.

During the 50 years 1880-1930, numerous telepathy experiments were performed. We have already indicated that in the light of present knowledge many of the early tests were of little evidential value, because the experimenters did not report their results in sufficient detail for us to be able to judge whether they took adequate precautions against sensory leakage and other sources of error. The modern phase of experimental work may be regarded as starting with the work of H. J. F. W. Brugmans at Groningen (1920), Miss Jephson (1924) in England, and J. B. Rhine at Duke University, North Carolina (1930 onwards). Rhine (now Professor of Psychology at Duke) whose contribution to the subject has been very considerable, published in 1934 a book entitled *Extra-Sensory Perception*, which described experiments in telepathy and telaesthesia. This book aroused a fierce controversy.

Critics of the statistical methods were particularly vociferous but soon found themselves in difficulties. Psychical researchers were well aware of the statistical pitfalls and had taken the precaution of consulting experts. As early as 1885 there appeared in the *Proceedings of the S.P.R.* an article by F. Y. Edgeworth, 'The Calculus of Probabilities Applied to Psychical Research.' Jephson, Carington, and Soal (see below), worked in cooperation with W. L. Stevens and Professor R. A. Fisher, who devised ingenious methods of evaluating the results of experiments on 'guessing' drawings and playing-cards. The statistical methods used to evaluate the earlier work at Duke University were so simple that there was little scope for adverse criticism, *provided that* the experiment had been properly designed and executed.

On the experimental side, the earlier work of Rhine and his colleagues was indeed much less satisfactory, and the outburst of criticism had the healthy result of leading to a

rapid tightening and refining of experimental conditions and methods. Most of Rhine's work was done with cards bearing the five symbols Star, Cross, Square, Circle, and Wavy Lines (the so-called Zener cards). It was found, for

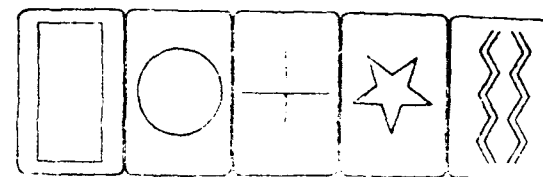


Fig. 8.—Zener Cards.

example, that with certain packs of these cards the symbols could be read from the backs in certain lights. Subsequently the investigators made it the practice to enclose them in opaque envelopes or to keep them out of sight of the percipient; sometimes agent and percipient were located in separate buildings, occasionally in separate continents. Many other criticisms and counterhypotheses have been advanced. It has been claimed, for instance, that the data have been improperly selected from a large mass of negative material, or that score sheets containing poor results were lost or destroyed. It is suggested that the tests were arbitrarily stopped at favourable points or that low-scoring percipients were dropped. Counting, recording, and computing errors have been held sufficient to account for the deviations obtained. Loose conditions and poor observation by the experimenters have been alleged; for example, the percipient may have been able to peep at the cards beforehand or to substitute another pack while the experimenter's attention was distracted, or to tamper with the record sheets afterwards. Lax supervision may have allowed the agent to give visual or auditory clues such as whispering, coughing, scraping the feet on the floor, or creaking of chairs.

The experimenters at Duke University were not long in answering these criticisms, and as the conditions were

tightened up, significant results continued to accumulate. A few of the more recent series of American experiments appear to be reasonably proof against all the counter-hypotheses which have been raised, even taken in combination, it being assumed that the records present a true picture of the procedures adopted.

Meanwhile, G. N. M. Tyrrell, in England (1934-6), was developing an electrical apparatus in which the percipient had to cognise in which of five closed boxes the agent had caused a lamp to be lit. An ingenious 'scrambling' device ensured that the agent himself did not know which lamp he had lit by turning his selector switch, so that any signalling code, conscious or unconscious, would have been stultified. The conditions were virtually those of teleesthesia rather than telepathy, since no mind was aware which lamp was lit until after the choice had been made. Highly significant results were reported with one subject.

In 1934 S. G. Soal, Lecturer in Mathematics at the University of London, began to carry out an extensive repetition of Rhine's experiments with Zener cards; and during the next five years he gave individual tests to 160 persons and recorded 128,350 guesses. The results appeared to be in close accordance with chance expectation, and they were put aside. However, in the autumn of 1939 Whately Carington, as a result of observations he had made while doing some telepathy experiments with drawings, persuaded Soal to re-examine his records in order to ascertain whether any of the percipients had scored hits, not on the cards focussed by the agent but on the immediately preceding or following cards. The search revealed that two persons had shown highly significant scores on the preceding (precognitive) and following (postcognitive) cards, while their score on the actual target card was insignificant, suggesting a kind of displacement effect. This of course had to be confirmed, and these two percipients were re-tested. The first of them, Basil Shackleton, a well-known West-End photographer, was tested by Soal and Goldney over a

period of 2½ years, and this displacement effect was confirmed.* The most elaborate precautions were taken to guard against fraud, and sensory leakage, such as unconscious whispering. Many of the safeguards were inherent in the design of the experiment, which will now be described.

A minimum of four persons took part – the Agent (A), the Percipient (P), the Experimenter controlling the Agent (EA), and the Experimenter controlling the Percipient (EP). In addition, a number of other persons including University professors, physicians and scientists, were invited from time to time as observers. (One of the present authors attended a single session at which significant scores were made.) EA and A sat at opposite sides of a small table separated by a screen having a small aperture (a) (Plate 26). EA was provided with five small cards numbered 1 to 5, and a prepared sheet (b) bearing the figures 1 to 5 in a random sequence, e.g., 2, 1, 1, 3, 5, 2, 4, 4, 1, 3, etc., taken from tables of random numbers (Plate 27). This sheet was taken from a sealed envelope just before the experiment. A was provided with five cards (c) bearing pictures of animals, Lion, Elephant, Pelican, Giraffe, and Zebra, placed face downwards inside a cardboard box (Plate 28). In the next room, but not in line with the door, P sat at another table with an identical set of five animal cards. EP filled in the record sheet. To start a run EA said: 'Ready ... Go!' and simultaneously held up at the aperture the card corresponding to the first number on the sheet of random numbers, say a 2. A, just before the word go, had shuffled the five animal cards and then placed them in line face downwards inside the box. On seeing the figure 2 at the aperture she picked up the second card from the left, looked at it and immediately replaced it. At the same time P made his guess by pointing to a card with a pencil. EP recorded the guess. EA then said 'Next!' and displayed the second random number at the aperture, and the process was repeated at three-second

* The second subject also gave significant results which have not yet been published.

results were obtained with a single gifted 'sensitive,' Carington's were contributed by a group of 20 or more friends and acquaintances.

Turning now to the theoretical side, the subject is still very much in the speculative stage. How does an idea 'get across' from one mind to another? Is there indeed any 'transmission' at all? The hypothesis that telepathy is a new form of radiation is now in disfavour, the chief objection being that the phenomenon appears to be independent of distance and time. It must be remembered, however, that our knowledge of the limits of *sensory* powers is still far from complete. Griffith and Galambos have shown that bats avoid obstacles in the dark by supersonic echosounding, and Yeagley's recent work with homing pigeons, strongly suggests that they navigate by responding simultaneously to variations in the earth's magnetic field and to variations in the Coriolis force caused by the rotation of the earth. F. W. H. Myers, one of the founders of the S.P.R., had realised at a very early stage that the unconscious mind was deeply involved in most paranormal phenomena, and later work has confirmed this view. H. H. Price, Wykeham Professor of Logic at Oxford, in a broadcast talk, has pointed out that it is nonsense to suppose that minds are spatially separate entities; minds are not objects in space. If we assume that every mind is a causally separate insulated system we are denying that an event in any one mind ever directly affects any other mind. But that is exactly what telepathy seems to be, so the question 'how does the idea get across?' is equivalent to 'how does telepathy happen, if we assume that it never can happen?' Price insists that we must revise our notion of what a mind is, and suppose that on the unconscious level there are no sharp boundaries between one mind and another.* Whately Carington has developed this notion of 'a common unconscious' in a recent book, *Telepathy* (London, 1945), and

* 'Philosophical Implications of Telepathy'. *The Listener*, February 13th, 1947, pp. 277-278.

combined it with the familiar laws of association of ideas. His hypothesis is that when an associative linkage between two ideas is formed in any one mind, it is theoretically available to all minds. In a telepathy experiment, for instance, the target drawing is associated by the experimenter with the 'idea-of-the-experiment.' The percipient is also concerned with the 'idea-of-the-experiment' and the linked idea of the target drawing emerges from the common subconscious to his conscious mind.

Scientists are not inclined to regard with favour ideas of 'precognition,' and attempts have been made (so far, we think, with little success) to discover serious flaws in Soal's experiments or failing that, to devise a telepathic hypothesis, however elaborate, which might circumvent an interpretation in terms of precognition. Soal's work lends some support to a precognitive explanation of the 'spontaneous' cases of premonitions, etc., which have been sifted and analysed by H. F. Saltmarsh.*

The fugitive and capricious character of telepathic and allied phenomena makes investigation difficult and time-consuming. Work is now proceeding at Duke University to try to correlate telepathy scores with psychological factors of personality, using such tests as the Rorschach, but investigators are still, after 70 years, almost completely in the dark as to the conditions which favour or inhibit telepathic activity. They are dealing, of course, with biological material which is notoriously recalcitrant, as workers in the field of animal psychology have found to their cost. That desirable goal essential to any real progress, the repeatable experiment, may be still a long way off; the techniques, indeed, are repeatable but positive results do not necessarily follow. That this state of affairs is highly unsatisfactory is recognised by all workers in the field, and future work will have to be concentrated on a study of the *modus operandi* of these elusive factors of the human personality.

* *Proceedings of the S.P.R.*, 1934. xlii, pp. 49-103.

Research Report

A. W. HASLETT

Structure of an Animal Virus

ELECTRON micrographs taken by Dr I. M. Dawson and Dr A. S. McFarlane of the National Institute for Medical Research, London, suggest that the viruses of animal diseases form an interesting link in the chain connecting the larger organisms, through bacteria, with the plant viruses. The bacteria, although often less than a thousandth of a millimetre in diameter, are still organisms. They are capable of independent existence, given a suitable food supply can be cultivated in the laboratory, and the chemistry of their single cells is little less complex than that of our own. Many of the plant viruses, on the other hand, can be prepared in crystalline form, and are presumably composed of a single substance. Yet in the particular environment provided by their host plant they can and do reproduce themselves. An animal virus is similarly limited as to conditions of reproduction – but, as these new electron micrographs show, it may possess structure.

The virus which Dr Dawson and Dr McFarlane have been studying is that of vaccinia. This is one of the smaller animal viruses although appreciably bigger than, for example, the virus of poliomyelitis or infantile paralysis which has lately been identified. Magnified one hundred thousand times, it is comparable in size with a non-austerity lump of sugar and shows surface 'bobbles' which are only a little larger in proportion. These 'bobbles' are remarkably regular in appearance and they are thought to represent individual protein molecules. In a few cases, chains of granules of similar size appear alongside or near the virus particles, as if stripped from their surface. There are also indications in

some of the electron micrographs of a relatively dense centre. However, the most interesting pictures are of virus particles which have been exposed, before examination, to the digestive ferment pepsin (the protein-digester of the stomach) (Plates 30 and 31). The appearance of these suggests that the pepsin has removed much or all of the material from the outer part of the virus, leaving only a collapsed membrane and the more dense and intact centre already mentioned. The collapsed state of the 'membrane' is suggested both by its greater elongation in the micrograph, and also by an appearance of folding in some cases. Finally, there is a suggestion, based on the manner of contraction of the virus particles under different conditions of drying, that there may be a supporting internal network which would permit of a concertina-like movement. This last, particularly, is speculative at the present stage. But there seems no doubt on the main point – that both chemically and in physical structure an animal virus may show local differentiation.

Dawson & MacFarlane, *Nature*, 1948, 161, 464.

The Earth's Changing Magnetism

If a magnet were freely suspended, so that it could swing vertically as well as horizontally, then at almost all points on the earth it would make use of its double freedom. In the northern hemisphere, the north-seeking pole of the magnet would dip downwards as well as pointing north; and in the southern hemisphere, the south-seeking pole of the magnet would behave likewise. And only on the magnetic equator would the magnet take up a horizontal position. In general as it was moved north or south, it would dip more steeply, and the north and south magnetic poles are defined as those positions on the earth's surface at which a freely suspended magnet would point vertically downwards. Incidentally, the horizontal component of the earth's magnetism corresponds with the horizontal pull exercised on the poles of a magnet, and the vertical com-

ponent with the pull in a vertical direction, and the term 'angle of dip' explains itself. Finally, it may be worth adding for convenience that the reason for talking about the earth's magnetic 'field' is that there is no pull or force exercised unless there is a magnet to be pulled — and, even then, the extent of the force depends on the strength of the magnet as well as on the strength of the field. The earth's magnetic field at any point is thus a local property, which we may think of for convenience as being there all the time, but which needs a magnet or other detecting instrument to make it show itself.

With that preliminary it may appear less alarming, although no less important for navigation, that the earth's north magnetic pole should have moved from the position in which it was last established. The first report of the kind resulted from a flight made by the British Lancaster aircraft Aries in May, 1945, and the position given for the north magnetic pole was between 200 and 300 miles to the north-north-west of the position on the west side of Boothia Peninsula, the most northerly promontory of the mainland of Canada, in which it was found by Amundsen in 1906. Much further work has been done in the interval, and the Dominion Observatory of Canada has lately issued a statement summarising the position. In addition to the change of position, which there was already reason to think must have taken place, it is believed that the north pole moves daily round a circle of about 80 miles diameter. This would be difficult or impossible to imagine if the pole were a physical point on the earth's surface to which a compass needle was attracted. But if it is remembered that there is a magnetic field at all points on the earth's surface, and that a change in the position of the pole means merely a small change in the direction of the earth's field in that neighbourhood, then the facts as reported appear less remarkable.

The most extensive observations were made during the summer of 1947, when an R.C.A.F. aircraft was used to carry Dominion Observatory geophysicists to Boothia

Peninsula and a number of neighbouring islands. These included Prince of Wales Island, where the Pole is now thought to wander, and Victoria and Somerset Islands to the west and east respectively. Survey ship observations, also in summer, were made in the neighbourhood of the straits immediately north of Boothia Peninsula and further north again. A number of winter measurements were made during the northern transport trials to which the name Exercise Musk-Ox was given, and it is perhaps worth emphasising that the whole of these observations were made either from the ground, or in a few cases from ships, and in no case from the air. Taken together they are said to have 'established the opinion' of the observatory as already indicated, although it was proposed that further work should be carried out during the present summer, and probably also in following years.

Long-term changes in both the horizontal direction and angle of dip of a freely suspended magnet have been known in the case of London from 1580 onwards. In that year a compass needle in London pointed 11° 20' East of True North, and in 1823 as much as 24° 30' West. These changes used to be attributed wholly to a corresponding movement of the earth's magnetic poles, and a cycle of some 480 years duration was deduced. But in fact there is no proof of the permanence of the suggested cycle, and as regards its generality there is evidence that there may be regional reversals of the direction of change which are not matched at all points on the earth. There are also daily variations both in intensity and direction, which can be followed by taking average figures for 'quiet days,' free from the larger and transient disturbances known as magnetic storms. These are attributed to tidal movements in the electrically charged layers of the upper atmosphere and to currents induced by these movements within the crust of the earth. Merely from London records, therefore, we know that there are both long-term and more rapid changes in the magnetic field of the earth, and similar

changes in the neighbourhood of the north magnetic pole should not be regarded in principle as any more surprising.

The same cannot be said of an investigation, bearing on the past history of the earth's magnetism, which has been made by Dr J. St G. Bruckshaw of the Imperial College of Science and Technology. What he has been doing is to examine in detail the distribution of magnetic material in the Armathwaite and associated dykes which sprawl from west to east across northern England and are traceable to the formerly volcanic island of Mull off the west coast of Scotland. Dykes in general are so many former cracks in the earth's crust through which molten material has been forced upwards, but not so far as to the original surface. The result is a long narrow band of alien rock which, in the present case, is about 30 to 80 feet in width and is comparatively rich in iron. From the conditions of its formation, it can be said that any previous magnetisation of this material would have been destroyed. The supposition, therefore, is that the direction of the present magnetisation of these dykes corresponds with that of the earth's magnetic field at a time when the dykes were cooling to solidity. Local variations in the present magnetic field of the earth, due to such dykes, have been measured before, and the results have been broadly the same in all cases. They are consistent with the apparently unlikely explanation that the average magnetisation of the dykes is in the reverse direction to that of the present field of the earth. That applies in places as widely separated as Saxony, South Africa, Brazil and New Zealand. But the effects in detail have been too complicated to allow of a direct conclusion. Dr Bruckshaw's contribution has therefore been to examine the physical magnetisation of rock specimens taken, from side to side, across 65 different sections of these British dykes. In some cases, all specimens have been similarly magnetised. In others the direction of magnetisation changes more than once across the width of the dyke. But

in all, if the whole width of the dyke is averaged, there is the same reversal on balance. There, then, are the facts. They make it probable that tens of millions of years ago there were either a series of local reversals in the earth's magnetic field, or that there was a simultaneous and general reversal. Either would be very much more difficult to explain than the comparatively minor movement in the magnetic north pole which also has been lately observed.

North Pole: *Terrestrial Magnetism*, 1948, 53, 97.

Bruckshaw. *Monthly Notices of the Royal Astronom. Soc. Geophysical Supplement*, in the press.

The Metre in Wavelengths

There is an appeal to the imagination in the recent announcement by the United States Bureau of Standards that a form of mercury, prepared from gold by transmutation in a nuclear pile, is likely to provide the basis of the future international standard for the measurement of length. The making of gold from base metals was for many centuries the dream of alchemists. And here we have mercury being made from gold, and put to strictly utilitarian employment.

As to the aim, it has long been recognised in principle that some particular and specified wavelength of light, radiated characteristically by the atoms of one of the heavier chemical elements when vaporised, would provide a more satisfactory length standard than the present metal bars, engraved with finely scratched lines to mark the beginning and end of the 'international metre.' The difficulty was that no light source was available from which a single completely sharp wavelength of radiation could be separated. One reason for this is that practically all of the natural chemical elements consist of mixtures of atoms which are identical in their chemical properties but differ slightly in mass - and these mass differences introduce very slight differences in the wavelengths radiated. The ideal material for use as a wavelength standard is accordingly

one in which all the atoms are identical – and, for other reasons, it is desirable that its mass should be an even, and not an odd, multiple of that of the hydrogen atom. Both conditions are fulfilled by mercury made by transmutation from gold. Whereas normal mercury consists of a mixture of some seven different kinds of atoms (isotopes), mercury atoms made from gold are all of the same kind and have a mass of 198 units. Dr W. F. Meggers of the Bureau of Standards has described how, after earlier attempts to prepare mercury-198 in adequate amounts by other methods had ended in disappointment, a 'a dirty gold bar with a secret history' was delivered at the Bureau, towards the end of the war, 'wrapped in oily paper.' It was said to contain mercury-198, and after 'successive heatings, pumpings and sealings of condensed vapour' yielded enough for one lamp. By this autumn, as much as 2 grams is expected to be available, and it should not be long before the other principal national laboratories receive supplies. Any formal change in the definition of the metre will depend on the General Conference on Weights and Measures, acting on the advice of an international technical committee. This achieved, it is expected that the British and American yards – which at present differ in length by about three parts in a million – will both be redefined in such a way as to remove this difference and bring the new British-American yard into a more easy relationship to the metre. The suggested connection between the two systems is that one inch should be made exactly equal to 2.54 centimetres. It happens, conveniently, that this relationship could be achieved by splitting the difference, roughly, between the existing British and American standards, so that no pride need be lost on either side. This would be of very real benefit in practical convenience – but it is obvious that nothing can usefully be done until the question of the international metre has already been settled.

Meggers. *J. of Optical Soc. of America*, 1948, 38, 7.

Malaria Discovery

The story of the life-cycle of the malaria parasite, which Sir Ronald Ross began to unravel in India in 1897, has lately been completed by Dr H. E. Shortt and others at the London School of Hygiene and Tropical Medicine. They have shown what happens to the parasites, in a human patient, between the time when they are introduced into the system by the bite of a mosquito, and the time, about ten days later, when they make their way as small worm-like organisms into the red blood cells. It is during this incubation

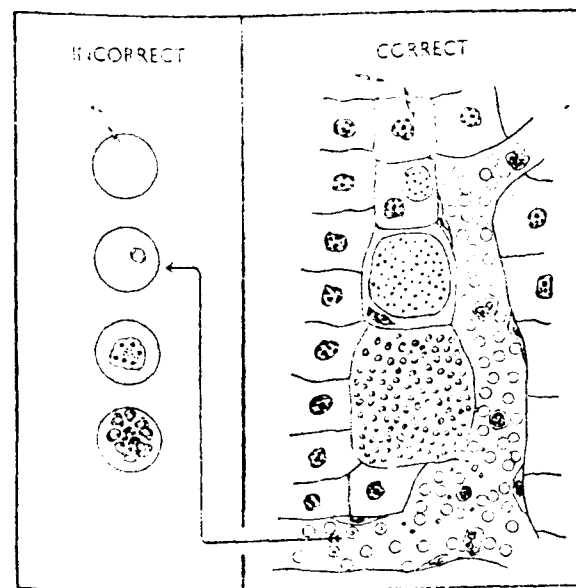


Fig. 9.—On the left is the incorrect representation of what happens to the sporozoite of malaria after its introduction into the blood by mosquito bite: the parasite was thought to enter the blood cells straight way. This theory was accepted for over 40 years; now Professor Shortt and Dr Garnham at the London School of Hygiene and Tropical Medicine have shown that, instead of entering the red blood cell, it goes first to the liver, as on the right, where it undergoes an elaborate cycle before returning to the blood.

tion period, naturally, they could be most usefully attacked, and it has been suggested that the recently introduced drug, paludrine, can do so. In the case of bird malaria, which is caused by a related but not identical parasite, it has been known for some time that the parasite remains during this period in the tissues of the infected bird, and it was accordingly suspected that there must be a corresponding phase in the development of human malaria. This belief was strengthened during the war when Dr N. H. Fairley discovered at Cairns, Australia, that within the first half-hour after being bitten by a malaria-infected mosquito, the blood of the bitten human being could transmit the disease to a second human being by direct inoculation, but that after any longer period this was impossible: in other words the parasites must have 'gone to earth' somewhere in the body. What has now been discovered is that, during the interval before active infection, the parasites are in the liver. The first demonstration of this was on a rhesus monkey. Later, human confirmation was obtained through a hospital patient to whom it was desired to give an artificial infection of malaria as a normal part of medical treatment.* And still more lately, indications have been obtained that the parasites are also in the liver during the quiescent period between an initial attack of malaria and a relapse. The practical result will be to give added confidence in tests carried out with avian malaria on the effects of drugs during the tissue phase of the disease. See Plate 29.

Shortt & Garnham. *Nature*, 1948, 161, 126.

Shortt, Garnham and Malamos. *British Medical Journal*, 1948, 1, 192.

Shortt, Garnham, Covell and Shute. *Ibid.*, 547.

D.D.T. and Malaria

Remarkable results in the control of malaria by comparatively simple and economical means have been obtained by the Research Department of the Colonial Office in

* For general paralysis of the insane - a late effect of syphilis.

British Guiana. Efforts have been concentrated in the low-lying coastal area where there are numerous drainage and other canals to encourage breeding, and as many as 1,400 mosquitoes have been caught in a single early morning 'round up' in one bedroom. Two sugar estates, both with a high incidence of malaria, were selected for experiment, and preliminary surveys were made to establish both the numbers of mosquitoes which were normally to be found in huts, and the proportion of malaria infection. This done, D.D.T. was applied in a simple kerosene solution to the insides of huts only. On one of these estates, where all huts were given a single such spraying, no clinical cases of malaria were seen for 21 weeks, and five months after spraying the malaria parasite rate was still no more than half its original level. Later, after the research party had moved to East Africa, a control system based on the same simple method was extended to cover between one-third and one-half of the population of British Guiana. In one centre, in which 60 per cent of school children were before infected, the proportion was reduced to 18 per cent; the birth rate had doubled and infant mortality had fallen to less than one-third of its original level. It cannot be assumed, unfortunately, that these figures will be universally reproducible, without local modifications in method. One difficulty is that the walls of mud huts have been found to absorb D.D.T. with inconvenient readiness. A partial answer to this is that powders of certain particle shapes and sizes are less readily absorbed, when applied as a suspension in water, than is D.D.T. from a solution or in an emulsion. Another difficulty, which was found during the first experiments in British Guiana, was that there was one particular species of mosquito to which the treatment described made little difference. It was not a carrier of either malaria or yellow fever, the two most important mosquito-carried diseases, but it does carry another tropical disease, filariasis. For such reasons, it is impossible to generalise from success in a particular area, dealing with particular

by precipitation with alcohol for example. Thus the bulkiness of the dose was reduced and the treatment became somewhat less unpleasant. A little later it was found possible to administer liver extracts by injection into a muscle or vein. An unexpected thing then came to light: the dose could be reduced to about one-fiftieth of that needed by mouth. It appears that the active principle is either destroyed by, or is not well absorbed from, the digestive tract.

This is rather surprising, because normal people apparently do succeed in taking in enough of the factor in this manner. They do not have to eat liver in order to get it: the healthy body has another mechanism. The stomach secretes hydrochloric acid and the enzyme pepsin, which act together to digest the proteins in food. Another enzyme is also secreted by the healthy stomach: it is called the intrinsic factor or the Castle factor, after its discoverer. It acts upon another substance called the extrinsic factor (a sort of vitamin) which is widely distributed in foodstuffs, to produce the factor present in liver (or a precursor of this substance). The product is then stored ready for use in the human (or animal) liver, and duly performs its function of looking after the supply of red blood cells. Now in pernicious anaemia the secretory glands lining part of the stomach cease to function properly; they may no longer pour out any hydrochloric acid in response to a meal, and they do not produce the intrinsic factor of Castle. The patient may still be eating plenty of the extrinsic factor, but it does him no good because there is no intrinsic factor for it to react with. We do not know how to get these stomach glands back into working order; in other words, there is no complete cure. However, we can borrow, as it were, the secretory mechanism of a healthy animal. It should be possible to do this in either of two ways and in fact they both work. Thus we can give the patient intrinsic factor from the stomach lining (of the pig for example) along with foods containing the extrinsic factor; alternatively, as we have seen, we can give liver extracts by mouth

or by injection. But, in every case, this substitution therapy must be kept going continuously, or at frequent intervals.

In these days it is not uncommon for a vitamin or other active principle to be isolated, characterised and synthesised within a few years of discovery. Yet this anti-pernicious anaemia factor has only just been isolated after 22 years of effort. There have been two reasons for this delay. One is the difficulty of separating this factor from accompanying substances of similar chemical behaviour; but the greater is that of securing sufficient tests to follow the progress of a fractionation. The chemist may observe, for example, that the constituents of a liver extract are progressively thrown out of solution (salted-out) by additions of ammonium sulphate. He may decide to try $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and full saturation with this salt, and a day's work will give him the four fractions. He must then seek clinicians who are willing to test these preparations on human cases of pernicious anaemia in relapse to see which of them is active in treatment, for until very recently there was no other method of assay. Because each test requires 3 weeks, it may well be months before he has the answer. Eventually he may learn that no very useful purification has occurred, for there is some activity in every fraction. If he is not already too discouraged, he must think up a new idea.

Highly active preparations were made by Laland and Klem in Norway, and by my colleagues Emery and Parker, while recently Parker and I have effected further purification. We have been greatly helped by the discovery that, after getting rid of most of the coloured impurities, we were left with pink material and this colour went hand in hand with the clinical activity. After 10 red fractions from separate experiments had all proved active, we became convinced that the anti-pernicious anaemia factor is itself a red substance. The best fraction tested, up to April 1948, was fully effective in a single dose of 0.3 mgm., but I have since made one 13 times as strongly coloured, which should be active at about 1.5 micrograms daily (about 1/20,000,000

The Americans give no information about their methods of purification, or the properties of their substance, so we cannot yet tell if it is the same as ours. The key techniques in the British work were adsorption chromatography of aqueous solutions on columns of charcoal or silica, and partition chromatography of butyl or propyl alcoholic solutions on columns of damp silica or starch. These recently-developed methods* permit the analysis, often as a series of coloured zones on the column, of mixtures impossible to fractionate by other means.

Since about 100 tons of liver are needed to make 1 gm. of the pure factor, not much progress has yet been made with deducing its chemical constitution. We have, however, been able to determine the molecular weight, and find it to be about 1,600, this is about 4 times as large as the penicillin molecule, for example. Penicillin proved extremely difficult to synthesise and, although mere size is not the only factor, we may safely prophesy that the anti-pernicious-anæmia principle will provide the organic chemists with a really tough problem.

Another point of interest is that the British anti-pernicious anæmia preparation is giving very promising results in alleviating the spinal cord degeneration that often accom-

* See *Science News* 4, page 66 and Plates 5 and 6.

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panies pernicious anæmia. This indicates that a single factor is concerned with these symptoms as well as with the blood regeneration; this is in contrast with the action of folic acid. This latter substance, now made synthetically, seems to act as a partial substitute for anti-pernicious anæmia factor; in doses 1,000 or more times larger, folic acid causes blood regeneration, but gives no benefit to the spinal cord condition.

It is necessary to conclude with a word of warning that these advances offer no immediate prospects of relief to sufferers. The pure anti-pernicious anæmia factor, even if it can be made commercially, will be very expensive; moreover we have no evidence as yet that it will do anything that cannot be done now with adequate doses of ordinary liver extracts. The pure substance could be given safely in very large doses, but it remains to be seen if they will prove valuable. Other indirect practical advantages may accrue, but the main value will be the opportunity for still more research, leading eventually perhaps to a cheaper synthetic product, and to a better understanding of its mode of action in the body.

Chemical analysis of the crystalline anti-pernicious anæmia factor has now revealed the presence of an atom of cobalt in the molecule; also probably three atoms of phosphorus. This unexpected discovery has created great interest in scientific circles. Although cobalt has long been recognised as an 'essential trace element', it was not known how it worked. Minute quantities are needed for the nutrition of some bacteria and animals. On pastures low in cobalt, sheep get 'pining disease' or 'coast sickness', a symptom of which is anæmia; this is promptly cured by treating the animals (or the soil) with tiny amounts of cobalt salts. Now at least we understand one extremely important function of cobalt; it is to produce this factor which looks after the supply of red blood cells. Incidentally its vivid red colour is easily explained, for this is a characteristic of complex organic compounds of cobalt.

The Deep Picture Process

COLIN BUTEMENT

ALTHOUGH stereoscopic photography is over one hundred years old, it was not until quite recently that a really practical method of producing stereoscopic prints, which could be viewed by reflected light without the aid of some sort of viewing device on the eyes of the observer, was perfected.

The older methods generally relied on the photographing of two views, by means of a special camera fitted with two lenses set at about $2\frac{1}{2}$ " apart, representing the distance normally separating the eyes. These two lenses, therefore, recorded the subject from the same position as the eyes of an observer, and prints made from them were viewed by means

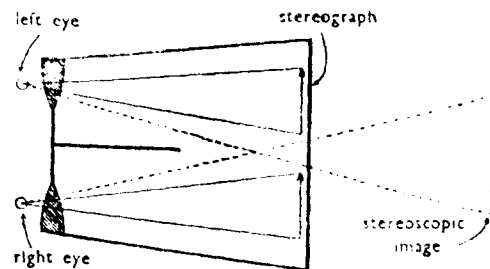


Fig. 10.—Diagram of the layout in an ordinary stereoscope.

of a stereoscope, so that each eye saw only one of the two pictures, which were merged in the brain to give the sensation of a single picture in relief. Examples of these viewing instruments are the Mirror stereoscope designed by Wheatstone in 1838 (see fig. 11), and the prism stereoscope produced some six years later by Sir David Brewster.

It was not until about 1940, over one hundred years after

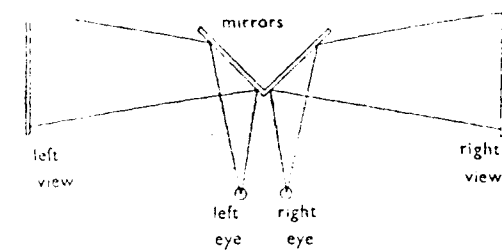


Fig. 11.—Wheatstone's Mirror stereoscope.

Wheatstone had produced his instrument, that a really practical commercial method was introduced by a French physicist, Maurice Bonnet. M. Bonnet, after several years of research, realised that the only practical method of producing a stereoscopic print, which could be viewed by any number of people at the same time and without the aid of any viewing instruments on the eyes, was by means of an optical lenticular grid, which would record numerous stereoscopic images in the camera itself, and which could also later be used for viewing the resultant prints.

This grid consisted of minute cylindrical lenses, very accurately embossed in plastic upon a glass support, so that each minute element had a rigorously defined width, focal

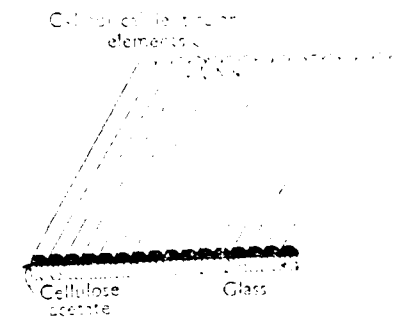


Fig. 12.—The plastic grid.

length and angle of view. In order to obtain these grids he engraved thin copper sheets, and embossed the plastic from these under heat and pressure to form a grid such as that shown in fig. 12. The latest type of grid now being produced is made entirely of plastic and has 65 lenticular elements to the inch.

Let us examine the properties of one of these grids in greater detail. If the grid is put into a normal camera with its plane surface in contact with the sensitive emulsion, and a photograph is taken through it, a gridded negative is obtained consisting of a series of very narrow black bands constituting the entire image, separated from one another by much wider clear bands of unexposed emulsion. This is due to the fact that every portion of the image is brought to a sharp focus under each grid element. If this negative is now placed in contact with the grid again and viewed from a

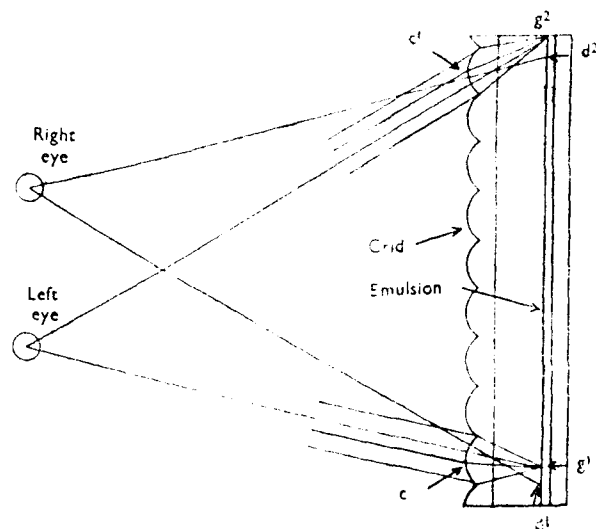


Fig. 13.—How the right and left eyes see different pictures through the grid. The left is focussed on points g^1 and g^2 , the right on d^1 and d^2

position corresponding to the position of the subject during exposure, a complete homogeneous negative image will be obtained, which will appear exactly like a normal negative, but if the observer moves a few degrees to either side of this viewing position, the image will become invisible, owing to the critical angle of view of the lenticular elements of the grid.

It is thus possible, by altering the angle of the grid and sensitive material in the camera, to record up to twenty entirely different subjects, upon one negative plate.

These twenty images may now be seen, one at a time, by viewing the combined negative and grid from various angles.

If the camera is made to rotate around the subject during the exposure, as shown in fig. 14, then about twenty slightly different views of the same subject will be obtained, and a print from the negative when combined with a grid and viewed through it will present to the observer all the various viewpoints of the subject photographed. See fig. 15.

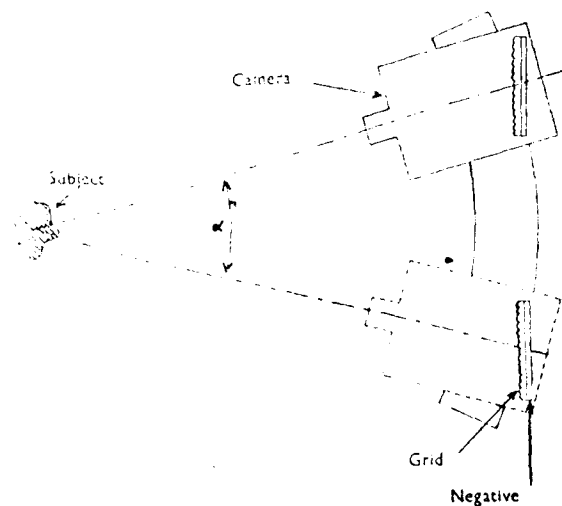


Fig. 14.—The camera rotates around the subject.

However, from any given viewpoint the two eyes will see only one pair of images – the one representing the left hand view, which will only be seen by the left eye, and the one representing the right hand view, which will only be seen by the right eye. Thus each eye sees a separate and different image of the subject and a stereoscopic picture results. Cf. figs. 13 and 15.

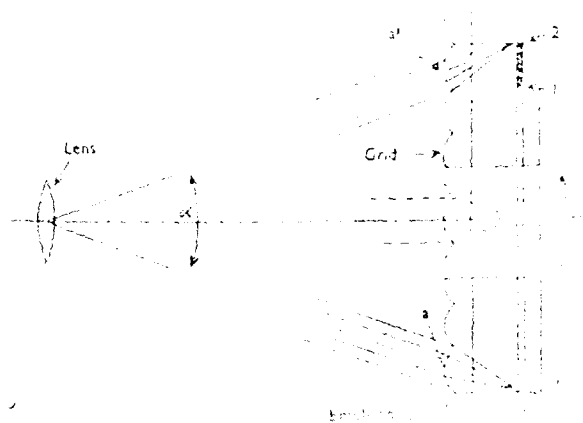


Fig. 15.—How the rotation of the camera shifts the picture on the film beneath the grid, for example from 1 to 2.

As the observer moves around the picture, he sees any of the remaining pairs of images which have been recorded at different angles, and thus obtains stereoscopic relief from whatever position he views the print.

Normally, studio pictures are taken by means of the rotating camera, which is electrically driven, and describes an arc around the subject in a period of about two seconds. As some twenty images are recorded behind each grid element during this time, each image is exposed for $\frac{1}{200}$ th of the time, or in this case for $\frac{1}{400}$ th of a second. The subject is therefore not obliged to remain completely motionless for

two seconds, as if movement occurs a photograph in relief, but with slight animation, will be obtained.

Another type of camera is now being developed in this country, in which a series of small individual negatives are obtained at one instantaneous exposure, and this type of apparatus is quite small and compact and can be used either in the studio or out of doors, enabling rapid action pictures to be obtained. The small negatives thus obtained are then combined during enlarging to produce a 'gridded' print which can be viewed in the normal way.

Among the many other applications of this new process which may be mentioned are stereoscopic X-ray prints, medical photographs, air photography, and the reproduction in relief of very small objects, which can be enlarged up to 50 diameters.

The process also lends itself to the application of colour photography so that three-dimensional photographs in full natural colour will be available as soon as supplies of colour materials are readily obtainable in this country.

Exploring Jan Mayen

Introduction

THE Oxford University Exploration Club was formed in 1927 and since that time, broken only during the war years, it has sent out a series of expeditions of scientific exploration to various parts of the world. Especially notable among these have been lengthy explorations in Borneo, Ellesmere Land and in the New Hebrides archipelago of the Western Pacific; but there have been many others extending through all the latitudes between North-west Spitsbergen and South America. Before the actual formation of the club as such, the University and one of its Colleges (Merton) had given their name and support to expeditions which visited various parts of the High Arctic.

Oxford has a tradition of exploration, and so it was very natural that, immediately the war was over, efforts should be made to revive the club. It was clearly desirable, in order that they should gain experience as leaders of future

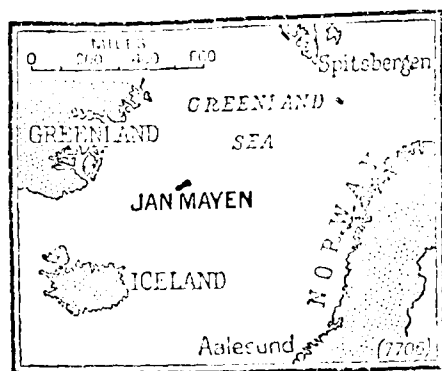


Fig. 16.

expeditions, to get as many men into the field as possible, but there were many difficulties. Equipment, slowly accumulated over many years, had been given to home defence organisations during the war. Travel was still restricted by high costs, lack of transport and official obstructions, so that more distant and ambitious expeditions were ruled out. Of the few possible places the sub-Arctic was among the more attractive, and so an expedition to the little-known island of Jan Mayen was planned.

The island, which lies 71° N. lat., 9° W. long., about 300 miles north of Iceland, is about 35 miles long and consists of little more than a series of extinct volcanic craters dominated at the northern end by the ice-filled Beerenberg Crater, nearly 8,000 ft. high. From the sea the island seems barren and lifeless, but it offers many interesting problems to geologists and biologists. Further, there was scope for geographical work in that the southern parts of the island are still inadequately mapped (Plates 17, 18).

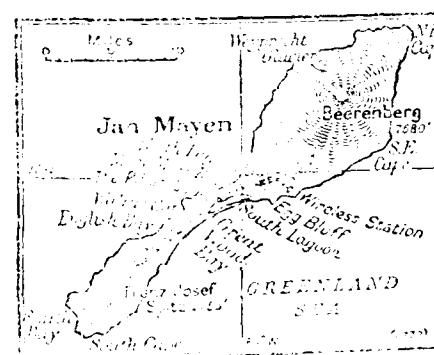


Fig. 17.

All the members of the 1947 expedition except the doctor and a small film unit sent by Gaumont-British Instructional Ltd., were scientists, each hoping to solve a particular set of problems especially related to Arctic conditions. These problems included the distribution and

ecology of soil animals, the study of lake and marine animals, bird ecology, the curious problem of 'non-breeding' in Arctic birds, and the living conditions of the plants.

The party was led by A. J. Marshall, past member of many of the club's expeditions and researcher on bird physiology, and included I. H. Hume, doctor and taxidermist; F. Huxley, ornithologist; A. N. Mitchison, marine zoologist; J. W. Wilson, botanist; A. Macfadyen, entomologist; J. Dollar, R. C. Bostrom and D. Boyd, geologists. The film unit was directed by Guy Blanchard and included K. Rodwell and R. Pike as cameramen.

In the past, two expeditions had overwintered on Jan Mayen, and some of us were assisted by their accounts and those of others. The two overwintering parties were those of the Austrian Polar Year Expeditions of 1882-3 and 1932-3. Other accounts most helpful to us were those of the members of the Cambridge Expedition, 1921, and that of the Imperial College of Science of 1938. Although the island has been visited by several other scientists, few have stayed for more than a few days en route to, or coming from expeditions to Greenland. Jan Mayen was famous as a whaling station in the 18th century and remains of ancient blubber-boiling establishments can still be seen at odd places. During the war the Norwegians maintained a small garrison on the island and left several serviceable huts behind them which we were able to occupy. This circumstance helped us immeasurably and enabled our botanist, in particular, to carry out chemical work which could not have been tackled under normal Arctic Expedition conditions.

The party landed from the Norwegian sealer *Polarbjorn* at 2.30 a.m. on Saturday, July 19, 1947, and re-embarked at 8.30 a.m. on August 24. During the intervening period we experienced ten dry days, confined to the first part of our stay, which constituted the finest summer on record for the island. The weather was extremely variable; mist, rain and winds up to force 8 alternating with milder periods.

The temperature remained throughout between 3° C. and 10° C. at sea level with a very few exceptions, and there was no 'night' time at all, except during the last few days.

As a source of meteorological information and as most hospitable and generous fellow-inhabitants the men of the Norwegian weather station, the only one in the Arctic to make daily radiosonde observations, deserve our most grateful thanks. The many and generous contributions from commercial firms and public institutions who contributed to the financial success of the expedition are acknowledged in the Club's Bulletin.

In the paragraphs below, some members of the expedition describe their fields of research and the relationship of their results to wider fields of study to which they contribute.

Non-breeding among Arctic Birds

A. J. MARSHALL

EACH spring countless numbers of migratory birds assemble in traditional breeding places throughout the Arctic. Some of them, probably, have come from as far afield as Tasmania, South America, and South Africa, for in these far-off countries small drab-coloured wading birds, which breed only in the Arctic, are found in great numbers during the southern summer. As the northern spring approaches, the gonads (reproductive organs) of both males and females begin to enlarge, and soon the birds take off for their northern breeding grounds.

The same phenomenon takes place among the millions of sea-birds which haunt the open seas. They too, obey some as yet unknown impulse and move in enormous mobs towards their breeding cliffs or islands. These are 'dispersive' rather than true migratory birds, but they all have one striking feature in common - a concerted move-

ment towards a traditional breeding site at a certain time of the year.

Travellers in Arctic countries for forty years past have reported however that many of these birds (the proportions varying with year and locality) do not breed after they make landfall. Thus, 1938 in North-east Greenland was reported as a 'complete non-breeding year' for all birds except passerines (perching birds) yet the account emphasised that the summer came early and that the weather was fine and that moreover there were plenty of birds around the customary breeding places. Since 1910, when the phenomenon appears first to have been recorded, a great number of theories have been put forward to explain it. One thing appears to be certain – that in many places the breeding of hunting-birds such as skuas, snowy-owls and falcons is inhibited by failure of the supplies of lemmings on which they mainly feed. The lemming cycle is possibly controlled by a climatic cycle which is synchronous throughout the Arctic. About every four years snowfall decreases sharply and lessens the lemmings' chances of successful hibernation. When the lemmings fail there is widespread non-breeding among the birds which eat them.

But few birds eat lemmings, and periodic non-breeding is very widespread. In the past, various people have suggested that late-melting ice and snow may delay the availability of nesting sites or cause failure of food supplies and perhaps inhibit breeding. It has been suggested that late blizzards might prevent courtship flights, or even delay the birds' arrival at their breeding grounds until after their gonads had regressed to a stage where breeding that year was no longer possible.

However, people never examined the gonads of the birds about which they speculated, and so the collection of the reproductive organs of a series of proven breeders and non-breeders was one of the expedition's principal jobs on Jan Mayen. This oceanic island was especially suitable for such a study because many factors such as lemmings,

extremes of temperature, sea and bay ice, late snow-cover and others considered to be responsible for non-breeding are absent. Yet non-breeding was known to occur there.

As the expedition ship approached the island, and after we had been ashore a few days it became obvious that almost every species exhibited partial or complete non-breeding. An ocean transect made by Francis Huxley, the expedition ornithologist, between Aalesund (Norway) and Jan Mayen revealed constant numbers of fulmars and kittiwakes which could not possibly nest that season on either coast.

Ashore, the open nature of the Arctic landscape made it relatively easy to prove whether a species was nesting or not, especially if it was colonial, as most Jan Mayen visitors are. Our non-breeders could be divided roughly into three categories:

1. 'Stragglers' which turn up year after year (recorded by each expedition that has called in) but never breed. These include whooper swans, Greenland falcon, Iceland redwing, king eider, oyster catcher, odd divers and others. These may pair, but do not breed because the inhospitable Jan Mayen environment offers none of the external stimuli necessary to reinforce the internal physiological state of the paired bird. The Iceland redwing not only fails to breed but often fails to survive – we, and others, have found them lying perished in the barren laval gullies. Another bird which fails to survive is the common snipe. Of highly specialised feeding habits, this marsh-loving species could not survive on Jan Mayen; we found them dead around our hutments.

2. Migratory wading birds such as ringed plover, knots, turnstones, etc., which pause in large numbers en route for their summer breeding grounds on North-east Greenland. Some of these do not continue their journey, and remain on the beaches and upland tarns of Jan Mayen until the return flight of the breeders in the early autumn. Although they may pair, and assume the characteristic bright nuptial

plumage of the breeding bird, they do not breed on Jan Mayen. Here we have another group of birds whose innate breeding requirements are not satisfied by the island environment.

3. In this group fall the true 'periodic non-breeders' – the birds which find the environment of Jan Mayen to their liking, return to it in great numbers year after year, and yet often still fail to breed. These include the kittiwake, the glaucous gull, the fulmar, the Arctic tern, the Arctic skua and possibly others.

As soon as possible after death, the gonads of collected birds were dissected out and preserved in fixatives designed to show different phases of the interstitial tissue. The testes in particular were important. The testis consists principally of two components – the tubules, in which spermatogenesis occurs; and the interstitium in which (most people now believe) the male sex hormone is elaborated. It is worth noting parenthetically that most of the pioneer work on the hormonal function of the testis was done on birds.

The most important result which has so far emerged from our laboratory studies is that all birds, whether they bred or not, passed through the same gonad cycle. The male interstitium in breeders and non-breeders alike went from a lipoid (fat-containing) phase into a secretory one, when spermatogenesis took place even among lone 'stranded' waders which had no possible chance to reproduce. About the time the eggs of the breeding birds hatched, spermatogenesis was inhibited abruptly and the interstitial tissue became lipoidal once more.

Experimental egg-destruction did not result in a second clutch being laid, and there was no attempt by non-breeders to use sites vacated by breeders after successful reproduction. In short, each species (though they may breed at different times each year) arrives, pairs, prospect a nesting site, breeds and rears its young and departs – but in the Arctic there is apparently no repetition of any part of the cycle if a serious check occurs. The flocks of non-breeders which

we found dotting the lagoons of Jan Mayen were all there for a reason connected with the failure of some part of their reproductive cycle as affected by the external environment – the 'exteroceptive stimuli' of Dr F. H. A. Marshall of Cambridge (Croonian Lecture, 1936). Looked at teleologically, the irrevocable cessation of spermatogenesis described above could serve a useful purpose: no parents would be caught tending a second family of helpless young when the winter blizzards sweep down the Arctic basin.

The work of correlating the field observations with the cytology of the gonads of each species is now proceeding at Oxford.

Limits of Endurance: Plant life at Jan Mayen

J. WARREN WILSON

The few that succeed

PLANT life can tolerate a wide range of conditions, as is shown by the scarcity of barren areas on the earth's surface. At Jan Mayen, plants are at the limit of their tolerance; a state hardly unexpected on a volcanic island in the middle of the Greenland Sea, some 350 miles within the Arctic Circle.

The full impact of arctic conditions on the island results in complete absence of plant life. Such a state is found on the bed of the South Lagoon, which is an area marked as a great lake on maps, but actually found dry last year. The bed would in this country offer a fertile field for rapid plant colonisation; in fact it was a desert with not one green plant as far as the eye could see – only a few bizarre rings of fungi. The bacteria might here number some 100,000,000/grm. of soil; counts suggested that only some 3,000 occurred. Causes of this infertility are strikingly obvious.

The wind is such that during storms the surface of the bed is whipped into black and white whirls of sand and water from temporary pools. Glass is frosted in a few days and stones become abraded smooth, while soil is stripped from the underlying lava flows. Where soil, formed by the break-up of lava, does collect it is a coarse black sand, so porous that rain runs straight through, carrying with it the substances needed for plant growth.

In all parts where such conditions prevail, as in the mountains in the south of the island, plant life is lacking and the country looks like barren and desolate cinder heaps. Where there is alleviation of the conditions, however, plants establish themselves on a more or less meagre scale.

Given shelter, lichens and mosses grow on lava which is little broken down, and flowering plants contrive to live where a soil has been formed. Some of the genera are not unknown in England – *Salix*, *Ranunculus*, *Cerastium*, *Arabis** – but the species are high arctic, and the plants are strangely small; few are more than three inches tall, and most are less than an inch. Moreover, the vegetation is open; that is, bare soil shows between the plants. Also, all the N.E. region – the extinct volcano Beerenberg, its crater filled with ice which cascades 8000 ft. down to the sea in huge glaciers (Plates 19 and 20) is snow-covered; though at 5,000 ft. (the snow line lies at 2,000 ft.) mosses and bright yellow lichens enliven a lava outcrop.

All except one of the species on the island are perennials; this is because snow blankets the island for over six months, and the short summer does not permit the full cycle from germination to flowering to occur. Midsummer mean temperature is below 6° C. and 25 days in the month average nine-tenths cloud or more.

In hollows, snow lies deep and persists late into the summer. If it persists long, the season becomes too short for any plants to grow. A certain degree of snow lie is however beneficial, in blanketing plants from the winds

* Willow, Anemone, Chickweed and Rockcress.

and severe frosts of late spring. In such late snow areas the vegetation is richer than in nearby parts, carpeting the ground and reaching a height of six inches or so.

These late snow areas are generally small; however at four places seen during exploration of the island, the generally drab vegetation broke into a lush carpet of bright refreshing green, covering an acre or more of ground; an amazing sight in the high arctic, contrasting against a backcloth of glaciated desolation. Such places, more fertile than an English meadow, were met at Cape Traill, amid the persistent mists of the southern end of the island; at Seven Hollander Bay, where a wooden cross marks the deaths of seven whalers; at the Pillar, bleak 200 ft. column north of the South Lagoon; and, most striking of all, covering several acres in the sheltered Fishburn Valley in the south-east. The same vegetation is reported from West Cross Bay in the north. These are places where the usual lava gives way to another geological formation, agglomerate, and it appears that the ease with which the latter rock weathers to a soil results in the vegetational difference. There are 16 species which are confined to some or all of the agglomerate areas; none is restricted to lava.

The island's flora is poor, there being known some 62 species of higher plants. All are of Norwegian affinity, and many have doubtless been carried by man, e.g., the recent introduction of *Matricaria inodora*, which is gaining a hold near the North Lagoon. This plant is common on the quay at Aalesund, whence leave ships bound for Jan Mayen. The Cup Fungus (*Peziza*) grows on sandbags protecting wartime gun emplacements.

Under the snow blanket

On an expedition lasting five weeks, one cannot follow the annual course of plant development. It is possible, however, to cheat time to a certain extent. In late snow areas (Plate 21) plants spring up in the wake of the retreating snow, so that near the snow line the plants are just putting

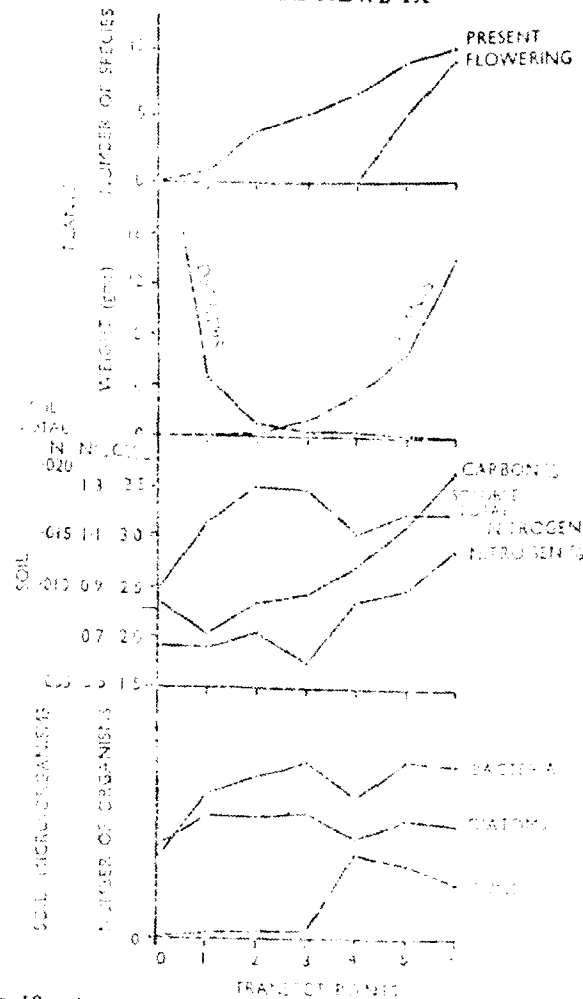


Fig. 18.—A composite series of graphs showing how plants increase as the snow clears. From left to right, longer after the snow has melted, as explained in the text. *Top graph:* Total number of species present, and number flowering; *next:* the vegetable remains in the soil vanish as the plants grow; *second from bottom:* changes in the nitrogen and carbon content of the soil, signs of living activity; *bottom:* changes in the numbers of soil micro-organisms.

out leaves, and at a distance of several metres they are full grown and flowering. The whole range of development is found at one time.

In one such late snow area, seven points along a transect running across the snow line were examined. Point 0 (Fig. 18) is beneath the snow and point 1 just free of snow. The interval between successive transect points is 3 metres, and the snow retreats about 1 metre in three days; so the plants are flowering just over a month after being freed from snow. This is surprisingly rapid, considering that they overwinter completely underground. The photographs (Plates 22-25) give some idea of the change in appearance, and increase in weight of plant matter is shown in the first graph. 'Detritus' is matter which is blown on to the snow surface, and becomes incorporated in the soil after snow melt; consisting largely of plant material, it greatly enriches the area.

The second graph from the bottom shows that the outer part of the patch where the plants enjoy a relatively long summer, is enriched, owing to the greater amount of plant matter returned to the soil each autumn.

The bottom graph shows changes in soil organism numbers following snow retreat. Fungi are almost inactive for over a fortnight after the snow has gone, and then suddenly increase. Bacteria and diatoms, on the other hand, are active under the snow, and increase relatively little in numbers following snow melt. At the time of rapid increase of fungi, however, they suffer a temporary setback, perhaps by competition for nutrients. The different behaviour of bacteria and fungi may be a result of different temperature demands. The bacteria commence activity below 0° C., whereas most of the fungi are active only above zero. The optimum temperature for growth of bacteria from Jan Mayen soil is about 19° C., but that of the fungi is near 25° C. The bacteria are therefore active beneath the snow, and after its retreat soon increase to saturation point; but the fungi cannot grow much until the snow has been melted some time and the soil is warming up.

It is said that the conversion of nitrogenous matter in the soil to a soluble form which is available to plants is a result of the activity of bacteria and fungi. However, in Fig. 18, the curve of $\frac{\text{soluble}}{\text{total}}$ nitrogen corresponds closely to that of bacterial numbers, and the fungal activity has no apparent relation.

On this particular late snow area, the snow lasts so far into summer that no plants can develop near the centre of the patch. Thus the nitrogen and carbon present there must have arrived in the form of detritus deposited by wind on the snow. The optimum snow-free period is probably attained near the edge of this patch.

Plants that lose weight

One annual grows at Jan Mayen - *Koenigia islandica*. This odd little plant occurs further north than any other annual; it grows about half an inch high, forming some ten tiny leaves, and then flowers. It is found in hundreds on alluvial beds which are stream-swept in winter, dry in summer. By its occurrence in large pure stands of plants of similar age, it is an ideal plant for measuring growth rate under natural conditions.

Growth of *Koenigia* (before flowering stage) over two fortnightly periods was measured in three different habitats, which had soils of the following compositions:

	Moisture % Fresh weight	Total nitrogen % Dry weight	Loss on ignition % Dry weight
Desert	1.03	0.010	0.90
Scree	21.43	0.006	0.51
Marsh	47.45	0.130	2.91

Of these three habitats only one, the marsh, has an adequate soil. The others are poor in nutrients, and the desert is dry into the bargain.

The growth rate of plants is often expressed as the Net Assimilation Rate: i.e., increase in dry weight, sq. dm. of leaf area/ week. It has been held that this figure gives a

measure of the efficiency of metabolism of the plant, and that it is roughly the same for all plants and all environments - even the Arctic. The value falls as a rule near 0.5.

Below are the Net Assimilation Rates found for *Koenigia* at Jan Mayen:

	First period	Second period
Desert	0.05	-0.20
Scree	0.20	-0.09
Marsh	0.23	0.15

In all cases the figure is less than half the usual Net Assimilation Rate, and in the worst habitat it falls to a negative value. There is clearly faster growth in the better habitats. Also, the Net Assimilation Rate is less in the second period than in the first, probably owing to a considerable deterioration of the climate.

These low Net Assimilation Rates, easily affected by the environment, are a sign that the plants are near their limit of tolerance. Negative values may be due to unusually severe conditions or may be a regular feature; if the latter, the loss in weight must not be so great as to prevent seed formation.

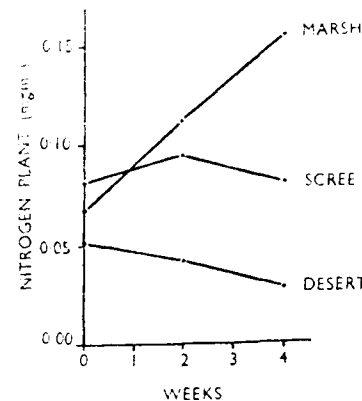


Fig. 19.

Also unexpected were changes in total nitrogen of the plants, on which the environment had an even more marked effect (Fig. 19). This actual loss of nitrogen from the living plant is an unusual phenomenon, and implies some metabolic upset - for the plants showed no signs of loss of leaves. It is probably relevant that in poor habitats plant nitrogen existed to an abnormal extent in soluble form; i.e., nitrogen which had been absorbed and apparently could not be utilized by the plant.

Similar nitrogen loss was found in English Rye germinated on the island. During the five-week stay on the island these seedlings grew in island soil to the height of three inches. It was somehow encouraging to see their green leaves waving in the cold Arctic winds.

The living soil

When the activity of soil bacteria and fungi is depressed (as in peat bogs, where the acidity inhibits them) breakdown of dead material is slowed down, and there is consequently a shortage of plant nutrients. It has been suggested that the low activity of these organisms in the Arctic is important in limiting plant growth there.

In this country, soils contain bacteria to the order of 100,000,000/gram of soil. At Jan Mayen, numbers were much lower; in some cases fewer than from any soil yet recorded, e.g.,

Desert	3,300
<i>Koenigia</i> bed	16,000
Poor moss area	31,000
Rich moss area	36,000

(All numbers on the basis of dilution culture counts).

In certain communities the numbers were much higher owing to obvious causes, e.g., in the fertile soil of Seven Hollander Bay (an agglomerate locality) there were 291,000/gram of soil; under the Pillar, where the presence of agglomerate is reinforced by manuring from the birdcliff above, 1,214,000; and in an area of poor moss vegetation

which had been artificially fertilised, and consequently bore a closed grass community, 13,920,000.

Fungi showed a similar general scarcity coupled with stimulation in particular places.

To understand the importance of these micro-organisms in humus decomposition, it is more important to know their physiological activity than their numbers. Activity was measured in three ways; the respiration rate of the soil, the rate at which ammonia could be utilised, and the rate at which nitrate could be produced (by methods outlined by Quastel in *Science News* 5). These three measures gave figures in very close proportion. However, where there was a 10,000-fold increase in numbers of bacteria and fungi, the increase in activity was only tenfold. In other words, the occurrence of low numbers of fungi and bacteria does not necessarily mean that physiological activity is very low. It was shown also that the bacteria at Jan Mayen are temperature-adapted in that they have a lower optimum than equivalent types in this country. The activity of these soil organisms seemed to be correlated mainly with the amount of unincorporated humus (their substrate) in the soil.

Perhaps the island's strangest contrasts were found in the soil diatoms.

Firstly, in some soils, despite the Arctic conditions, they were more frequent than in any soil anywhere in the world where they have been counted - over 140,000 diatoms/gram of soil.

Secondly, there was a close correlation of numbers with nitrogen supply; but it was an inverse correlation.

Thirdly, feeding experiments suggested saprophytism, and the diatoms were growing buried in the soil; but they possessed photosynthetic pigment.

Fourthly, nitrogen manuring increased numbers (as expected) up to 450 per cent in poor soils; but decreased numbers up to 28 per cent in all rich soils.

Geology of Jan Mayen

R. C. BOSTROM

To the geologist, Jan Mayen is of interest for the light it may throw upon the phenomenon of igneous episodes, for connections it may show between rock types in one part of a large petrographic province and those in another (as outlined below) and, in the long run for any information which may be gleaned towards the understanding of such perplexing incidents as 'ice ages.' More immediate issues, - for example the mere history of such an island - are also, of course, of great interest.

This question of the history of the island is perhaps the basic point to be kept in mind during an investigation such as that of the geologists of the 1947 expedition: our hammering and mapping may almost be said to have been done with this as the immediate object. At any rate the specimen collecting, the surveying, the glaciology were done, with the realisation that each fact deduced therefrom was a fragment of the island's story: if once this tale could be fully told the larger points outlined could be tackled later and in the light of mature consideration. The unfolding of such a history, the unravelling of a tangled skein of sea-floor eruptions, explosive outbursts, piled lava flows upon older cones, each new phase partly at least obliterating those previous to it, is much more easily suggested than carried out, but is dependent on comparatively few factors.

Upon considering the matter, one can systematise such a varied pile as Jan Mayen either by discovering the sequence of the rock types - which floor lies underneath which - without knowing the absolute age of any; or by determining in separate operations the dates of appearance of each, and afterwards correlating them. This dating can sometimes be done in two fairly precise ways. Satisfyingly arithmetical and apparently exact is the 'radium clock' method, by

which the results of the inexorably constant radioactive decay of the uranium content of rocks to known lead isotopes gives us an idea of the absolute time which has elapsed since the rock solidified. We were unable to use this effect as, for one thing, the 'clock' measures years only by the million, whereas the age of our island, so young by geological standards, is of the order of tens of thousands as a first approximation.

The second method of dating, the constant stand-by of the geologist, is, of course, the evidence of fossils. Fossils are only abnormally associated with igneous rocks, but this type of evidence has frequently proved critical in igneous districts; for example in Mull where well preserved leaves of ancient species of plane, oak and other plants have long been known, and have comparatively recently, by their Eocene affinities, dated the massive basalt lava-flows in which they and their gravelly matrix have been entombed. It is still possible that this type of fossil will turn up in Jan Mayen, but militating against this chance is the very fact of the island's apparent youthfulness: if the period of its existence has been confined to the recent chill phase of the earth's history, the present struggling flora is hardly likely ever to have been much more numerous. In Mull, warm Eocene climatic conditions probably ensured abundant vegetation which, by the laws of probability, stood a good chance of being represented later by fossils.

Indirect evidence of age, then, must be involved in Jan Mayen's case - a casual utterance which conveys little idea of the number of features which it covers. These features range from the form of a river-valley during its youth and old age to the effects of glaciation upon topography, with endless details. A glacier, provided that it has tenanted its valley for a sufficiently long time, gouges upon its bed a series of unmistakable traces of its existence. Thus we know that comparatively recently many of the U-shaped valleys of Wales must have contained glaciers: striae upon bare rock surfaces, spreads of boulder-clay and a host of

other details all go to confirm this, and it could be deduced therefrom, were it necessary, that these valleys must, *a priori*, have been in existence during the recent 'ice-age.' The geological section of this year's expedition, then, kept a constant eye open for traces of vanished glaciers, which traces would of course indicate by their very presence the existence of the island a certain length of time ago. Immediately striking to the observer, although such superficial indications are notoriously unreliable, was the very sharply defined and impressive cone of Beerenberg, the 8,000-ft. volcano dominating the north-eastern end of the island. This mountain, composed as it is of vulnerable interbedded layers of ashes and lava, must be most susceptible to the attacks of an Arctic climate of heavy precipitation, and it is hard to believe that it could be other than very young indeed.

The interlayering of lavas and ashes is well displayed in the sea-cliffs of the island which provide a ready-made section showing some of the structure: where erosion is unusually rapid and the layering horizontal these crags reach a height of 2,000 ft. and their variations provide interesting insight into the relationship of geological structure to animal life. Without going into petrological detail, much of the rock of the Beerenberg region is of an ultra-basic type known as ankaramite, heavy with ferromagnesian minerals and shining in the hand-specimen with large green crystals. Much time and energy were spent last summer collecting this and other types of rock on Jan Mayen. Our knowledge of these has previously been limited and the new information forthcoming from subsequent laboratory study by Dr Dollar of Glasgow will, without doubt, add considerably to what is known of the distribution of rock-types in the tertiary igneous province of N.W. Europe – the huge area which stretches as far south as Ireland and our Western Isles. Such a petrographical province is characterised by the presence of certain chemical peculiarities running through many of its rocks – their trade-mark as it were, suggesting

that, though occurring in scattered places, they may be referred to some common origin. A feature already known was the relative abundance of potash in the Jan Mayen rocks: we may expect further such points to be discovered and deductions drawn therefrom, as a result of last summer's work.

Precision Measurement of Time

DR W. VAUGHAN

BECAUSE of the supreme importance of the sun's rôle in all human affairs, its apparent motion in the heavens has been used as a basis for time measurement in practically all parts of the world since the most primitive times. So long as man was concerned only with agricultural pursuits, there was little necessity for dividing the day up into smaller units, but as society became more and more complex, the need for measuring smaller intervals of time became increasingly insistent. From about the third century B.C. until medieval times, water clocks, hour candles, and sand glasses of various forms were devised to meet the requirements of the Mediterranean civilisations, but these devices served, in the main, to measure arbitrary intervals only roughly related to the length of the day. The sundial, which was a product of the interest in astronomy and mathematics which characterised the Moorish civilisation, was the first practical attempt to use the earth itself as a clock.

It was not until the beginning of the 17th century that, following the investigations of Galileo, the pendulum was used as a device for accurately dividing the day into hours, minutes and seconds. Largely as a result of the work of the Dutch astronomer Huyghens, the development of the pendulum clock made rapid progress, so that by the beginning of the 18th century, clocks of considerable accuracy were to be found in most European observatories. The growth of maritime enterprise had by this time created a new demand for accurate timekeeping for the purposes of determining longitude at sea, a demand which the best pendulum clock was fundamentally incapable of satisfying.

The time-period of a pendulum is governed by the gravitational force of the earth, but this varies from place to place, with the consequence that a pendulum clock adjusted to give accurate timekeeping in one locality will gain or lose as it is transported to others. By 1714 this navigational requirement had become so important that the Board of Longitude, a body set up by the British Government, offered the princely prize of £20,000 for any method by which a ship's navigator could estimate longitude to within 30 miles at the end of a voyage to the West Indies.

Abandoning the idea of employing a pendulum, and using instead the timekeeping properties of a coiled spring, Harrison in 1761 demonstrated a marine clock which achieved this object with an error substantially less than that stipulated by the Board of Longitude. Almost at the same time, Le Roy produced what is now generally regarded as the prototype of the modern chronometer. During the next century and a half, the design of clocks steadily improved, but although the timekeeping properties of many other devices were investigated, it is only within the past twenty years that the accuracy of the observatory pendulum clock has been surpassed by an entirely new system of time measurement employing a quartz crystal oscillator. The main purposes of this article are to show why accurate subdivision of time into intervals as small as one-millionth part of a second has in recent years become of considerable practical importance, and to describe how efforts to do this have placed at the disposal of the astronomer a clock of better regularity than the rotation of the earth on its axis.

In our early schooldays we are taught that the earth spins on its axis once in twenty-four hours, and that in the same way as our motion when travelling in a train is revealed by the apparent movement of the landscape, so the apparent drift of the heavenly bodies across the sky gives visible evidence of the earth's rotation. So far as we are concerned, the sun is by far the most important of the

heavenly bodies and it therefore appears natural to use its daily reappearance for fixing a unit of time. The instant at which the sun crosses the meridian, that is, a line running in a true north and south direction at the place of observation, is termed Noon. We may therefore define the Solar Day as that interval of time which elapses between successive appearances of the sun at the meridian, or between consecutive noons. It is very important, of course, that a unit should not vary from time to time, but this is precisely what does happen to quite a serious extent in the case of the interval which we have just specified. One reason for this seasonal variation in the Solar Day is to be found in the fact that the earth's path around the sun is not quite a circle, with the result that the earth does not remain at a constant distance from the sun throughout the year. According to the second of Kepler's three Laws of Planetary Motion, the radius joining the sun to any planet will sweep out equal areas in equal intervals of time, so that only if the earth followed a circular orbit would it move at constant speed along its track.

This lack of constancy of the Solar Day was recognised long before the pendulum clock had made its appearance, and even until the middle of the 17th century it was the practice to make daily alterations to mechanical clocks to bring them into agreement with the sundial. We need only imagine the complications which would ensue if we had to make daily adjustments to all our clocks, to appreciate the total unsuitability of the Solar Day as a unit of time. The effects of the irregularities of the earth's speed along its annual orbit around the sun may be averaged out by observing the length of each Solar Day in the year and obtaining their mean value. This gives an interval known as the Mean Solar Day, and this is used as the unit of time for all commercial and domestic purposes.

The common clock shows Greenwich Mean Time, and it will mark midday at the instant at which the sun crosses the meridian on April 16th. Subsequently, a perfect mechani-

cal clock at Greenwich, if compared with a sundial, will appear to lose until by the middle of May it is nearly four minutes slow. The difference between Mean and Sundial Time will then gradually decrease until June 15th when they become the same. Thereafter the mechanical clock will gain on the sundial and will show a maximum difference of rather more than 6 minutes on July 26th, after which it will again show sundial time on September 1st. It will then start to lose again, reaching a maximum difference of nearly $16\frac{1}{2}$ minutes on November 3rd. The clock and sundial will next show the same time on December 25th, but it will then appear to gain and will show a maximum difference of just over 14 minutes on February 12th. If the mechanical clock has, in fact, been a perfect timekeeper it will once more show midday at the sundial noon on April 16th. The corrections which must be added to, or subtracted from sundial time in order to give Mean Time on any particular day of the year are known as the Equation of Time and are to be found in such reference works as *Whitaker's Almanack*.

It is unfortunate that the interval represented by one Mean Solar Day cannot be directly determined, and it would be a serious matter if observatories were able to obtain direct checks for standard clocks on only four occasions during the year. If instead of concentrating our attention on the sun's apparent motion, we observe the passage of any other of the heavenly bodies across the meridian, we have at our disposal an alternative method of determining a standard time interval. Because they are also moving in orbits around the sun, the planets have apparent paths which appear very complicated, so that their reappearances are quite unsuitable for fixing a unit of time. On the other hand, the fixed stars offer unique advantages for observing the rotation of the earth on its axis. The interval between successive reappearances of any star at the meridian is in fact the period taken by the earth to make one complete rotation and is termed the Sidereal Day.

Since the earth does not follow an orbit around the body we are now observing, it is not surprising to find that the Sidereal Day is remarkably constant and that it shows none of the daily variations which characterise the Solar Day. If we measure the interval separating the reappearances of a particular star at the meridian by means of a clock showing Mean Time, we find that the Sidereal Day is about four minutes shorter than the Mean Solar Day. The explanation of this discrepancy lies in the number of rotations on its axis which the earth makes in the course of a year. The direction of the earth's travel along its orbit is such as to delay slightly the appearance of the sun at the meridian. In the course of a year, the sun has reappeared 365 times, but because the earth has completed one circuit of the sun, it will in fact have rotated 366 times on its own axis. During this period, the fixed star which we have been observing will therefore have appeared at the meridian 366 times. The Sidereal Year therefore contains one more day than the Solar Year, and it follows that $366\frac{1}{4}$ Sidereal Days are equivalent to $365\frac{1}{4}$ Mean Solar Days.

A clock showing Sidereal Time may be checked at very frequent intervals by observing the transit across the meridian of celestial bodies which the astronomer terms Clock Stars. Because of the constancy of the Sidereal Day and of the ease with which mechanical clocks showing Sidereal Time may be verified, the Sidereal Day is used as the fundamental standard unit of time.

We have now revealed a rather strange state of affairs. We all possess an abstract idea of the time of day, amounting almost to an instinct, but of course closely related to our consciousness of the sun's position. This demands that our clocks show the time as midday when the sun is near its zenith, and we are therefore compelled to use Mean Solar Time for all normal purposes. Sidereal Time would be quite unacceptable as an alternative to Mean Time because the sidereal clock can coincide with sundial time at only one instant in the year and thereafter it gains continuously

day after day. In practice, the world's observatories provide us with our time signals and it falls to the astronomer to combine the advantages of both time scales. This he does by employing a clock which will divide the Sidereal Day into 86,164 parts – these will then each be equal to 1 second of Mean Time, and a clock so constructed will in fact show Mean Time if its noon coincides with the sundial noon on April 16th. We shall presently see that the quartz crystal oscillator is capable of marking an interval of time even more constant than that provided by the rotation of the earth, and it might be asked if this ought not to replace the Sidereal Day as the unit of time. The difficulties which would arise as a result of using a standard not related to the earth's rotation can now be appreciated, and we are led to the conclusion that the Mean Solar Day must remain the most practicable unit for all normal timekeeping purposes.

Scientific progress in the latter half of the nineteenth century gave rise to demands for the accurate subdivision of the second into a thousand equal parts (milliseconds). A variety of ingenious methods based on the distance covered by a falling body were developed for doing this, but these have all been superseded by electrical methods and are now mainly of interest for the degree of originality which they displayed. If an electrical alternator is governed so that it runs at constant speed, it will produce an alternating voltage of constant frequency, that is, the voltage will reverse its direction exactly the same number of times in each second. If such a supply is connected to a simple electromagnet, between the polepieces of which a pivoted magnetic needle is placed, once the latter is set into motion it will continue to rotate at a constant speed which depends only on the supply frequency.

If instead of using a magnetic needle we employ a toothed wheel we have a device known as a phonic wheel which will run at a definite fraction of the supply frequency depending on the number of teeth. A phonic

wheel driving a train of gears will function as a clock which, in effect, counts the number of alternations of voltage in any specified interval of time. This arrangement is, of course, the familiar type of A.C. mains clock. It is now a simple matter to compare the readings of a counter such as this with a standard pendulum clock or with observatory time signals and so determine the frequency of the alternator. Under normal conditions, the frequency of A.C. systems in this country is maintained at 50 cycles per second, that is, the regulating mechanism controlling the speed of the turbo-alternator used for generation is adjusted to give 50 reversals of voltage per second.

By using a phonic wheel clock and checking its readings against Mean Time, even quite small drifts in frequency are soon recognised. Thus if the frequency is 0.01 per cent too high, the A.C. clock will be 3.6 seconds fast after an hour. Periodic fine adjustments are made to the alternator speed, so that the electric clock is continuously brought back to Mean Time. Although in any one second it is most unlikely that there will be 50 reversals of voltage, great care is taken to ensure that over a period of hours the average number of alternations is exactly 50 per second. We may therefore say that whilst the long-term accuracy of the A.C. clock is of the same high order as the time signals against which it is checked, the short-term accuracy may be very poor indeed. Stated more simply, the electric clock will show correct time to within a few seconds for weeks on end, yet the minutes which it measures may vary by a few seconds either way. It is clearly of the greatest importance that we should distinguish between these types of accuracy when we attempt to assess the merits of any particular timekeeping system for a specific measurement.

The facilities which an A.C. supply provides for driving domestic clocks are only incidental to the electrical engineer's primary concern in synchronising the generating installations in different power stations when these have to supply common networks. As can be well imagined, the

practical problems of maintaining constant the speed of rotation of large alternators under continuously varying loads are very great indeed. Small alternators with refinements for close control of the frequency may be used for giving better short-term accuracy, but substantial improvements can be achieved by employing entirely different methods of generating the alternating voltage. If electrical energy is supplied in an appropriate manner to a circuit consisting of a coil and a condenser, electrical oscillations will occur and will persist so long as we continue to supply energy. The frequency of these alternations depends upon the physical dimensions of the coil and condenser, such as the number of turns and shape of the former, and the size and number of plates which make up the latter. This system is, of course, the familiar tuned circuit used in all radio transmitters and receivers. By choosing suitable sizes for these components, it is quite a simple matter to generate oscillations which have frequencies ranging from a few hundred cycles up to twenty or thirty million cycles per second.

It might be thought, therefore, that providing we take care to ensure that no variations can occur in the dimensions of these two comparatively simple components, we have at our disposal a convenient source of alternating voltage whose constant frequency makes it suitable for time measurement. Unfortunately, although reasonable constancy can be obtained without much complication, the high degree of stability over very long periods, which is so indispensable for accurate timekeeping, cannot be achieved. The effects of temperature changes on the circuit dimensions can be almost eliminated by the choice of suitable materials and by placing the assembly in a thermostatically controlled enclosure, but this is far from solving the problem. The method of supplying the energy from the batteries to the tuned circuit involves the use of a valve, and because this is really a small part of the tuned circuit, it has a limited but by no means negligible effect on the frequency of

oscillation. This effect is, however, very susceptible to changes in the voltages of the batteries which supply the arrangement, and an additional complication is that gradual changes take place in the valve itself with the passage of time.

Thus it soon became evident that long-term stability could not be expected with any type of arrangement in which the valve plays any part in controlling the frequency.

In 1919, Eccles devised an arrangement for maintaining a tuning fork in continuous vibration by means of a valve, and in this system the valve and battery voltage can have very little effect on the frequency which the fork generates. If placed in a thermostatically controlled enclosure, the long-term stability of a valve-maintained fork is enormously greater than that of the tuned-circuit type of oscillator. By 1924, valve-driven tuning forks of a special steel alloy known as Elinvar and vibrating at frequencies in the range 100 to 1,000 cycles per second were in widespread use as devices for controlling the transmission frequency of radio stations. With satisfactory temperature control, the frequency of the fork is constant to at least 100 parts in a million over long periods, so that if the output of such an arrangement is used to drive a phonic wheel type of electric clock, this would gain or lose something of the order of one minute per day. Clearly this type of electronic clock could not compete in accuracy with the ordinary pendulum clock.

As long ago as 1881, the Curie brothers had discovered that certain crystals such as quartz and tourmaline if subjected to pressure showed quite substantial electric charges on their faces. They later observed the inverse effect, namely that if such crystals were subjected to an electric stress, they would undergo slight changes in their shapes just as though they were being compressed. These phenomena, known as piezo-electric effects, were turned to practical account in 1922 by Cady who, taking a thin slab cut from a quartz crystal and placing it between a pair of flat plates, was able to maintain it in continuous oscilla-

tion by supplying it with energy from a battery by means of a valve.

This type of oscillator was soon found to have remarkable properties so far as the constancy of its frequency was concerned. The actual frequency generated depends on the thickness of the crystal and is singularly free from variations due to the valve and to small changes in battery voltage. By 1928, quartz crystal oscillators operating at a frequency of fifty thousand cycles per second and remaining constant to about one part in a million were being produced, and in 1935 one such oscillator, operating in a carefully controlled constant-temperature enclosure, ran at the National Physical Laboratory for a period of eight months with a degree of frequency stability of 2 parts in 100 million. Such a device might be used as the controlling element of a phonic wheel type of clock, and with the constancy quoted, this would gain or lose less than 0.2 seconds in 100 days. The electronic clock was now beginning to come into its own.

Painstaking researches into the properties of quartz crystals and into the design of the associated circuits for maintaining them in oscillation, led to improvements in even this remarkable degree of stability. At the present time, the best performance has been achieved with crystals having frequencies of about 100,000 cycles per second, and these have a short period constancy of one part in a thousand million and a long period constancy of better than two parts in ten million. These crystals are mounted in evacuated glass envelopes and to secure these stabilities they must be operated in enclosures fitted with thermostats to keep the temperature constant to within one-thousandth part of a degree Centigrade. Some heat is, of course, produced within the crystal itself as a result of its vibrations, so that it is necessary to keep the amplitude of oscillation strictly constant. Special circuits have been designed to do this despite slight changes in the supply voltages and gradual ageing of the valve. New crystals have to be

operated for periods of about a year before their frequencies settle down to the order of stability quoted above, but subsequently they will operate indefinitely without observable deterioration. If we assume a day to day constancy of about one part in a thousand million for one of these oscillators, we have an element capable of driving an electronic clock which would show a daily gain or loss of a fraction of a thousandth of a second (1 millisecond). Clocks of this type in use in this country and in the U.S.A. revealed in 1945 a slowing down of the earth's rotation of about $4\frac{1}{2}$ milliseconds per day, a phenomenon which would otherwise have become apparent to the world's observatories only after the passage of a considerable period of time.

The quartz crystals from which the plates for these piezo-electric oscillators are cut are found principally in Brazil, Madagascar and Japan. Natural crystals suitable for this purpose are often as much as six or eight inches in length and are in the form of six-sided prisms terminating in a pyramid. The direction in which the plate is cut in relation to the various facets of the crystal is of particular importance since it influences the susceptibility of the frequency of oscillation to changes in temperature. Blanks from which the final plates are ground are cut from the natural crystal in the required direction by means of a rotating disc of copper charged with carborundum paste or a plastic wheel impregnated with diamond dust.

Before work is allowed to proceed beyond this initial stage, the slab so prepared is examined in polarised light to ensure that the crystal is, in fact, a perfect specimen as regards its structure.

The next operation involves the grinding of the plate to the appropriate thickness, and this is invariably a tedious business involving a high degree of skill in the final stages. The relation between thickness and frequency of oscillation depends on the direction of cut, but as a rough indication it may be stated that a plate of thickness

one millimetre will have a frequency of approximately 2,750,000 cycles per second. Since the frequency of oscillation is inversely proportional to the thickness of the plate, it follows that a 100,000 cycle per second crystal will, in fact, be a bar approximately 2.7 cm. thick. In the earlier stages of the final grinding, micrometers are used for checking the thickness of the plate, but neither these nor optical methods of measurement are suitable for ensuring the required degree of accuracy in the finished product.

The final stages of lapping to the appropriate thickness are carried out by hand, and at frequent intervals the frequency of oscillation of the plate must be checked against a suitable standard. Fortunately, means are available for doing this to a very high degree of accuracy, but for obvious reasons, this alternating process of lapping and checking must necessarily be a slow business. Particular care must be exercised in the design of the mounting of the crystal since this must neither influence its frequency nor restrict its activity.

It is not possible to use the high frequency output of the crystal oscillator for the direct control of a phonic wheel, so that arrangements must be made for subdividing the frequency until a more suitable fraction is reached. A frequency divider is, in effect, a form of valve oscillator having a frequency of operation which is lower than that of the crystal output. The latter controls the operation of the divider in such a way that its output is always a definite fraction of the input frequency. Providing that this fraction is not less than about one-fifth, by careful design and with reasonably constant supply voltages, reliable subdivision may be maintained over very long periods. In order to subdivide a crystal frequency of 100,000 cycles per second to give an output of the order of 100 cycles per second, a chain of some five or six frequency dividers will be required. Quite apart from the risk of interruption, the normal voltage fluctuations of the ordinary supply mains make them quite unsuitable for driving the crystal oscillator and

its associated circuits, so that banks of accumulators are used for this purpose. Mechanically the quartz crystal clock is an extremely simple device, but the complication of its electrical circuits, which employ many valves, is very considerable.

From the point of view of time measurement, it would be most unsatisfactory to place complete reliance on the performance of any one crystal, and it is usual to employ not less than three in the electronic clock. Only one of these is used to drive the phonic wheel, but the frequencies of all these crystals are continuously compared and are automatically recorded so that unexpected deviations in any one may be detected. This is a fairly simple matter, since if one of a pair of crystals has a frequency say, five cycles per second higher than that of the other, their outputs will come into step five times in every second. Circuits can be devised for counting the number of times the two sources come into step in any given period of time. Records of these counts are made on a moving tape, so that any erratic behaviour of one crystal, or a slow drift in its frequency over a long period of time, will be revealed. Similar means may also be employed for checking that a new crystal plate has settled down to its final frequency after the initial 'ageing' period to which we referred earlier.

In the first part of this article we saw how increasing practical demands pressed for more and more exacting methods of timekeeping and the reader may now enquire whether recent advances have not, in fact, outstripped our immediate requirements. The electronic clock is a very complex electrical equipment and is very expensive to construct and to maintain, so that it might well be asked if it is able to serve any more useful purpose than enabling the astronomer to study small variations in the period of the earth's rotation. The determination of frequency is, of course, a particular form of time measurement, and is one which is of very great importance in modern radio engineering. All types of radio transmission involve energising

an aerial system by means of a high-frequency alternating current, that is, a current which changes its direction upwards of a hundred thousand times per second. The tuning arrangements at the receiver enable signals of a particular frequency to be selected and others excluded so that interference between stations is avoided.

The first demand for a reasonably constant transmitter frequency arose from the undesirability of having to make troublesome adjustments to the receiver in order to maintain communication, but as more and more radio transmitters came into use, a new problem had to be faced. In order to transmit speech or music, a narrow band of frequencies must be used, and the broadcast receiver must be capable of responding to the whole of this band if reasonable quality is to be maintained. Thus, when the receiver is tuned to one station, it may in fact pick up part of the transmission of another station operating on a slightly different frequency. Suppose, for example, we set our receiver to pick up a programme being radiated on a frequency of 1,000,000 cycles per second and there happens to be another station transmitting on a frequency of 1,001,000 cycles at the same time, then part of the second transmission will also be received. Apart from hearing a troublesome background of the programme from the second station, we shall also hear an audible whistle of 1,000 cycles per second – the difference between the carrier frequencies of the two stations. The only way of avoiding such interference is to raise the pitch of the whistle to such a frequency that the receiver is incapable of responding to it.

This can be done only by adopting a frequency plan for all stations located in the same part of the world, and arranging that their frequencies are separated by not less than 9,000 cycles per second. The success of such a plan calls for international cooperation and, from a technical point of view, necessitates means for maintaining transmissions on precisely their allotted frequencies. It was this need which gave rise to investigations for controlling

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frequency first by tuning fork oscillators and later by means of quartz crystals. The temperature controlled crystal oscillator has been found completely satisfactory for maintaining constant the frequency of radio transmitters of all types under the most exacting conditions of operation.

The development, during the 1939-45 war, of radar methods for determining the range of an aircraft or a ship gave rise to unprecedented demands for the determination of extremely short intervals of time with a high degree of accuracy. The principle involved in practically all these systems is the measurement of the time taken for a pulse of energy to complete the journey from the radio transmitter to the target and back again after reflection. The speed of the electromagnetic wave which carries the energy of the pulse is 186,000 miles per second, so that a pulse reflected from an aircraft flying at 100 miles from the transmitter will return after roughly one-thousandth part of a second (one millisecond). The accuracy with which we are able to measure this interval will determine the exactitude with which the range of the target can be given.

Radar systems have been devised for an immense variety of purposes, but we need consider only two typical examples to gain some idea of the precision required in the measurement of these short time intervals. For the purposes of naval gunnery, ships at ranges up to about 40,000 yards must be located with an error not exceeding 40 yards. The time interval between the transmission of a pulse and its return from a target at this range will be about two ten-thousandths of a second (200 microseconds), and to achieve the required accuracy, this period must be determined with an error of less than 0.1 per cent, that is, within two ten-millionths of a second (0.2 microseconds). The second example we might consider is the case of the 'Oboe' system of directing an aircraft to a specified target up to a range of about 200 miles, with a location accuracy of about 100 yards. The problem in this instance is the measurement of

an interval of about 2 milliseconds with an error of less than a microsecond.

For purposes such as these, we require a method of subdividing the second accurately into several million parts and here again the properties of the quartz crystal oscillator may be turned to good account. A crystal plate having a frequency of 5 million cycles per second completes five cycles of oscillations in one-millionth part of a second, so that each of its cycles occupies an interval of 0.2 microseconds. It may therefore be employed to give a time scale against which the period between the transmission and the return of the pulse may be compared. The practical details of the methods by which such a timing standard may be used are outside the scope of this article. A cathode ray tube is employed to display, in what we may regard as a stroboscopic form, a comparison between the continuous oscillations of the crystal and the repeated pulsing of the transmitter and the reception of the reflections.

The great versatility of the quartz crystal oscillator as a means of measuring time is, as we have seen, due to its remarkable frequency stability over both long and short intervals. The former enables us to employ it as a timing device for an extremely accurate clock. The high degree of short term stability which it shows, permits us to use it for subdividing time into intervals shorter than one-millionth of a second. The foregoing account shows the quartz crystal oscillator to be a device which now places the determination of time intervals in the realm of the most accurate measurements which the modern scientist is able to accomplish.

Taste and Flavour

R. W. MONCRIEFF

'Oh for a draught of vintage that hath been
Cooled a long age in the deep-delv'd earth
Tasting of flora and the country green,
Dance, and Provencal song, and sunburnt mirth.'

Keats, *Ode to a Nightingale*

The Sense of Taste (and a little about Smell)

Sight, touch, hearing, taste and smell are the five commonly recognised* senses with which we are endowed, and most of us would probably agree that the first three of these are much more important than the last two. Blindness is the affliction perhaps most dreaded; the sense of touch is not ordinarily lost, but deafness is a severe handicap, and yet many people have deficiencies in their senses of taste and smell and go through life unaware of them. Total inability to taste or to smell is rare, but partial loss of these senses is by no means so, and often the people concerned are not greatly inconvenienced, nor indeed aware that they are in any way abnormal. One or two cases that have been investigated will illustrate the point. In 1918 A. F. Blakeslee published a paper on 'Unlike Reactions of Different Individuals to Fragrance in Verbena Flowers.' Two kinds of verbenas were used for the test, a pale pink which smelt like *arbutus* to Blakeslee but had no pronounced smell for his assistant and a red flower which Blakeslee could not smell at all, although it reminded his assistant of the perfume of a carnation. A group of 42 people were asked to give their reactions to these flowers. There was an amusing uniformity in their first reaction when asked to do so, for the subject would generally say he feared he was

* There are others.—Ed.

not smelling well that day, would then blow his nose and almost at once pick out either the pink or the red and wonder how anyone could think the other fragrant. Seventeen men and nine women picked out the pink flower, nine men and four women the red flower, and two women thought both fragrant. Clearly there must have been considerable differences in the olfactory powers of the people who comprised this group.

Similar differences are to be found in the case of taste. There is a substance known as *p*-ethoxyphenyl thiourea and most people find it bitter, but some cannot taste it at all. L. H. Snyder in 1931 carried out tests on a large number of individuals and found that of the people he tested 68.5 per cent thought it bitter but 31.5 per cent could not taste it at all. This 'taste-blindness' as it is called runs in families; it is a hereditary characteristic, and there is some evidence that it is partly at least a racial characteristic: it is much more common amongst whites than amongst the American Indians.

Although the senses of taste and smell seem nowadays so unimportant that gross deficiencies or abnormalities in them may never be noticed, it was not always so. To primitive man, smell and taste may well have been the most useful and highly-developed of the senses. These senses were largely responsible for the finding of food, for the rejection of dangerous berries, for the detection and evasion of dangerous enemies, and possibly also they assisted in the reproduction of the species. Certainly in animals to-day we see the supreme importance of taste and smell, the chemical senses as they are called. The cat searches by smell for food although it is well within its range of vision, and it has been proved repeatedly that fishes will not feed, even though starved and well able to see food, unless also they can smell or taste it. Olfaction initiates feeding, and taste, the final arbiter, decides whether the food shall be swallowed or rejected. In the case of reproduction too, animals clearly depend largely on the sense of smell. At their zenith, ages ago, taste and smell were the

supreme senses in man, and they made such a powerful impression on his central nervous system, that even badly blunted as they have been by civilization they are still extraordinarily sensitive. We all know how a smell or a flavour will take us back in a flash to some previous incident, how it will recall with startling vividness an emotion or a nostalgia.

And yet, despite their one-time importance to our race, despite their sensitivity, despite the fact that they constitute two of the senses which contribute to all our mental life and consciousness, the study that these two senses receive is meagre in the extreme. Consider how other senses are catered for; at school we are taught heat, light, and sound, but there is no teaching of the sciences of smell and taste; the most the student will pick up is a familiarity with a few laboratory 'stinks.' Perhaps we may try to fill the gap a little so far as taste is concerned. We shall have to leave the question of smell; it is too wide a subject to be discussed now.

Where we taste

We see with the eyes, we can feel more or less all over our bodies. Where do we taste? Easy, you say; with the tongue. The answer is true, but not quite complete, for we taste not only with the tongue, but also with the soft palate, the epiglottis and the beginning of the gullet, and when we are children we taste even with the interior surfaces of the cheeks. It is true that taste is confined to the mouth in humans and indeed in all animals higher than fishes in the evolutionary scale. Fishes can taste over wide areas of their bodies, particularly with their flanks.

What we taste

There are four main kinds of taste, and these are salt, sour, sweet and bitter. They are well-defined and so separate that they may almost be considered as separate senses. Any taste (note that I do not write 'flavour') can be

copied by mixing two or more of these tastes. For example if we take salt, dilute acetic acid which is the main constituent of vinegar, sugar and quinine, i.e., one salty substance, one sour, one sweet and one bitter, we can reproduce the taste of any other substance by mixing the salt, acid, sugar and quinine in suitable proportions. This does not apply to flavours, for the sense of smell plays an important role in the perception of flavours, but for true tastes it holds well. In 1922 E. von Skramlik showed that tastes could be imitated by mixtures of salt, tartaric acid, glucose and quinine, and in 1926 E. P. Barysheva claimed that the taste of any substance may be imitated by using mixtures of solutions of salt, oxalic acid, sucrose and quinine hydrochloride. If the reader wishes to try this he should of course use tartaric acid or vinegar as the acid component and on no account use oxalic acid which is extremely poisonous. But so far as the reproducibility of tastes is concerned, various research workers have shown that all that is necessary is one salty substance, one sour, one sweet and one bitter.

Perhaps it should be noted that some workers consider that other tastes such as an alkaline taste, a metallic taste and a 'meaty' taste, should be added to the four tastes usually accepted. The subject is debatable but in the writer's view these are not true tastes, the first two at least being simply manifestations of the common chemical (irritant) sense, and the meaty taste being due mostly to odour. We will now consider the four tastes in a little more detail.

Saltiness

Because we are descended from sea-inhabiting invertebrates we should expect the salt taste to be the most primitive. Very lowly organisms, which are so rudimentary that they can hardly experience sensation as we know it, but whose behaviour is determined by involuntary reflex action – as automatic as the way we blink our eyes involuntarily if something approaches close to them – are sensitive

to the saltiness of water in which they live and will move to or from patches of water containing more or less salt than their normal habitat. The salty taste and also the sour taste were originally concerned with environment and with the safety of the animal.

In man the salt taste is experienced when many kinds of salt are taken into the mouth. Common salt is sodium chloride and has a typical salt taste, and so have many similar compounds such as the chlorides of potassium, ammonium, lithium, and rubidium, and the bromides of sodium, ammonium and lithium, as well as the iodides of sodium and lithium. All these substances are very similar chemically and all are characterised by the possession of a typical salty taste. Salts that are otherwise similar but which are composed of heavier molecules such as potassium bromide have a taste that is not only salty, but also intensely bitter, and in the case of potassium iodide the bitter taste is so pronounced that it overpowers and almost completely hides the salty taste. Potassium bromide, which has a molecular weight intermediate between the chloride and the iodide, has both salty and bitter tastes well-defined. If the reader will look at the short table that follows, he will see clearly what is meant:

Substance	Molecular weight	Taste
Ammonium chloride	53.5	Salty
Sodium chloride	58.5	Salty
Potassium chloride	74.5	Salty
Potassium bromide	119	Salty and bitter
Ammonium iodide	145	Salty and bitter
Potassium iodide	166	Bitter
Rubidium iodide	212.5	Bitter

Thus although the salty taste is typical of the salts, a well-defined class of chemical compounds, some salts may also have other tastes. Perhaps if he has ever taken a dose of Epsom Salts, which is another name for magnesium sulphate (molecular weight 120), the reader will already be cognisant of this state of affairs, for Epsom Salts are both salty and bitter to the taste.

We are extremely sensitive to the taste of salt. Experiments were made in 1939 by C. P. Richter and A. MacLean on the response of fifty-three adult individuals to the taste of salt solutions. In general it was found that solutions containing only 0.016 per cent salt, which corresponds to about one-twentieth part of an ounce of salt dissolved in a bucketful of water, could be distinguished by the taste from pure water. The taste threshold, as it is called, varies from one individual to another; some people are more sensitive than others, and some could detect the difference in taste between water and a 0.007 per cent solution of salt.

Cold salt solutions taste saltier than warm ones.

Sourness

The sour substances with which we are familiar all contain acids. There is acetic acid in vinegar, citric acid in oranges, lemons and grape-fruit, malic acid in apples and fatty acids in sour milk. The stimulus for the sour taste is an acid; strong acids are intensely sour, weak acids are less sour, but usually still very sour, and sourness is a property common to practically all acids. Just as some salts have a taste additional to the salty taste, so some acids also have other tastes; e.g., picric acid is extremely bitter. Now the feature common to all acids is that when dissolved they break down into two or more parts, one or more of these parts being the hydrogen ion, and the higher the concentration of hydrogen ions in a solution the more acidic it is and the more sour is its taste. There is a very marked parallelism between hydrogen ion concentration and sourness, almost a linear proportionality, and practically the only important exception to this proportionality is that fatty acids, which dissolve readily in the fatty tissues, taste more sour than would be expected from a simple consideration of their content of hydrogen ions.

It may be because the presence of acid in water is extremely dangerous to water-inhabiting forms of life that we are very sensitive to the taste of acid, but it is a fact

that we can detect by sourness the presence of acid in water in such high dilutions that it has no irritant effect. In fact, four parts of hydrochloric acid in 100,000 parts of water give a detectably sour taste; if we were to add one fluid ounce of ordinary concentrated hydrochloric acid (26 per cent hydrogen chloride) to a 40-gallon drum of water, the mixture would be perceptibly sour. Acid solutions taste more sour when they are warmed.

Sweetness

Although saltiness is a characteristic of salts, and sourness one of acids, sweetness is not confined to any one chemical class. The sugars are the best known of sweet substances, but there are other substances as sweet as the sugars, and often sweeter, which are in no way related to them chemically. The sweet taste has developed later than the salt and sour tastes, and is concerned exclusively with nutrition. But the senses were not developed to deal with synthetic materials that do not occur in Nature, and there are some sweet synthetics that are poisonous. Lead acetate, also known as 'sugar of lead', is one of these. Taste may be a reliable safety guide for natural products, but is unreliable for synthetics.

'Sugar' as we use it in the home is sucrose, and is obtained either from the sugar-cane which yields 13 per cent on the average, or from sugar-beet which averages 16 per cent. There are many other sugars but they are not all equally sweet. Some of the best known have sweetness (related to a sweetness of 100 arbitrarily assigned to cane sugar) as follows:

Fructose (occurs in many fruits)	173
Sucrose (cane sugar)	100
Glucose	74
Maltose (malt sugar)	22
Lactose (milk sugar)	16

The usual method of comparing the sweetness of different substances is to determine the minimum concentrations of solutions of the substances which will just produce a

perceptibly sweet taste. The sweetness is the inverse of this concentration, and for convenience figures are usually adjusted to sucrose = 100. This is known as the 'threshold' method of determining sweetness.

Another method, due to R. Pauli, has the advantage of enabling the observer to compare concentrated solutions. A two per cent solution of sugar is usually used as a standard, and then two solutions of the substance which is being tested are found by trial and error, such that one of them is sweeter than the standard solution of sugar, and the other is less sweet. Then about seven intermediate solutions of known concentration are made up and the observer determines which of these are sweeter and which less sweet than the standard solution. By a process of 'bracketing' the sweetness of any substance relative to that of sugar can be determined quite accurately.

Perhaps honey is our most natural sweetening agent and historians assure us that in the time of Henry VIII it was customary to smother joints of meat in honey and raisins. Sugar is a more modern addition to our diet and when first introduced into this country sugar was known as 'honey of reeds'. In times of plenty it serves satisfactorily, although it may be that in the preparation of the highly refined pure white crystals there is a loss of nutritive value just as there is in the preparation of white flour. In times of shortage such as we have experienced for the last nine years, synthetic sweeteners like saccharin are widely used, and at all times used by diabetics to whom sugar is dangerous.

Saccharin was discovered as long ago as 1879 by I. Remsen and C. Fahlberg, and like very many discoveries it was due to a chance observation which the observer was not too lazy to follow up. The work on which these two people were engaged was an investigation of the oxidation products of some derivatives of benzene: one evening Fahlberg, when eating his supper, noticed that his bread tasted sweet, and he traced the source of the sweetness to his own hands and arms, and concluded that it must have

come from something with which he had been working that day in the laboratory. He returned to the laboratory and identified the sweet substance as an oxidation product of a substance known as *ortho*-toluene sulphonamide. The chemical name of the sweet substance which we call saccharin is *ortho*-sulphobenzimide, and its structural formula is:

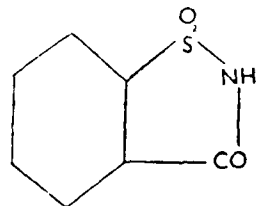


Fig. 20

Judged by the threshold test, saccharin is about 675 times as sweet as cane sugar. In addition to its sweet taste, it has a bitter after-taste which some people dislike.

Another of the synthetic sweetening agents is dulcin; its chemical name is *para*-ethoxyphenyl urea and it first aroused interest in Germany in the 1914-18 War. Dulcin is harmless to animals and man and it is free from the defect of the bitter after-taste which is associated with saccharin. It is about 200 times as sweet as cane-sugar (or as beet-sugar, for sucrose is always the same whether it comes from the sugar-cane or the sugar-beet).

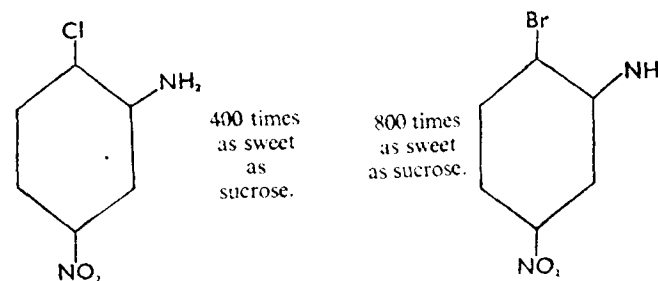
It was only to be expected that, having found two synthetics, saccharin and dulcin, so greatly superior to sugar in sweetness, the scientists would make a lot more synthetic compounds on similar lines, in the hope that they would find some materials even sweeter than those already known. This they did, adopting all kinds of devices, making homologues and isomers of saccharin, combining in one molecule the structural features of saccharin and dulcin, doubling the molecules, increasing the number of groups thought to be responsible for the sweetness, and so on. But although many of these new synthetics were sweet none of them was

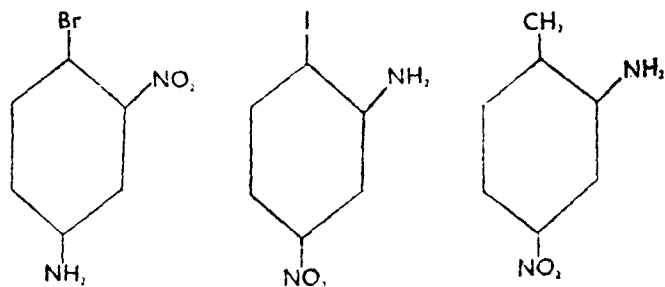
appreciably sweeter than saccharin, nearly all of them were markedly inferior in sweetness, and some were bitter and others tasteless.

However there now are new synthetics that are much sweeter than saccharin, but their discovery was more or less accidental in the sense that when they were made there was no reason to anticipate that they would be excessively sweet, and even now that we know they are so, it is still difficult to give any reasonable explanation of the sweetness.

One substance known as hexyl chlormalonamide was reported by A. W. Dox and B. Houston in 1924 to be 300 times as sweet as sugar; a 0.02 per cent solution of this substance was as sweet as a 6 per cent solution of sugar, whilst in 1928 A. W. Dox and E. G. Jones found that a very closely related compound called amyl chlormalonamide was 400 times as sweet as sugar. To illustrate how a very slight change in the molecular architecture of a substance may profoundly modify its taste, it may be mentioned that isoamyl chlormalonamide which has exactly the same number and kinds of atoms in its molecule as the very sweet amyl chlormalonamide, but has them arranged a little more compactly, is not sweet at all, but bitter.

Within the last few years more compounds have been discovered with excessively sweet tastes. J. J. Blanksma and his collaborators at Leyden University have made and described the following synthetic derivatives of nitroaniline, which is an intermediate used in the manufacture of dyestuffs:



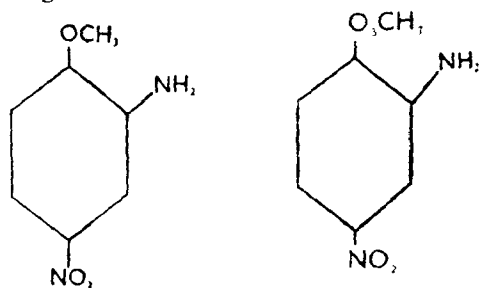


Tasteless. This illustrates how very slight rearrangement of the molecule will profoundly alter the taste.

1,250 times as sweet as sucrose.

330 times as sweet as sucrose.

P. E. Verkade and collaborators at Delft have prepared the following:



220 times as sweet as sucrose.

4,100 times as sweet as sucrose. This substance is called 2-amino-4-nitro-propoxybenzene.

The taste of these compounds is purely sweet, there is no bitter after-taste as there is with saccharin. I am afraid that only those readers who are also chemists will fully appreciate the significance of the formulae, but all will be interested to note the colossal sweetness of some of these new synthetics and to see how it is dependent on very slight changes in structure.

Sweetness is detectable in a one-half per cent solution of sugar or in about a one-thousandth per cent of saccharin.

The sweetest of the synthetics, substances like 2-amino-4-nitro-propoxybenzene will still be detectably sweet if dissolved in half a million times their own weight of water. Like sourness, sweetness is enhanced by warming.

Bitterness

Like sweetness, bitterness is found in a variety of compounds. The alkaloids are outstandingly bitter and quinine is said to be detectable if present to the extent of one part in a million of water. Brucine and strychnine are even more bitter. Bitterness, like saltiness, is diminished by a rise in temperature.

Taste-buds

It is fairly generally known that sensation is experienced when various spots on the body are stimulated; there are spots sensitive to heat, others to cold, and so on. In the same way there are spots, known as taste-buds, on the tongue and some of the other surfaces of the mouth, which are sensitive to saltiness, others to sourness, others again to sweetness, and still others to bitterness. These spots are not

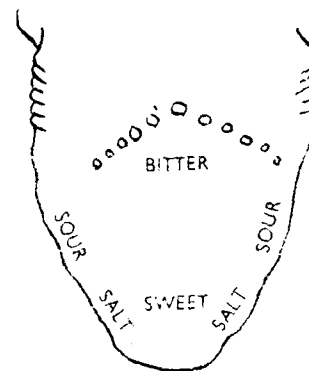


Fig. 21.—The tongue, tip downwards.

equally distributed over the tongue; there are more sweet-sensitive buds at the tip of the tongue, and consequently we taste sweetness with the tip, whilst the bitter-sensitive buds lie to the back. We taste a substance like bittersweet, sweet at the tip and bitter at the back of the tongue simultaneously. The sour taste is sensed chiefly at the edge of the tongue and saltiness both at the tip and the edge. Fig. 21 illustrates this distribution. In adults the centre of the tongue is insensitive but in children it is sensitive to sweetness.

Flavour

If there are only four tastes you may well ask how do we enjoy such a host of flavours. The answer is that there are two main components of flavour, and these are taste and smell, and smell plays by no means the inferior part. If we hold our nose we find that grated apple, grated onion and grated turnip all taste alike - slightly sweet. A cold in the head has more or less the same effect and makes food seem flavourless. Most of our food sensations are in fact due to smell and only a small part to taste; some also are due to touch. Occasionally as the result of an accident which results in damage to the olfactory nerve, people lose entirely their sense of smell, and because food seems flavourless they say they have lost their sense of taste, although in fact their perception of true taste is unimpaired. One such person who as a result of a fall from a horse lost his sense of smell through tearing his olfactory nerves, could not distinguish one meat from another, or boiled onions from boiled turnips, and his palate could not distinguish the aroma of wines. Another person thought port seemed like sugar and claret like vinegar. In other cases where smell remains and true taste alone is lost the patient is almost regardless of his changed condition. Touch enters into the question of flavour too; one recalls with distaste lumpy porridge or a gritty chocolate. Hotness and coldness also affect flavour; peppermint has a cooling taste, pepper and ginger have hot tastes. Apart from the æsthetic enjoyment

derived from flavour when we eat food, the flavour performs a useful biological function in stimulating the flow of salivary and digestive juices. The mouth waters when we smell a delicacy, the appetite sharpens if we smell bacon for breakfast. In these cases the reaction to flavour is one of pleasure, but in other cases disgust may ensue; an egg may be stale, cheese too ripe. As he grows older man develops a taste for *recherché* flavours, for example a 'high' bird. Savages are said to share with civilized humanity the liking for partly decomposed food. But the balance between appreciation and disgust is finely balanced on a knife-edge. A slight tilt and the pleasurable becomes disgusting. Some with hypersensitive olfaction find the pineapple disgusting, although to most of us it is delicious.

There is a good deal too in association of flavour with specific foods, and it has been well said that a flavour which might be appetising in cheese would definitely condemn an egg.

Generally, flavour becomes more pronounced when food is warmed, because the odoriferous components become more volatile. Meats and vegetables have more flavour when hot than cold. Several times the normal quantity of flavouring essences must be added to iced food. Iced coffee has but a fraction of the flavour of hot coffee.

Farming Front

R. N. HIGINBOTHAM

Health of Bees

Diseases of bees can be classified into two stages, as affecting the adult bee, or its larval and pupal forms before emerging from the cell. Of the latter the most serious is known as 'American Foul Brood'. This is a bacterial disease. Spores of a microscopic organism known as *Bacillus larvae* get into the food given to the larvae by the nurse bees, germinate within their bodies and multiply. They feed at the expense of the tissue of the larvae, which collapse and die soon after being sealed over for pupation. The bacteria, then without food, transform themselves back into spores and are in time distributed through the hive by house-cleaning bees, to start the whole cycle over again, but more intensively. An increasingly large proportion of the brood is destroyed until the colony fails to reproduce itself and dies out.

The symptom of an affected cell is a moist and darkened capping, which from being convex becomes concave as it shrinks back into the cell mouth with the collapse of the larva. The bees nibble holes in it and eventually remove it, leaving only the remains of the dead larva. A healthy larva is pearly-white, but an infected one gradually turns a very dark brown, while it dries up through the stages of a rope-like, slimy mass soon after collapse to a rough scale. The brood combs of a sick colony, variously subject to these changes, look patchy. The bees have great difficulty in removing the tacky scales and the queen will not lay in cells containing them. Attempting to get them out, the bees only succeed in distributing the spores of *B. larvae* through the hive. As the colony gets weaker, it will be robbed out by a stronger

colony and its stores of honey taken away to their hive. This honey is of course contaminated and so the disease spreads from hive to hive and apiary to apiary, aided very often by the carelessness of the beekeeper in leaving contaminated honey exposed or in using infected appliances.

The history of this disease is documented and it has been a permanent feature of bee life. Aristotle refers to a disease causing a bad smell in the hive, which is a characteristic of the decomposition stage of American Foul Brood. The name Foul Brood, generic to a number of decompositions whether or no caused by *B. larvae*, appears to have been originated by Schirach in 1769. During the 19th century these troubles were usually attributed to fungi, but in 1874 Cohn detected a rod-shaped bacterium which he thought to be the cause. In 1885 Cheshire and Cheyne, supposing that there was only one type of brood disease, announced the discovery of *B. alvei* as the agent. There are in fact two major, as well as some minor, brood diseases, known as American Foul Brood, and the less important European Foul Brood, and attributable to *B. larvae*, discovered in 1904, and *B. pluton*, discovered in 1912 respectively. White, who made these discoveries, stated that *B. alvei* was not pathogenic, but it is an elusive germ and there seems to be some doubt whether it is not the same as *B. pluton*. American Foul Brood has been more important in America than here, largely because they have a honey industry, whereas we have a lot of retired gentlemen in straw hats. The destruction of a large commercial apiary is a serious matter. In this country the disease has been reported from all parts, but is particularly prevalent in Devon, Somerset, Surrey and Wiltshire.

The spores of *B. larvae* are very resistant. They remain active after boiling in water for 10 minutes, and up to 40 minutes in honey. In honey they can survive exposure to sunlight up to 40 days and up to 41 hours in the dry condition. Strong caustic solutions of sodium hypochlorite and alcoholic solutions of formaldehyde have been used to kill the spores, but everyday antiseptics are no use.

There is no practical method of disinfecting diseased combs and the only thing to do, as Della Rocca said in 1790, is to burn them, together with all quilts and other internal fittings of the hive, which must itself be scorched out with a blow-lamp. As for the bees, there is a method of saving them by shaking them, stupefied with saltpetre, from their diseased combs on to new foundation in a clean hive – a trick described by Moses Quinby in his *Mysteries of Beekeeping Explained* (1864). Such diseased honey as the bees may carry with them will be used up comb-building and will not be given to the larvae. It is a very dangerous procedure in bad hands and the public authorities both here and in America discourage it and enforce a policy of burning all diseased stocks, bees and all, and burying the remnants. The Minister of Agriculture, guided by the Bee Diseases Advisory Committee, gave to Agricultural Executive Committees, by the *Foul Brood Diseases of Bees Order*, 1942, the duty of inspecting and destroying colonies infected with Foul Brood and securing the decontamination of the hive. Under this order eradication of the disease has made progress, as the following published figures show.

	1944	1945	1946	1947
Apiaries visited	6,600	9,300	10,900	12,400
Apiaries in which Foul Brood was found	1,015	941	819	888
Colonies examined	26,500	35,200	45,200	52,000
Colonies in which Foul Brood was found... ..	1,845	1,632	1,409	1,506
Percentage of infected apiaries	15.4	10.1	7.5	7.2
Percentage of infected colonies	6.9	4.6	3.1	2.9

While, since the introduction of the Order, the number of colonies examined has steadily risen until, in 1947, it represented over one-tenth of the estimated total for England and Wales, the incidence of Foul Brood went down from 6.9 per cent in 1944 to 2.9 per cent in 1946. (The majority of

these cases were American Foul Brood, though European is included in the Order and the figures). All infected colonies were totally destroyed and the hives decontaminated under supervision. In America there is apparently no Federal legislation on the topic and control is therefore better in some States than in others. The state legislation is usually similar to our own, and where it has been rigidly enforced similarly encouraging results, amounting in some cases to a high degree of control, have been achieved. It is apparent that a policy of destruction does answer, but of course it must keep the goodwill of beekeepers.

Against this background, in 1943 certain private experiments with sulphonamides in the treatment of American Foul Brood were brought to the notice of Rothamsted bee department. The infected colonies, which had been treated with sulphonamides, were later examined under the Order and showed no sign of Foul Brood. In 1945 the results of experiments in the same line with sulphathiazole at the University of Columbia, Missouri, were also published. After initial trials, Rothamsted in 1946 put into effect a scheme whose interim results were published by P. S. Milne in the Ministry's *Journal* for May, 1947. Sulphapyridine as well as sulphathiazole were used in these experiments. To test their curative value, colonies were fed with a suspension of *B. larvæ* in sugar syrup. Symptoms of infection would follow, whereupon syrup containing sulphonamides would be fed as treatment, while control colonies were fed with plain syrup. To test the prophylactic value for colonies exposed to infection, a suspension of *B. larvæ* in sugar syrup was divided into four equal parts and fed to four colonies. Sulphonamides were added to three of the parts but omitted from the fourth as a control. A few days later syrup containing sulphonamides was given to the colonies which had received the drug in the initial dose, while the control colony was fed with plain syrup. Thirty-two colonies in Devon, Somerset, Surrey, Bucks, Dorset, Essex, Hampshire, Warwickshire and Wiltshire

were included in the experiment. In all but two, visible evidence of disease disappeared during the course of treatment in from 33 to 148 days. In one colony the disease re-occurred within six weeks of the cessation of treatment. In two colonies response was unsatisfactory and symptoms persisted throughout. There was no obvious difference in the results of treatment with sulphapyridine and sulphathiazole. It may be concluded that the drugs are capable of eliminating or suppressing symptoms of the disease at least temporarily, by contrast to a diet of plain sugar syrup as fed to the controls, which does not have this effect. It was also shown that they had a certain prophylactic value for colonies first exposed to infection from other hives. On the other hand, the disease can recur after the cessation of treatment. Secondly, some colonies did not react successfully to the treatment as applied, though it was extended to the limit of what is reasonable. Thirdly, at six of the centres included in the trials it was observed that the disease appeared during treatment in combs which, at the beginning of treatment, were clear. Fourthly, free sulphonamide, in quantities up to 40.8 mg. per 100 gm. of honey was found in nine out of ten samples of honey from treated colonies submitted for analysis. Apparently, however, such quantities are harmless to the consumer.

As a result of this work and of American research, it was necessary to review the Foul Brood Order, and a full report was therefore submitted to the Bee Diseases Advisory Committee. Obviously there is nothing conclusive about the present stage of information on this type of treatment. It is not, for instance, yet understood how the sulphonamides produce the effects observed. They are not, certainly, disinfectants: that is, they cannot destroy spores of *B. larvae* present when a case of American Foul Brood is discovered. The spores remain dormant and potentially dangerous and control of the disease is really a matter of chance. It is true that a further outbreak could possibly be suppressed by further doses, but this might well be more expensive than

burning in the first place. Nor do we want highly susceptible colonies of bees perpetuated all over the place. Weak colonies under treatment would always be liable to be robbed out and the disease would be likely to spread. An American instance is reported, where reliance on sulphathiazole resulted in the spread of the disease from a commercial apiary to the surrounding area. The Committee therefore concluded that a general recommendation of the use of sulphonamides would put in jeopardy all the control of Foul Brood achieved under the Order, at a time when the Order was beginning to have encouraging results; and they therefore refused to recommend its modification to the Minister. The policy of total destruction is thus to be continued.

As has been said, sulphonamides apparently have a prophylactic effect when fed to bees in contact with infection. Further research into this question may be able to discover some reliable general technique, whereby the method of shaking the bees on to a clean foundation in a clean hive and destroying the old frames, and thus destroying the spores, could be worked in with the drug in its prophylactic aspect to give a satisfactory control. Meanwhile, in America, State and Federal authorities are studying strains of bees which exhibit a high degree of 'resistance' to American Foul Brood. This is not resistance properly so termed; it is merely a matter of better house-cleaning on the part of these strains; sanitation. However these clean bees turn out to be poor honey-producers and bad tempered. They are also highly susceptible to European Foul Brood, which is capable, with proper mismanagement, of becoming a really serious disease. The house-cleaning propensity is a hereditary character and no doubt will be bred into the honey-producing strains sooner or later. Artificial insemination for queen bees is now practicable and line-breeding can therefore be made use of.

Cultivations

In order that plants may grow with the artificial density

and reliability which we call a crop, they must be provided with the most favourable possible conditions. The soil must constitute a suitable physical medium for the germination of seeds and the anchorage of roots. It must not, for instance, be so cloddy that the plants cannot grow evenly, nor so smooth and set that they cannot break through. It must not be too acid nor too alkaline. The plants must have sufficient light and air. Further, the soil must be able to hold a balanced supply of nutrients, including trace elements, in an adequate soil solution, without, on the other hand, being waterlogged. Finally, unofficial competition for these assets from weeds – plants in the wrong places – must be eliminated. Thus the farmer, in his attempts to maintain an ecology artificially favourable to a single plant grown in overwhelming numbers, manures, limes, irrigates, drains and cultivates.

While all these factors have to be attended to, it seems that the question of water is the most important and the one which in the event gets the most attention. This might seem rather surprising in this country, which is without the spectacular disasters of, for instance, flooding in China or soil erosion in the United States; or the equally impressive remedies applied to counteract them in the way of irrigation and drainage schemes and erosion controls. The Fen country, however, which in spring, 1947, was washing away and in spring, 1948, was blowing away, gives a case on a smaller scale. Again, it has been stated that potato rationing was caused as much by the drought of summer, 1947, as by an actual short acreage planted. Similarly pointing to the importance of water is the substantial government subsidy paid on drainage schemes initiated by farmers: while, on the other hand, market gardeners, with their high financial commitment per acre, have achieved great increases of production and profit from the installation and efficient use of irrigation machinery.

Now it is generally true that nutrients must be in solution to pass through the plant root-membrane and

in practice plants cannot live and develop without a soil solution. If it is too concentrated, intake of nutrients is inhibited, while if the soil is too wet the roots are 'drowned'. All special measures concerned with water, such as irrigation, come down to this one matter of achieving a suitable soil solution, which in turn reduces itself to the capacity of soils to retain moisture, and to the way in which moisture moves in soils generally and in particular soils.

Part of the water which falls on the ground drains away under the pull of gravity. Part is hygroscopically absorbed by the soil particles, does not move in the soil and is not available for plant nutrition. A third part may be pictured in and around the soil particles, adhering to them or in cohesion with other water molecules and thus resisting the pull of gravity. This is the 'soil solution' and the reservoir for plant growth. Originally the farmer was instructed to imagine the spaces between the particles, in which this water was, as a mass of fine tubes, capillary tubes, and to call this water capillary water. In the laboratory, water can be demonstrated to rise to considerable heights under the influence of capillarity, and it was explained that water rose to the top of soils from underneath in a similar way. The movement of the soil solution was a capillary movement. Latterly these ideas have been revised, principally as a result of work at Rothamsted. The pore space in soils is now to be visualised as having a cell-like structure. The movement of the soil solution through it is discontinuous and, after drainage ceases, very slow and over short distances. That is, water is not appreciably 'drawn up' through the soil.

Such a conception is contrary to usual ideas. If the reader asks himself, he will probably find that he has been supposing that water evaporates from the surface of the ground, which is true, and is replaced by a fairly steady gentle oozing from underneath, which is false, until the whole ground is dried through. Probably most farmers think of retained water as moving fairly freely in soil. But suppose a farmer

has to change his theory, it does not follow he will change his practice. It is true that virtually all cultivations, except those specifically to kill weeds, are undertaken to obtain a desired soil structure, and also that both the quality and the behaviour of the soil solution will be determined by that structure when obtained. Indeed in any particular soil, with a given humus content and manurial history and affected by a particular sub-soil and moisture table, the only ordinary practical way of affecting the soil solution is by cultivations.

But, while moisture is a real consideration in tillage, it is not an immediate one and correspondingly any idea of the movement of water a farmer may have is likely to be, except in special cases, more like an illustration, a rationalisation, of what he has already done. On his way to his soil structure, his seedbed, he ploughs to bury manure and rubbish, and from then on what the weather will not do in the preparation of a physical medium in which seeds, especially fine seeds, will germinate and grow, he must do himself. If asked why seeds sometimes grow and sometimes do not, he will have a variety of answers, but the determining factor is his personal experience of that particular ground. This is one of the meanings of the statement often made by experts that 'tillage is not a science but an art': the *practice* of tillage is largely intuitional. In any case the farmer arrives, more or less, at his 'season', his 'crumb'. That is, he has the soil in a mass of little aggregates. Such a seedbed is in fact best from the point of view of the soil solution: it is permeable without being saturated.

The farmer also wants his seedbed firm. He has found that germination is more uniform from a firm seedbed and, when he comes to ride on the binder, he does not want to be shaken to bits. He may also know that numerical counts have shown considerable improvement in the germination of sugar-beet seedlings on firm seedbeds, with a resultant higher population per acre after singling. So he rolls his seedbed. In the days of the capillarity theory, scientists

could have given him an additional reason. The soil is a mass of capillary tubes. The finer the tubes the higher the water will rise. Seedbeds must be rolled to make the tubes finer and bring the water higher. 'Rolling brings up the water'. Experiments have shown that rolling does no such thing and the capillarity theory is abandoned. Yet the roll remains a useful tool.

The farmer refers to his individual memory, whereas the scientist talks from records. Memory, 'experience', can make subtle immediate judgments or grotesque errors and there is no means of ascertaining, at the time, which is in fact occurring. Scientific judgments, on the other hand, are relatively laborious but more reliable. Further, they are comparative, whereas experience is individual: that is, the farmer may achieve his end, but he needs the scientist to tell him whether he has achieved it in the most economical possible manner. He does not know, but the scientist can tell him, what techniques are used in the next continent or the next parish. He can find out whether those techniques are applicable to his condition by trying them, or he can ask the scientist for a prediction based on the records of past technical experimentation and past theoretical advances. But the farmer who tries to improve his practice of cultivation by incorporating the soil-structure record finds it incomplete. What he gets is first another of the meanings of the statement 'tillage is an art and not a science' – namely a *rite d'entrée* to a mystery; followed by an apologia about the undeveloped state of this branch. The ideal, whereby a scientist could apply himself to a field, which is after all a perfectly objective and material affair, and state the most economical method of growing on it named crops under alternative conditions, is not here yet. Old notions about cultivations are discredited but the new line is not yet fixed.

For instance, how much cultivation is really necessary? Here we go solemnly inverting the soil every year with ploughs, which is a long job. We could often get a seedbed

in half the time, with disc or other harrows. One school of thought would limit cultivations to the minimum. According to them the plough is not only an uneconomic but a dangerous implement. Ploughed soil, over-aerated, is subject to too intense bacterial action and is exposed to the weather. It loses its humus and its structure is irreparably damaged. They point to the Dust Bowl as a warning and idealise a forest or prairie type of soil, in which organic matter – twigs, stems and leaves, augmented under cultivation by composts – is continually deposited on the surface and dragged in by insects and worms, while the soil beneath is full of humus in the various stages of decay of rootlets. It is certain that the humus content of British soils has been greatly depleted during recent years.

An opposite school is exemplified in various market-gardening practices, where ploughing is frequent and as deep as possible. Here the object is avowedly to liberate nutrients by 'burning-up' humus quickly, but to replenish the supply by manuring so that the soil suffers no net loss. Obviously, however, the manure itself has to come, originally, from some other soil somewhere, and it may be significant that the price of dung is continually rising.

A related, but not identical, question is: To what depth is it advisable to cultivate in ordinary farm practice? Farmers equally successful on apparently similar soils will sing diametrically opposite songs on this topic. There has always been much opinion in favour of deep cultivations, which have become more frequent in recent years since the introduction of modern power units capable of doing the work without too much labour. Yet in Germany – where horses are far more used than here – the latest trend is apparently towards shallower cultivations.

Until 1944 little experimental knowledge was available, but in that year the Agricultural Improvement Council, blessed by the Agricultural Research Council, initiated a number of trials based on Rothamsted to test the effects of deep cultivations (which includes deep ploughing

and stirring the subsoil without inverting it). It has not yet been possible to ascertain the relation to extra yields of the increased depth of worked soil given by deep ploughing and it is therefore not yet possible to discuss it as an economic practice. That it gives a good control of weeds, by bringing up soil which has not been exposed to the deposition of seeds, is confirmed. Also confirmed is the necessity for a free-draining subsoil or a good drainage system in any field to be subjected to deep tillage. Deep tillage loosens the soil and increases the number and size of the pockets of air in it. Such pockets will fill with water and, without drainage, the field will become a marsh until everything has settled down. The most determined opponents of deep tillage are among farmers who have had this experience. Otherwise it does not appear to be a dangerous operation, provided that the poor subsoil brought up into the seedbed is properly fertilised.

One old controversy, however, does seem to have been settled, again principally as a result of Rothamsted work on soil moisture. Between-the-row cultivation, typically hoeing in its hand or mechanised forms, used to be considered to have two objects – to kill weeds, which competed with the crop for light, air, water and nutrients, and to make a 'mulch' of loose, dry earth to stop loss of water from the soil. In terms of capillarity, by mulching you broke the tops of the little tubes, the water did not come up them and so escaped evaporation.

But some people maintained that cultivating to get a mulch, where there were no weeds to kill, was waste of time. The contention appears to be correct. The upward movement of water in soils is now shown to be very slight. It is indeed much less rapid than the rate of evaporation from the surface of the ground and hence a layer of dry soil (constituting a mulch) is developed inevitably, without any cultivations. There is no greater loss of total moisture during the formation of this natural mulch than there is during the formation of a tillage mulch and, when formed, the one seems as effective

as the other, if either are. Moreover, before the surface soil has become dry enough to cultivate down into a tillage mulch, most of the water which will evaporate has already done so. Soils are self-mulching and cultivation of clean soil does little to conserve moisture, except in the special case of heavy soil which has cracked, where the cracks are better broken up. These conclusions have been tested in practice by the John Innes Horticultural Institution. In plot trials on carrots, lettuces and cauliflowers no significant benefit accrued from hoeing to secure a mulch. On the other hand, cultivation to kill weeds should never be neglected. The competitive effect on crops of even a few weeds is much greater than is usually realised.

The Bergship Plan

DR M. F. PERUTZ

Introduction

IN the autumn of 1942, when the German army had advanced almost to the gates of Alexandria and the U-boat war had reached one of its most critical phases, it was thought that many of the Allies' difficulties were due to their lack of air power in the distant battlefields. The reason for this lay not only in a shortage of aircraft, but also in the difficulty of bringing them into operation where they were most needed, and in their limited range. It had been a common experience that the carrier-based aircraft of the Allies were inferior in armament and speed to the land-based planes of the enemy and it was feared, therefore, that in an invasion of a distant shore the Allied armies would be handicapped by lack of air support until they had actually succeeded in establishing air-fields on the invaded territory.

Thus it was only natural that a proposal for the *apparently* cheap construction of gigantic aircraft carriers, capable of operating land-based aircraft thousands of miles from their base, was seriously considered by those responsible for the strategic planning of the war. In October, 1942, Mr Geoffrey Pyke, the originator of the plan, submitted a memorandum to the Chief of Combined Operations, in which he proposed that an iceberg, either natural or artificial, should be hollowed out to shelter aircraft and levelled to provide an adequate runway. It should have a mobility of at least a few knots and be guaranteed against melting, if not indefinitely, at least until it had fulfilled its strategic purpose. Mr Pyke pointed out that all strategic materials, such as metals, wood and concrete, were already being used to the full for the war effort and that ice, requiring for its manu-

facture only one per cent of the energy needed to make an equivalent weight of steel, would be ideal as a basic material for the construction of large carriers. Ice, he considered, possessed the advantage of being difficult to break up with explosives, as shown by the tenacious resistance of icebergs to shellfire, and of melting only very slowly when insulated. The greatest attraction of a floating airbase made of ice is, of course, the fact that it cannot be sunk.

In December, 1942, Mr Churchill issued a directive that research on the project should be pressed forward at the highest priority, but expressed the opinion that it would be essential "to let Nature do the job" of making the Bergship, as otherwise the technical difficulties would prove insuperable. He also suggested that ice-floes might be towed into the Atlantic from the Arctic Seas and used as airfields until they were broken up by melting.

It soon became apparent, however, that neither natural icebergs nor ice-floes are suitable as air-bases, the former because their surface above the water is too small and the latter because they are too thin to withstand the waves of the Atlantic - the Russian North Pole Expedition under Papanin, for instance, had shown the thickness of the pack-ice even at the North Pole to be less than 12 feet. Moreover, the experts of the Fleet Air Arm considered a freeboard of at least 50 feet essential for the continuous operation of aircraft from the deck of a carrier. The minimum length of runway required for bombers at that time amounted to 2,000 feet, and 200 feet was considered the most desirable width. Thus the engineers and physicists were given the task of building a raft or vessel of those gigantic dimensions, made basically of ice and satisfying a number of essential requirements: the vessel must be sufficiently seaworthy to withstand the waves of the Atlantic and Pacific Oceans, it must be self-propelled, have a speed at least sufficient to prevent its drifting in the wind, and it must be difficult to sink.

In order to design such a Bergship, as it was decided to call it, the naval engineers needed accurate information on

the mechanical strength of ice. A search of the literature revealed a mass of conflicting data which were of little assistance to them, and it soon became clear that most of the physical constants which were needed would have to be redetermined. A variety of mechanical strength tests were done both in this country and in Canada, but their results were very disappointing. The average modulus of rupture of ice beams in bending, for instance, was found to be about 320 lb./sq. in., but individual beams sometimes failed at stresses as low as 70 lb./sq. in. (Soft wood fails at about 100 lb./sq. in.). As a structural material ice was found to be too unreliable and its resistance to explosives quite unpredictable.

In February, 1943, the state of the Bergship project was not very hopeful, when the outlook was suddenly transformed by the discovery that the inclusion of a small percentage of wood-pulp improved the mechanical properties of ice beyond recognition. In view of its similarity with concrete and in honour of the originator of the Bergship project the frozen woodpulp was given the code-name pykrete (Pyke's concrete).

Pykrete

Wood-pulp consists of mechanically ground spruce or pine-wood and is the raw material used for the manufacture of newsprint. A mixture of 10-15 per cent wood-pulp with water is a spongy mush, while a 5 per cent suspension has a consistency rather like porridge. If such wet pulp is frozen, its mechanical properties are vastly superior to those of ice. Lumps of the material do not disintegrate on being hit with a hammer and the impact of small arms' projectiles does not crack them. Preliminary results with the new material were in fact so hopeful that a small research unit was immediately established in one of the refrigerating rooms of a London meat store and charged with the production of large blocks of pykrete. With these a variety of tests were carried out by different teams in this country and in Canada; some of the

more striking results obtained in these tests are quoted below.

Table I gives a series of values for the modulus of rupture in flexure of beams of different pulp content. These measurements were made by supporting a beam of pykrete at both ends, say, and applying a load at the centre. In practice, the beam is bent by the movement of a piston which is driven down by a hydraulic pump at a constant rate of, say, 1 in. per minute, and the maximum load which precedes rupture is recorded on a dial.

TABLE I

Modulus of rupture of beams in flexure at -17°C . (Mean values).

Pulp content in per cent	Modulus of rupture in lb./sq. in.
0	320
1	325
2	455
4	710
6	725
7	765
8	875
14	950
Wood alone (spruce)	100

It is seen that the strength increases rapidly up to a pulp content of 4 per cent, after which the increase is comparatively small. Table II shows a comparison of some of the mechanical properties of pykrete containing 14 per cent Scotch pine wood pulp with the corresponding values for pure ice.

TABLE II

Mechanical strength of pykrete and ice at -15°C .
(Mean values in lb./sq. in.)

	Pykrete	Ice
Ultimate strength in compression	1,100	620
Ultimate strength in tension	700	165

More important even than the increase in the mean values which these tables represent was the comparatively

small scattering of the individual test results in pykrete, as opposed to ice. Beams of pure ice, for instance, might break at any stress between 70 and 500 lb./sq. in., while ice containing wood pulp gave results which were reproducible to within about ± 25 per cent. Pykrete, in fact, was ductile and could even be machined on a lathe. Its resistance to projectiles and explosives was weight for weight as good as that of concrete. Measurements of the penetration of a .303 rifle bullet show the resistance of pykrete compared to some other materials (Table III).

TABLE III

Penetration of .303 rifle bullet.	
Material	Penetration in inches
Soft wood	25
Pure ice (-7°C .)	14
14 per cent pykrete (-7°C .)	6.5
Brickwork	6
Concrete	2.75

From the results of small-scale underwater explosive tests it was calculated that a torpedo hit would produce a crater 2 feet deep and about 15 feet in diameter. Nevertheless it was considered that a minimum wall thickness of 30 feet would be required for the Bergship to be safe against the blast effects of underwater attack.

These results were most encouraging, but soon a new difficulty emerged which imperilled the realisation of the project. It was noticed that the ultimate strength of pykrete in compression depended on the rate of loading, i.e., if a piston, driven by a hydraulic pump, was lowered on to a cylinder of pykrete at a constant velocity, the load at which fracture occurred became greater the slower the movement of the piston. Ultimately, at a very slow rate of compression, fracture never occurred at all, but the cylinder of pykrete underwent plastic deformation until it had assumed the shape of a flat disc. Behaviour of this type is a characteristic property of materials which are liable to undergo permanent deformation under the continuous action of small stresses, a phenomenon technically known as creep. If pykrete was

subject to creep, the possibility had to be faced that a Bergship built of this material would sag under its own weight. It was essential, therefore, to test the creep properties of pykrete as a function of all the possible variables, such as load, time, temperature and pulp content. For this purpose batteries of creep test machines were installed in cold rooms at different temperatures. Their principle of construction is illustrated in figure 22.

By means of the piston *p* the lever *L* exerts a pressure on the pykrete block *P*. Weights are applied in the scale

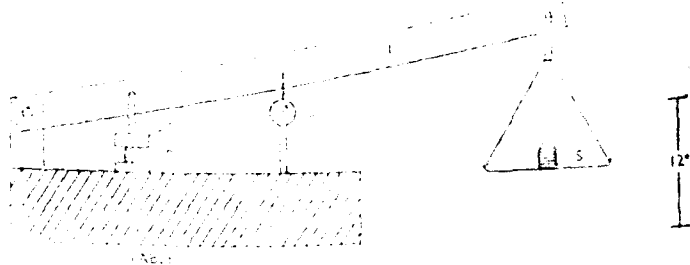


Fig. 22.—Machine for testing creep in compression.

pan *S* and the movement of the lever can be read on the dial of the gauge *G*. When an experiment is started the dial is read every few hours; later, readings are continued daily until the rate of compression assumes a constant value. The type of curve obtained in such an experiment is illustrated in figure 23 where total compression in inches is plotted against time for a series of different loads. The figure shows that with loads of the order of 100-200 lb./sq. in., a rapid initial compression (which is partly elastic) is followed by a gradual slowing down until, after a few days, the rate of compression becomes constant.

On the basis of the creep curves it was possible to predict that in a Bergship made of 4 per cent Canadian spruce pulp plastic deformation of the ship would cease after an initial period of sagging lasting several weeks. The curves also

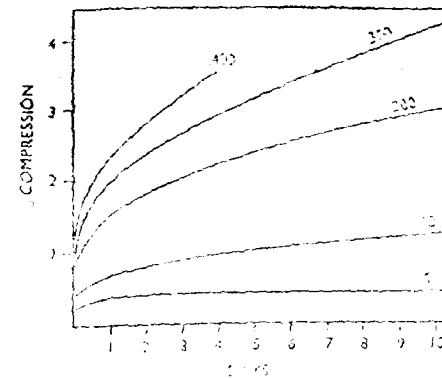


Fig. 23.

showed that -15°C. was the highest permissible working temperature if deformation of the ship through creep was to be avoided. By the summer of 1943 the mechanical properties of pykrete had been well enough established, at least in small scale tests, to proceed with the ship's design.

Plans for Design and Construction of the Bergship

With a runway of $2,000 \times 200$ feet, a freeboard of 50 feet and an all-round wall thickness of 30 feet, it was found that the Bergship would have to have a draught of 150 feet and a displacement of 2,200,000 tons. To build a ship 26 times heavier than the *Queen Elizabeth* from a material which had never been used before was a formidable proposition; many experienced engineers, in fact, regarded the difficulties as insuperable, particularly so as our directives required that at least a prototype of this monster should be built in the short span of one winter, and that an entire fleet of Bergships should be ready in time for the projected invasion of Japan. Nevertheless considerable progress was made on the design and many ingenious plans were developed for the construction of these floating islands.

For the sake of simplicity of construction it was decided

to give the ship the shape of a hollow square beam, with bevelled edges to reduce the drag under water (Figure 24). The outside walls were to be surrounded by a waterproof insulating skin and the pykrete was to be kept at a constant temperature of -15°C . with the help of artificial refrigeration. U-shaped ducts of the type shown in figure 24A were to be built into the walls. These ducts were to be placed about 4 feet away from the outer surface of the pykrete and cooled with compressed air at -30°C . Sixteen refrigerating plants, each with its own circulating system, were to supply the cold air. To reduce the danger of flooding to a minimum, each circulating system was in turn to be broken down into subsections, with the air distribution to these subsections arranged above water level. Under the worst possible conditions, i.e., in tropical waters, the total power requirements of the refrigerating system were estimated at 3,600-3,900 B.H.P.

The Bergship was to be propelled by over 20 separate

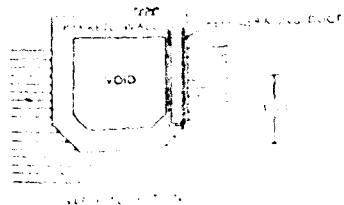
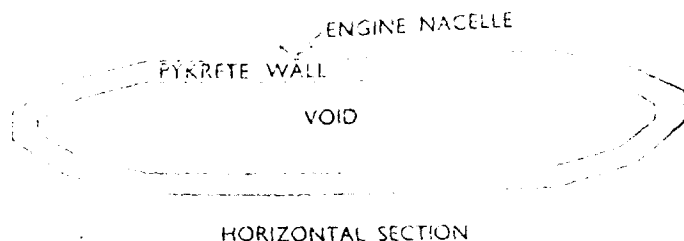


Fig. 24A.



HORIZONTAL SECTION

Fig. 24B.

THE BERGSHIP PLAN

1,100 H.P. electric motors housed in pressure hulls. These engine nacelles were to be distributed along the side of the ship, so that the putting out of action of one of them would have little effect on the speed of the ship as a whole. The power for the motors was to be supplied by a central turbo-electric generating plant.

Since the power needed to propel a ship increases about as the cube of the speed, the size of the generating plant needed to propel the Bergship at a velocity comparable to that of the fleet would have been astronomical, and even at seven knots, which was considered the absolute minimum necessary to prevent the ship's drifting in the wind, turbo-electric generators totalling 32,000 B.H.P. would have been required. In terms of effective h.p.'s the power requirements for different speeds were determined in small scale tank trials to be as follows:

Speed in knots	Effective horse power
5	6,000
6	9,500
7	14,500
10	90,000
20	350,000

Thus if power losses are taken into account, a speed of 20 knots could only have been achieved with turbo-electric generators totalling about 700,000 B.H.P., which is more than twice the capacity of Battersea Power Station and three times that of the largest battleships (*King George V* class).

The steering of the Bergship presented a particularly difficult problem to the naval engineers. At first it had been proposed to change course merely by altering the relative speed of the propelling units on each side of the vessel, but the experts took the view that this by itself would not enable it to maintain a steady course, for which a fin and a rudder would be essential. The design and fixing of a rudder which would have had a weight of several hundred tons was a problem which was never satisfactorily solved. Another serious problem was presented by the void $2,900 \times 140 \times 140$ feet in the centre of the ship. If this void were

left empty, the walls would be liable to bend inwards as result of creep and a single crack in the wall, due to repeated torpedo hits, say, might lead to the void being flooded. The Bergship would not sink, of course, since it was to be made of buoyant material, but flooding would have reduced the freeboard to a few feet and thus put the flight-deck out of action. In order to prevent flooding, it was proposed as one stage to fill the void with a kind of honeycomb structure made of pykrete, but this could only have been achieved at the expense of a further increase in the total displacement. Internal supporting structures and partitions made of steel or timber would have involved the use of thousands of tons of materials in short supply. No doubt a compromise solution might eventually have been found, but there were other difficulties which upset the project.

These were partly connected with the problems of construction. When Admiralty charts and meteorological handbooks were scanned for a suitable building site it was soon realised that no accessible place on this earth was cold enough to 'let Nature do the job' of freezing the pykrete. The locality eventually selected as most suitable for the building of the prototype Bergship was Corner Brook on the West side of Newfoundland, where an average daily temperature of -5°C . could be reckoned with for a period of about 100 days, and where protected waters more than 150 feet deep (the draught of the Bergship) could be found.

In order to avoid having to launch the ship, it was proposed to lay the keel on a large number of barges fixed together with bolts and connectors and anchored in protected waters. The pykrete was to be laid down in blocks precooled to -10°C . and cemented together with pykrete mortar. As the pykrete was laid down the keel would gradually sink, so that the refrigerating machinery had to be installed at an early stage in the construction in order to keep the pykrete sufficiently cold. The manufacture of the pykrete itself was, of course, one of the most formidable problems. One Bergship required 1,700,000 tons of it, and

to produce this quantity within the short span of one winter would have needed a plant covering some 100 acres.

These difficulties were in part responsible for the abandonment of the project early in 1944. There were other reasons, not connected with the technical difficulties themselves, which played their part. Since 1942 the range of aircraft had increased so much that it had become possible to provide air-cover over most of the Atlantic with land-based planes. The island-hopping campaign of the American forces in the Pacific had been successful beyond expectations and made an eventual invasion of Japan appear feasible even without large floating air-bases. Finally, the length of runway needed for the new types of aircraft had increased far beyond the 1943 estimates, and by 1944 a flight-deck 2,000 feet long had become insufficient for the heavy machines for which the Bergship had originally been intended.

From the point of view of the war effort the research and planning spent on the Bergship project proved to have been wasted. Yet, looking back, it is easy to understand how this daring venture came to fascinate men's minds and was welcomed as a possible solution for one of the most difficult military problems facing the Allies. When judging the Bergship plan now, it must be remembered that it was only one of several apparently impossible engineering feats conceived during the war (e.g., the atomic bomb) and that the question was not so much one of absolute feasibility but rather of whether the ultimate strategic advantages to be gained by the Bergships were in proportion to the expenditure of man-power and materials involved. In fact, I think that had not the course of the war and the state of our armaments changed, the Bergship could have been made, though at prodigious cost.

(This article is a modified version of a more extensive description of the Bergship plan which appeared in *The Journal of Glaciology*, No. 3, April, 1948.)

What are Wave Guides?

L. F. H. BOVEY

It is rapidly becoming clear that the advances made in science during the war were mainly technical and based on fundamental research previously carried out. Thus the atomic bomb project was really the result of applying large sums of money and a vast army of scientists to theories originally put forward by Rutherford, Bohr and others. The advance in radio techniques - radar - used knowledge mainly accumulated in the past fifty years although the invention of new types of valves - e.g. the 'Klystron' in 1939 by the Varian brothers, may be said to have been new lines of research, even though these were based on known properties of the electron. One of the most interesting developments which assisted the advance of high frequency radio was the use of wave guides, and this short article is intended to give a general introduction to the principles which lie behind their use.

Reason for Wave Guides

For normal commercial radio working (down to stations working on 'short waves') an ordinary wire is just as satisfactory a conductor or carrier for the radio signal as it is for conveying the electricity to the light bulb in the ceiling from the 'mains supply', and no special precautions are necessary for a household aerial in the sense discussed below. As the wavelength is decreased (i.e. signals generated from stations in even shorter short-wave regions), however, this method involves many disadvantages, the main two being high loss (the signal loses much of its strength) and distortion (the signal is altered so that what is obtained from one end of the carrier bears little resemblance to

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what is put in at the other). An arrangement known as 'transmission lines' is necessary in this region and although normal broadcasting does not extend to these wavelengths, they are important because of the use made of radio waves of this wavelength for navigational purposes. In this method, the signal is carried by 'free space' (a physical term to describe what is normally the atmosphere) between the wires, which serve to guide it, and hence both the wire and the free space must be considered as conveyors, and not the metal itself as is the case in domestic electricity. They can take two main forms - twin, where there are two wires running parallel to one another, and coaxial, in which case one wire is within the other; in both cases the relevant 'free space' is that existing between the two wires. This means

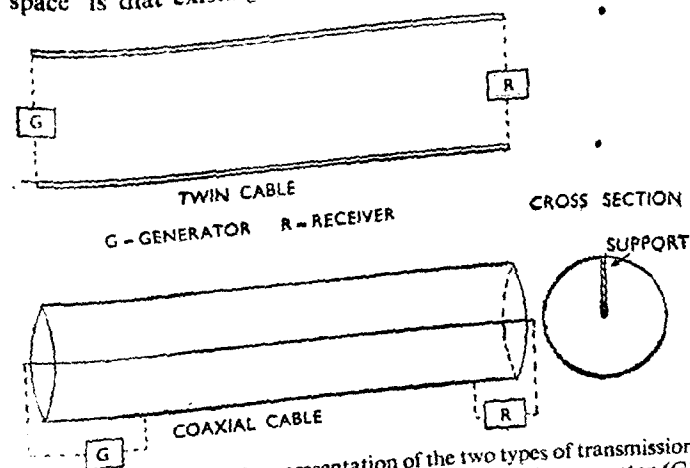


Fig. 25. Diagrammatic representation of the two types of transmission lines, illustrating the fact that to convey power from the generator (G) to the receiver (R) - usually an aerial - the power may either be transmitted by two similar parallel wires or by a cable in which one wire is within the other. The size of the cables has been magnified out of all proportion to the generator and receiver, since their usual cross section is about half an inch. Special methods are available for putting in and abstracting the power from the lines at each end.

and more accurate devices are possible, which can also be made portable, e.g., for use in aircraft. It is also possible to get narrower beams of the radiation, which for certain purposes is advantageous, cf. the general illumination from a bulb and the beam from a torchlight. Since it is practically impossible to pass these signals using methods suitable for longer wavelengths, it is very important to develop a new method of conveying power from the generator to the aerial. In other words, a way must be found of guiding these electromagnetic oscillations without the losses mentioned above, and it is found that tubes such as might be used to convey liquid can under certain conditions, such as correct size and cross-section, transmit the power.

Simplified Theory

Simplified Theory

Wave-guides can be considered as a form of coaxial cable in which the inner conductor is eliminated and hence the supports are no longer necessary. To engineers familiar with the concepts of transmission lines, the theory of these guides offers no great difficulty, since many of the concepts are similar and many of the technical terms are carried from one branch to another. In general, the theory of microwaves can be approached either from this analogy with transmission lines, where such terms as inductance and

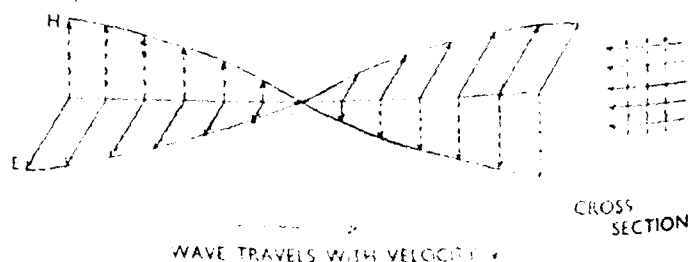


Fig. 26. Electric and magnetic fields in a radio wave in free space. It can be seen that the curve joining the ends of the arrowed lines, representing the strength of the fields, gives an outline similar to a sea wave. (H, magnetic field; E, electric, throughout; V, velocity of light for free space.)

capacity are used, or from the more physical basis of electromagnetic optics. The latter wave can be considered as

The path of an ordinary radio wave can be considered as a succession of electric fields of different strengths – just as the sea-wave can be considered as a succession of different heights of water. Associated with this electric field is a magnetic one whose strength alters in the same way but which is pointing at right angles to the electric field (see Fig. 26). The presence of an electric field owes its existence to the fact that no electric current can flow ; this can be visualised by considering the field as a measure of the height of water and electric current as a flow of water, in the water-wave analogy. If water can flow from one position to another then this will occur until there is the same level in both positions. Hence there can be *no* electric field along

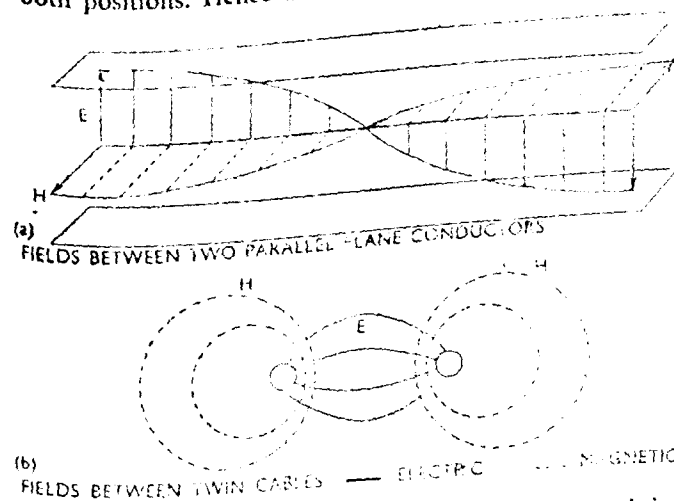


Fig. 27. (a) The electric and magnetic fields within a transmission line are limited by the boundary of the plane conductors.
(b) The fields in a twin cable line are centred on and controlled by the wires - the electric fields beginning and ending on them whilst the magnetic fields are in circular loops round about.

the *length* of a conductor, and it can only be at right angle to the surface. Just as in a dynamo the field of the magnet (altering because of rotation) produces a current, so do the varying field in this case produce current and so the can be a magnetic field along the conductor; it can also be shown that the magnetic field cannot be perpendicular to the surface. There are thus three main conditions to be satisfied.

(a) The electric and magnetic fields must be perpendicular to one another.

(b) The electric field must always be perpendicular to the surface.



Fig. 28. These diagrams show how more detailed are the field configurations in wave guides: only three-dimensional models can show the real relation of the fields, but it should be noted how there are loops of magnetic lines along the guide, whilst the electric field across it is most intense in the middle and diminishes towards the edges - shown by a lesser number of lines. The second diagram illustrates the significance of the two in the suffix H_{11} - there now being two loops and two sets of electric field systems across the guide.

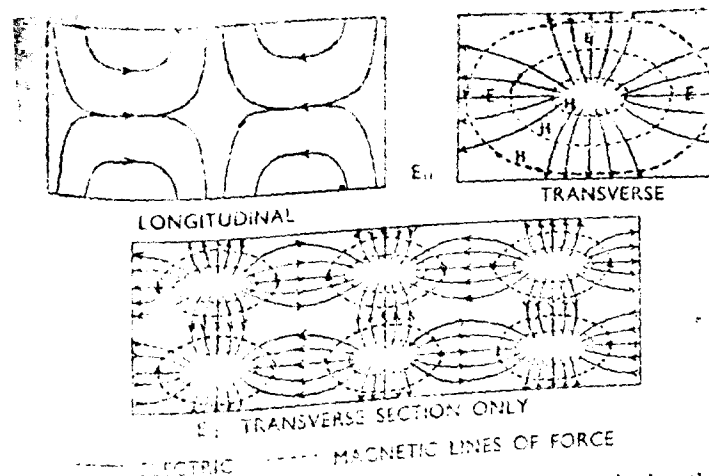


Fig. 29. This is intended to show how, from the E_{11} unit, the other higher and more complicated modes are built up.

(c) The magnetic field must always be parallel to the surface.

The type of field patterns existing in transmission lines is shown in Fig. 27 and in wave-guides in Figs. 28 and 29.

The magnetic lines of force are perhaps easier to visualise since they portray the pattern that would be taken up by iron filings if scattered at a particular part of the guide. The conditions outlined above may be verified from a consideration of these diagrams: e.g. in Fig. 28a the magnetic loops (dotted) are parallel to the side, whereas from the transverse section it can be seen that the electric field, which is a maximum at the centre (represented by the closeness of lines) is zero at the top and bottom.

The waves which exist in a wave-guide have, in addition to the fields perpendicular to the direction of motion, fields pointing in the line of travel.

Analysis of the problem shows that two distinct types of waves can be transmitted.

(a) T.E. (Transverse Electric) or H waves in which there is a magnetic field component along the direction of motion and (b) T.M. (Transverse Magnetic) or E waves where the component along the line of travel is the electric field.

Group and Wave Velocity

In addition to the wavelength discussed above, waves have two other important quantities characterising them - velocity and frequency. These are related by the well-known expression

$$\text{velocity} = \text{frequency} \times \text{wavelength.}$$

In free space the velocity of electro-magnetic waves is that of light (3×10^{10} cm./sec. - usually denoted by c). In the wave-guides the wavelength is altered because of the presence of the walls, and since the frequency remains unchanged, the wave velocity alters, and is in fact greater than c .

This velocity is known as the phase velocity and is the speed by which the patterns portrayed in Fig. 28 move. This is analogous to the speed at which ripples from a disturbance in water set out; there is, however, another velocity to be considered, and that is the rate at which the group of ripples as a whole, move; appropriately enough this is termed 'Group' velocity, and since any signal in radio must consist of several waves (cf. ripples) it is transmitted with this velocity which in this case is *not* equal to the phase velocity but is given by

$$\begin{array}{lll} V \cdot V_g & = & c^2 \\ \text{where } V & = & \text{phase velocity} \\ V_g & = & \text{group velocity.} \end{array}$$

The dimensions of the wave-guide depend on the wavelength of the signal it is desired to pass, and in the case of rectangular guides with dimensions 'a' and 'b' where 'a' is greater than 'b', then no signal with a wavelength greater than $2a$ can be transmitted. Any signal of greater wavelength than this is rapidly lost. This maximum wave-

WHAT ARE WAVE GUIDES?

length is called critical and is denoted by λ_c . It can be shown that if

$$\begin{array}{ll} \lambda & = \text{free space wavelength} \\ \lambda_g & = \text{guide wave-length} \end{array}$$

$$\left(\frac{1}{\lambda_g}\right)^2 = \left(\frac{1}{\lambda}\right)^2 - \left(\frac{1}{\lambda_c}\right)^2$$

and where

$$\lambda_c = 2a$$

$$\left(\frac{1}{\lambda_g}\right)^2 = \left(\frac{1}{\lambda}\right)^2 - \frac{1}{4a^2}$$

It follows from this that as the wavelength is decreased λ_g and λ approximately equal one another. The dimensions of the wave-guide have been chosen so that the wavelength of the signal that will pass along it is near the critical value and is therefore approximately equal to twice the bigger dimension of the guide. This explains why the use of such devices only becomes practicable now that these very short wavelengths are possible; their otherwise bulky size rendered them too expensive as well as too clumsy when other means of transmitting power existed.

Type of Fields

The nomenclature of the various types of waves is based on a mathematical analysis of the types of waves possible. Thus the suffixes in the designations H_{01} , H_{02} , E_{32} , etc. really arise from solutions of equations, needing the sets of integers 0,1; 0,2; 3,2; but a more physical significance of say a H_{02} wave can be obtained from studying Fig. 28(b) where it is seen that the suffix 2 denotes the number of magnetic loops placed across the wave-guide. Similarly an E_{mn} -wave can be regarded as a number m times n of E_{11} wave patterns (shown in Fig. 29) fitted into a single tube and joined into a continuous pattern.

Practical Aspect

For most applications, the H_{10} wave is used as it has the greatest cut-off wavelength: it is possible to choose the size of the wave-guide (bearing in mind the critical wavelength considerations mentioned above) so that other types of waves are suppressed and hence the power is carried in a field configuration that is known – a property which means that it is possible to radiate from the wave-guide into the aerial in a predictable fashion. In addition, with a known type of wave propagation, it is possible to use various techniques (adapted from analogy with transmission lines) more easily. The means of introducing the waves into the guide also governs the mode which can be produced; this is usually done by means of a probe whose position and, to a certain extent, shape, control the required field.

In general, rectangular wave-guides are used, since, whilst other cross-sections (e.g., circular, elliptical) will transmit power, it is not possible to keep the state of polarisation (i.e., the direction of the electric field) constant without high mechanical limits in their construction.

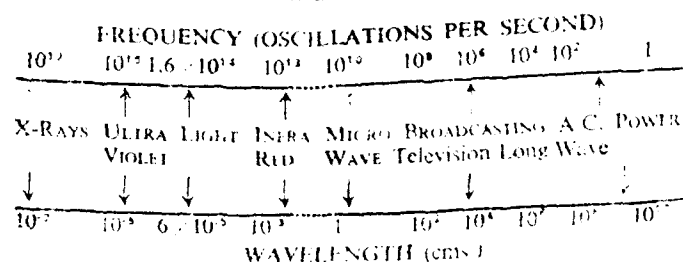


Fig. 30.—A representation of the parts of the electromagnetic spectrum mentioned in the text; the range of wavelength is so great that it is not possible to make the spacing between the various radiations proportional to the true separation. The way of writing the wavelength and frequency in powers of ten is the most convenient manner of describing small and large numbers: e.g., 10^3 means a thousand, 10^5 a hundred thousand, etc., whilst 10^{-3} denotes the fraction $1/1000$, etc. The actual frequencies are three times the values given in the figure.

Microwave Techniques

These electromagnetic oscillations are not the only ones known, since such phenomena as X-rays, light and radiant heat are similar in their character; one of the major achievements of physics is that it has been found possible to classify them in one table (Fig. 30), known as the electromagnetic spectrum, since their position in it is determined by the wavelength. A glance at this table will show that whereas with other tools of science (X-rays on the one hand and low frequency power supplies on the other) the wavelengths are much less than or much greater than the size of objects convenient to handle, microwaves, having a wavelength of say, 3 cm. – the diameter of a penny – are comparable with the actual size of laboratory instruments. Hence with the method of wave-guides have arisen the various techniques which, while perhaps not unique in character, have interesting modifications for use in this region.

The means of producing the electromagnetic waves are different from ordinary radiovalves and circuits. Normal valves, which basically involve a source of electrons (the cathode), a means for controlling the stream of electrons (the grid), and an anode to which the electrons are attracted by the action of the strong electric field in the valve, cannot be used because the time that the electrons take to cross the valve between cathode and anode becomes an appreciable factor. Oscillations inside a valve depend on the same sort of conditions applying when the electron leaves the cathode as when it arrives at the anode, but if, as in microwaves, the frequency is high (frequency is the number of oscillations occurring per second and is greater the smaller the wavelength) a large number of oscillations can occur whilst the electron traverses the valve and this alters the condition referred to above.

For low power, a continuous working 'Klystron' is used, and for very high powers a 'Magnetron', where, because of the large amount of heat produced, the valve is only allowed to operate for a fraction of a second,

thus giving pulses of radiation. The former depends on sorting out the electrons into 'bunches' of fast-moving and slow-moving types which then form the equivalent of the peaks and troughs in a wave; the latter depends on the spiral motion of an electron under the influence of a magnetic field.

Because of the low wave-lengths, it is not possible at the moment to use valve circuits of any form directly to detect and amplify the signals, and hence the old 'crystal and whisker' technique has been revived for the former purpose, and plays an essential part in all radar work. The wave guides themselves are made in sections and have coupling joints to make continuous lengths; these must be well made to close measurements, since any lack of alignment entails loss of energy as well as possible distortion. Provided that the change is made smoothly, it is possible to transmit signals through curved wave guides - a very big advantage. The wavelength is actually measured with a 'wavemeter' which is an instrument involving a micrometer screw (such as engineers use to measure diameters of wires, etc.) which, when associated with a device for indicating maxima and minima of power, measures the distance between two peaks or troughs. This reversion to fundamentals which is characteristic of this region is also followed in the measurement of power, the normal method being to note the heating effect which occurs when the radiation is passed into water whose temperature and weight can be found experimentally, from which the heat gain can then be deduced.

Uses

The main use of microwaves and the essential wave guides has been, and is, in connection with the transmission of short wave signals in purely electronic applications, but a more academic use has begun to be important - the determination of some absorption bands of gases and liquids. Thus in some liquids, the molecules, owing to the out-of-balance electric forces between the electrons of the

constituent atoms, possess a resultant charge which means that the molecule as a whole will be affected by an electric field. If this field is not steady but alternating with a certain frequency, then the charged molecule will tend to vibrate, just as a cork on the sea will bob up and down under the effect of the waves, and hence absorb energy for the movement. As the wavelength of the waves is altered, then so will the ability of the cork to keep in step with the waves change until finally, when the crests follow each other very rapidly, the cork will be unable to follow the movement of the water at all. In an analogous way, the molecule can follow the alternating electric fields up to a certain limiting frequency only; beyond this it will not be affected and hence will not take any power from the field. This critical frequency depends on the structure of the molecule and by noting the frequency where the absorption of power falls off, valuable information about the arrangement of the atoms can be obtained. For many liquids, the region where this occurs lies in the centimetric wave lengths, and hence this radiation has been used to obtain information about the liquid state. There is a similar effect in gases where however rather different conditions apply. When energy (of electromagnetic origin and wavelength in the region of the infra-red) falls in a gas molecule, the absorption can cause two main changes - it can make the constituent atoms in the molecule vibrate quicker (cf. a spring given a knock) or it can make the whole molecule rotate faster, like a top. The basic concept of modern physics states that this energy, taken up in these two forms, must be in discrete units in much the same way as penny and half-penny stamp machines need units of a penny and a half-penny respectively to start the wheel rolling; four farthings would be useless in either case, as would an interchange in the coins. These energy units (E) are connected with the frequency by the general relation

$$E = hf$$

where h is a proportional conversion constant known as

Planck's constant, f is the frequency, and it is seen that this is plausible since the more vibrations one gets per second, then the more energy one would expect to be involved. The vibrational changes need more energy than the rotation, and it is found in general that the absorption in the microwave region involves rotational transitions whereas the vibrational changes occur for radiation of much higher frequency.

Various gases have been examined for this effect, and it should be noted that this subject is of importance to the radar engineer as well as the theoretical physicist, since this absorption of power may occur in the gases of the atmosphere. Oxygen and water-vapour show marked effects for certain critical wavelengths and hence care is taken to avoid these for actual transmission purposes. Another gas which has been examined quite considerably is ammonia, not because it has any practical application but because there is great theoretical interest in its structure: the gas molecule is made up of three atoms of hydrogen symmetrically arranged at the base of a pyramid, the apex of which is occupied by a nitrogen atom. This atom can be on either side of the hydrogen plane and the energy necessary for the transfer is such that the molecule absorbs it from radiation of centimetric wavelengths. The principle behind the measurement of such effects is very simple and consists merely in determining how much power is put into the gas contained in a length of wave-guide and how much emerges: the difficulty comes in cases where the absorption is not very great, and long lengths of waveguide together with very sensitive detectors are necessary.

Future

The whole trend of radar is towards shorter wavelengths, and, as can be realised from the consideration that a wave guide is of approximately the same dimensions as the wave it is carrying, it can be seen that mechanical difficulties prevent it being successfully used much below centimetric

WHAT ARE WAVE GUIDES?

width, and hence other means for transfer of energy must be found. It has however become indispensable in the region of radiowaves developed mainly during the war (3-20 cm.), and forms an interesting example of the application of theoretical physics to a practical problem.

FURTHER READING

Wave Guides - H. R. L. Lamb et al. Methuen Monograph.
A Survey of the Principles and Practices of Wave Guides - L. G. H. Huxley, C.U.P.

About Our Contributors

Bob Bostrom, of Merville College and Keble College, Oxford, intends to make oil geology his career as he believes that at present his interests lie in geology as a means of exploiting mineral resources rather than in the purely academic side of the science.

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Colin Butement was born in New Zealand in 1911, but came to England when he was four. Has done research at Dufay Chromex, was a Photographic Officer in the R.A.F. during the war, and is now Research Manager of Deep 1.

Colin G. Butler, who is 35 years old, was educated at Monkton Combe School, Bath, and at Queens' College, Cambridge, where he obtained his Ph.D. in 1938. He carried out research at Cambridge on Whiteflies whilst holding a Research Scholarship from the Ministry of Agriculture, and later on Locusts. Since 1944 he has been Head of the Bee Department at Rothamsted, where his particular interests are the physiology and behaviour of bees and bee breeding. He is happily married with two children, and his chief hobbies are natural history photography, bird watching, and fishing.

J. L. Crammer has been editor of *Science News* from the first issue, originally under a pseudonym. He has had experience of Service life and of journalism, is a Science graduate of Cambridge, where he has done research, is medically qualified, and has practised medicine.

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A. F. M. Harford was born in Gresham (B.W.I.) in 1922. B.Sc. (London) and at present on the technical control side of production in a G.E.C. factory. A keen amateur actor and very active member of the Conservative party.

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R. W. Moncrieff was born at Preston in 1903, the first member of the family to be born outside Scotland. First-class Honours in chemistry in 1923 at Manchester. Prolific inventor, with more than a hundred British Patents. Author of *The Chemical Senses*.

Denys Parsons was educated at Eton and University College, London. Has spent 5½ years in industrial research on rubber latex and plastics. Since 1945 has been engaged in the production of scientific educational films. Became interested in psychical research as a side-line in 1940, and has done a fair amount of experimental work, with negative results.

Max Perutz was born in Vienna in 1914. He studied chemistry at Vienna University, and came to Cambridge in 1936 to do research in X-ray crystallography with Professor J. D. Bernal. In 1939 he was appointed research assistant to Sir Lawrence Bragg. During the war he worked at Combined Operations H.Q. for some time, and is now a member of the staff of the Medical Research Council at Cambridge University. His main work is concerned with the molecular structure of the crystalline proteins. On his holidays he pursues glaciology along with climbing and ski-mountaineering.

E. Lester Smith obtained his D.Sc. for research on saponification of oils and physical chemistry of soap solutions. Joined Glaxo Laboratories in 1926, where he has in turn taken charge of research, development and production of vitamins, synthetic drugs and penicillin. At present is in charge of biochemical and biophysical research. Has been working on the pernicious anaemia problem on and off for ten years with his colleagues, but the work was interrupted by other urgent problems, such as penicillin, during the war years.

W. C. Vaughan, M.B.E., after graduating in the University of Wales, carried out experimental research in radio physics in the University of London, for which he was awarded the degree of Ph.D. Author of a number of contributions to scientific journals on radio subjects. During the latter half of the recent war was Senior Training Officer of the R.A.F. No. 1 Radio School.

J. Warren Wilson is a botanist, at present engaged on research into the inter-relationships of roots and soil. He is going on an expedition to Mount Kenya in 1949.

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