

SCIENCE NEWS

EDITED BY ARCHIE AND NAN CLOW

49

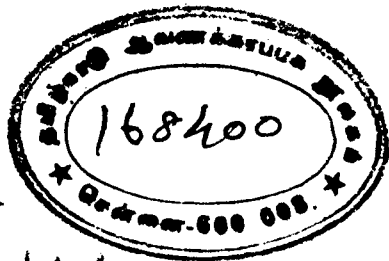
PENGUIN BOOKS

Penguin Books, Ltd, Harmondsworth, Middlesex
U.S.A.: Penguin Books Inc., 3300 Clipper Mill Road, Baltimore 11, Md
AUSTRALIA: Penguin Books Pty Ltd, 762 Whitehorse Road,
Mitcham, Victoria

First Published August 1958

Copyright © Penguin Books Ltd, 1958

Made and printed in Great Britain
by The Campfield Press,
St Albans



Am1, N46
N58-49

In 1958 there will be four issues of *Science News*, appearing in February, May, August, and November. Subscriptions are accepted at 11/- for four issues, post free. Numbers 5-7 and 21-48 inclusive are still available. If there is any difficulty in obtaining any of these from a bookseller they may be had by writing direct to the publisher

CONTENTS

GRAVITATIONAL WAVES W. B. Bonnor	7
UNCONVENTIONAL PRODUCTION OF FOODSTUFFS N. W. Pirie	17
SILICONES M. H. Thorndike	39
BUBBLE CHAMBERS AND NUCLEAR RESEARCH J. R. Atkinson	56
THE STUFF OF BONES G. M. Wyburn	76
COMMUNICATION IN THE FIELD OF SCIENCE R. H. Macmillan	93
RESEARCH REPORT A. W. Haslett	105
CORRESPONDENCE	120
SOME BOOKS RECEIVED	122
ABOUT OUR CONTRIBUTORS	127
CONTENTS OF RECENT ISSUES	128

16 illustrations are between pages 64 and 65

GRAVITATIONAL WAVES

W. B. BONNOR

OF all physical phenomena, none affects us more in our everyday life than does gravitation. To learn to live with gravitation, or as the physicist puts it, in a gravitational field, is one of an infant's most urgent tasks; and he is able to accomplish it fairly easily because he is the latest product of a line of biological evolution in which the need to live efficiently with gravitation has played an essential part.

From this point of view it is not surprising that two of the greatest theories of physics – those of Newton and of Einstein – should be concerned with gravitation. With these theories it is possible to predict gravitational phenomena with amazing accuracy, on both the terrestrial and the astronomical scales.

But in spite of this, gravitation is still far from being completely understood. It is not merely that gravitational forces stand apart from the other forces of physics, lacking unification with them; or that they are unexplained in terms of atomic physics, which most physicists regard as more fundamental. Our lack of understanding is shown too by our inability to influence gravity, or to use it very effectively for our own purposes. We lack almost completely any practical means of creating or destroying gravitational fields.* Even the recent spectacular achievements of launching earth satellites are cases of escaping from the Earth's gravity, rather than of controlling it.

To appreciate this lack of control more fully, we may compare our gravitational impotence with the power we have gained over electrical and chemical forces, and more recently, over the

* A gravitational field can be created by centrifugal force caused by rapid rotation – a method sometimes mentioned in connexion with space travel.

forces of the atomic nucleus. As sources of power, these play an enormously more useful part in our civilization than does gravity.

In this short paper I want to describe some ideas which, though offering no immediate hope of changing this situation, are at least relevant to it. The basic idea is that in certain respects a gravitational field is like an electromagnetic field. In particular, we now have reason to believe that electromagnetic waves have a counterpart in gravitation, called gravitational waves, and since knowledge of electromagnetic waves helped us towards the use of electromagnetic fields, we may hope that a study of gravitational waves will help us in finding ways to use gravitation.

Waves

If a stone is dropped into a pond, the crests and troughs of the resulting waves travel outwards in circles. At first one might suppose that a drop of water involved in the disturbance travels along with the wave. This is not so, however, as may easily be seen by watching a cork floating on the surface: the cork simply moves up and down as the wave passes by. The waves nevertheless carry energy with them; this means that part of the energy given to the water by the stone is taken away by the waves, and could in principle be used at some distant point to drive a machine.

The above refers to water waves: another simple example is the waves propagated along a stretched rope when one end is moved up and down. Here again the motion of a particular bit of the rope is simply up and down, but, as before, energy is transferred from the operator along the rope by the wave.

Important properties of all wave motion are the *wavelength*, *frequency*, and *speed of propagation*, which are related by

$$v\lambda = c$$

where v is the frequency, λ the wavelength, and c the velocity of propagation.

In the case of water waves we speak of water as the medium of propagation; similarly, air is the medium for sound waves, but,

as we shall see, it is not always possible to think of the medium in this simple way.

One final important concept is the *source* of the wave motion. In the water waves mentioned at the beginning of this section, the source is the stone; in the case of the rope, the operator moving the end constitutes the source; and in sound waves, the source is some agent which disturbs the air, such as an organ pipe or the vibrations of a violin string.

Electromagnetic waves

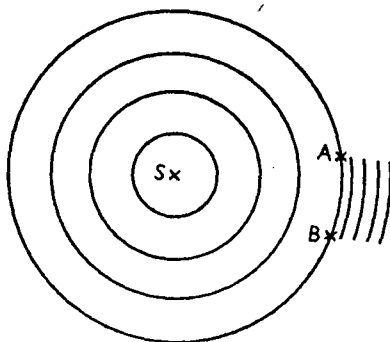
Wireless waves and light are electromagnetic vibrations of different frequency. Here, the notion of a 'wave' is more difficult. To start with, the quantity that is varying is nothing like so simple as the changing height of a water surface. It is in fact the strengths of the electric and magnetic fields that vary, and the situation is further complicated because the directions in which the strength are pointing vary too, but this need not worry us here.

Another thing which is hard to understand about electromagnetic waves is the medium of propagation. This difficulty was a blind-spot for nineteenth-century physicists who called the medium the *aether*, and endowed it with various strange properties in an effort to make it resemble the more familiar media of wave-propagation. When the special theory of relativity was discovered, however, the idea of the aether was given up, and attempts were no longer made to visualize electro-magnetic waves as moving in a material medium. Nowadays physicists are quite content to think of electromagnetic waves as moving *in vacuo*. This, incidentally, is an interesting example of how a question in physics may disappear, not because it is answered but because ideas change so that the question is no longer asked. When it was realized that the problems of electromagnetic waves could all be solved just as well without postulating the aether, the concept was dropped.

In spite of the difficulties one has in forming a mental picture of electromagnetic waves, there is no doubt that they do have the properties of true waves. One can identify wavelength and

frequency; and the speed of propagation is the well-known constant – the speed of light. Moreover, everyone knows that the waves carry energy, because it is by electromagnetic vibrations that solar energy is conveyed to earth; and, of course, wireless waves carry energy from the transmitter to the radio receiver.

The source of electromagnetic waves is moving electric charges. Imagine two electric charges one at each end of a spring, and insulated from it. If the spring is made to vibrate, waves are emitted, and they carry energy away from the system. This causes the motion to run down, and if one wanted to radiate waves continuously from this apparatus it would be necessary to provide energy to make up that lost by radiation. In practice, for the generation of radio waves, the source is an antenna carrying alternating current. Changes in current have the same effect as the movement of the charges in our model. If the antenna is small, for mathematical purposes we can treat it as a point and think of the waves as radiating from it in expanding spherical surfaces. If we take a very large sphere, and consider a part of its surface which is not too large (such as AB in the figure), we can consider this part as a plane surface.



It follows that, at great distances from the source, we can treat the wave-crests as lying approximately in parallel planes. This simplification gives rise to what are called *plane waves*. The mathematical solution of the equations of electromagnetism

(Maxwell's equations) for plane waves is fairly simple, whereas the exact calculation for spherical waves is difficult. For this reason many of the properties of electromagnetic waves have been worked out from the plane wave solution, but it must always be remembered that plane waves are mathematical fictions to be used only for great distances from the source. We are, however, justified in using this fiction because we know from observation that spherical waves do become like plane waves at these distances; for example, the plane wave approximation is a very good one for light reaching us from the sun.

Gravitational waves

In the above section reference was made to Maxwell's equations. These are a set of partial differential equations which describe the electromagnetic field. This is typical of what are known as field theories; that is to say, each such theory has a set of partial differential equations (called *field equations*) which describe it. Progress in field theory consists in discovering special solutions of the field equations corresponding to particular problems – such as the spherical wave and the plane wave above.

The properties of the gravitational field were described in the General Theory of Relativity put forward by Einstein in 1915. Finding special solutions of the field equations of general relativity is an exceptionally complicated mathematical task, and ever since 1915 relativists have tried to find solutions that would reveal hidden properties of gravitational fields, and also enable the theory to be tested further. The two most important solutions that have been discovered so far are, first, the solution for the field of a single mass, such as the Sun; and secondly, the solution for the expanding Universe, considered on a very large scale, without taking account of local irregularities. It is on the properties of these two solutions that the observational tests of general relativity are based.

Since the field equations of general relativity are so difficult to solve, it is common to try to solve them step by step, by successive approximations. The first, and crudest approximation, which was early studied, led to the remarkable prediction that a

gravitational field must show the properties of waves. Among other things, this means that gravitation must be propagated at a finite speed – the speed of light – and if it were possible to ‘switch on’ a gravitational field suddenly, a measurable time would elapse before the effect reached a distant place. As yet, in fact, we have no means of switching on gravitational fields; those we have are always with us, because the masses that generate them, such as the Sun and Earth, are always there.

Another property of these gravitational waves, as predicted by the approximate solutions of the field equations, is that, just like other forms of wave motion, they carry energy away from the source. Moreover, like electromagnetic waves, they have no ‘medium’, but move *in vacuo*.

All this is very different from Newtonian gravitational theory, according to which, gravitation should be propagated instantaneously, and which makes no reference to gravitational waves.

So far reference has been made to the solution of Einstein’s field equations in the first, or crudest, approximation. Owing to mathematical difficulties, progress in finding better approximations has been very slow, and it was not until 1938 that real improvements were made. Einstein and the Polish physicist, Leopold Infeld, then showed how to solve the equations of general relativity by successive approximations with a method that could, in principle, be carried to any desired accuracy. Much valuable light has been thrown on the theory by this method, particularly concerning the motion of bodies, as, for example, Planets moving about the Sun.

The approximation method of Einstein and Infeld indicates that gravitational waves are not emitted in the motion of the Planets round the Sun. Their work says more than this however: it shows that waves are not emitted when two or more bodies move under the influence of their gravitation alone. This means that waves can be given off only when there are non-gravitational forces acting on the bodies. Thus waves might be given off by two masses at opposite ends of an oscillating spring, because the masses are subject, not only to their own gravitation, but also to the (non-gravitational) forces of the spring. Waves might

also be emitted by a rotating body, because in this example there are cohesive forces between the molecules of the body. Thus, although, according to Einstein and Infeld, the Earth could not emit waves on account of its motion round the Sun, waves might be given off because of its rotation about its own axis.

Recent work

The work of Einstein and Infeld, which seemed to show that no waves are emitted in the ordinary gravitational motion of bodies, naturally made physicists doubt whether gravitational waves had any real existence at all. It must be emphasized however that the approximation method of Einstein and Infeld was not convincing in every respect. It seemed, for example, that there ought to be different approximation methods, and it was possible that these might give different answers. To be quite sure, more exact solutions of the field equations were needed.

Within the last two years an exact solution has been found which looks highly significant. This solution, discovered by Ivor Robinson of the University College of Wales, at Aberystwyth, and later, independently by Professor H. Bondi of King’s College, London, refers to plane gravitational waves. The importance of electromagnetic plane waves as a solution of Maxwell’s equations was mentioned above: the gravitational plane wave is similar, though much more complicated mathematically, and one can show that it too carries energy.

The Robinson-Bondi exact solution, and certain others that have recently been discovered, suggest that general relativity definitely predicts the existence of gravitational waves. None of them, however, gives any reliable information about the source of the waves, so, until this problem has been solved, we cannot be sure about the truth of our conjecture that masses on the ends of an oscillating spring, or a rotating body, can act as sources of gravitational waves.

The results of work done recently in Russia on gravitational waves have just been published in an important book by V. Fock, not yet, unfortunately, translated into English. It seems, however, that Fock has no doubt that gravitational waves have

a real existence. Moreover, he has calculated the rate at which energy is lost as gravitational radiation from the solar system.

The significance of gravitational waves

Since waves carry energy away from a source, it follows that waves travelling through space with the speed of light, such as electromagnetic or gravitational waves, are a means of transferring energy very quickly from one place to another. If such waves are to be put to any practical use, there must be an absorber to receive them, otherwise they will simply go on travelling indefinitely. Let us consider the two ends of the wave process, source and absorber, in turn.

As has been said, we believe that gravitational waves are emitted during certain sorts of motion of bodies. Two examples were mentioned – masses on the ends of an oscillating spring, and rotating masses. Such systems must lose energy corresponding to the amount transferred by the waves. Therefore, if no fresh energy is supplied, the motion of the systems must run down. Thus one would expect the rotation of the Earth to be slowing down because it is emitting gravitational waves.

Turning now to the absorption of the waves, it seems that it should be quite simple to transform their energy into kinetic energy by placing a small particle in the field of the waves. The variations in the gravitational field caused by the waves would result in regular motions of the particle, and in principle it should be possible to use these motions to drive a machine. In fact, we can imagine an absorber consisting of two small masses on the ends of a spring like one of the transmitters already mentioned, but much smaller. Mechanical energy would be transferred from one system to the other by the waves.

This process is similar in principle to the transfer of energy by wireless waves, in which an electrical disturbance at the transmitter induces a smaller disturbance in a distant wireless receiver. One might, therefore, envisage gravitational waves as a method of communication similar to wireless waves.

Here, however, one meets the main difficulty in any practical use of gravitational waves – the extremely small magnitudes of

the effects involved. Fock calculates the entire output of gravitational waves of the solar system as 450 watts. The rate of loss of energy by the Earth due to its rotation must be less than this, and quite below the limit of experimental detection. The minuteness of this figure is well brought out by comparing it with the output of electromagnetic radiation by the Sun, which is about 10^{26} kilowatts! The energy radiated by a wireless transmitter is usually of the order of hundreds of kilowatts. It seems hard to conceive at present how it would ever be a practical business to build a gravitational transmitter with anything approaching such a power.

The extreme weakness of gravitational radiation from ordinary sources also prevents one from being very optimistic about its use as 'anti-grav'. For those who do not read science fiction it should be explained that 'anti-grav' is a device which, when switched on, counteracts or modifies the natural gravitational field within some region of space. Now we can imagine a ring of gravitational transmitters sending out waves which, at the centre of the ring, interfere to produce a gravitational field just sufficient to cancel the natural gravitational field. Such a project, though conceivable in principle, is, even more than gravitational communication, dependent on finding some very powerful source for the radiation.

Should we, therefore, say that gravitational waves are only of theoretical interest? Though our present knowledge suggests that this is so, my own view is that it would be premature to assert this too dogmatically. We cannot rule out the possibility that for certain special motions of our oscillating spring the rate of energy transmission might become large enough to be of practical interest. It is possible, too, that theory may reveal other types of source that can radiate energy much more freely.

Practical considerations apart, however, it seems likely that knowledge of gravitational waves will be important for theoretical purposes. For example, in spite of many attempts, it has not been possible to apply to gravitation the ideas of quantum theory. The unique position of gravitation in this respect is one of the most puzzling problems of modern physics. This being so,

it is reasonable to hope that knowledge of gravitational waves may help here. Another subject to which gravitational radiation may be relevant is cosmology. The motions of the cosmic masses in the evolution of the Universe must have caused the emission of large amounts of gravitational radiation, and it would be surprising if this had not played a significant part in the past history of the Universe.

REFERENCES

- Robinson, I.: To be published.
 Bondi, H.: *Nature*, 1957 179 1072.
 Fock, V.: *Theory of Space, Time, and Gravitation* (Moscow, 1955).

UNCONVENTIONAL PRODUCTION OF FOODSTUFFS*

N. W. PIRIE

WHY should anyone want to make an unconventional food? Not simply because of an itch to make or taste something novel, but because more food is needed now and, as populations increase, the need will become more acute. This is not a new state of affairs. The world has always been a hungry place with famines and lean years occurring constantly. Even in good years, and even in the better fed countries, only a minority could be certain of enough to eat throughout the year. Most people in the past accepted this as the natural condition of Man, and those who maintained that it was avoidable if human intelligence and energy were properly directed, have been variously labelled Atheists, Dreamers, Communists, and various other things according to the fashion of their day. During the last half-century there has been a radical change. A few countries, containing perhaps one-fifth of the world's population, have by a mixture of skill and cunning broken loose from the historical pattern and maintained a system in which nearly everyone had enough to eat and expected to continue in that state indefinitely. Not only have they collected enough to eat themselves but some, such as U.S.A. and Australia, accumulate a surplus that they find embarrassing. This surplus tends to distract attention from the fact that the world as a whole still needs more food. But the facts are clear. Table 1, taken from a 'Commodity Policy Study' by the Food and Agriculture Organization¹ shows that there is a wide gap between the food intakes of the better and worse fed

* This is a somewhat extended version of a paper contributed to the symposium on 'The Biological Productivity of Britain' organized by the Institute of Biology in October 1957.

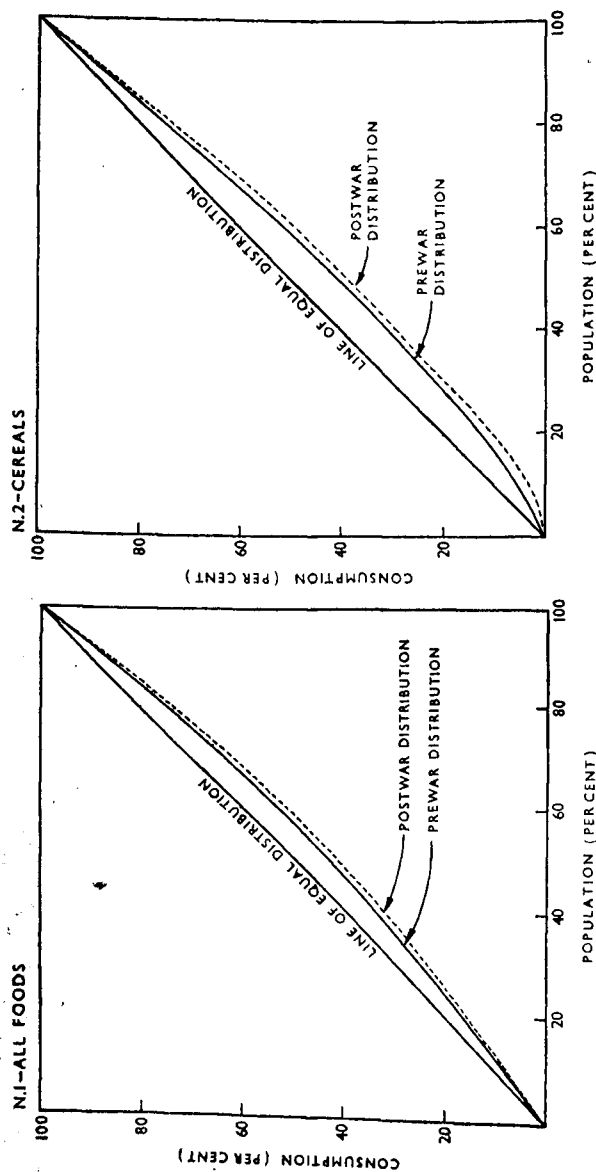
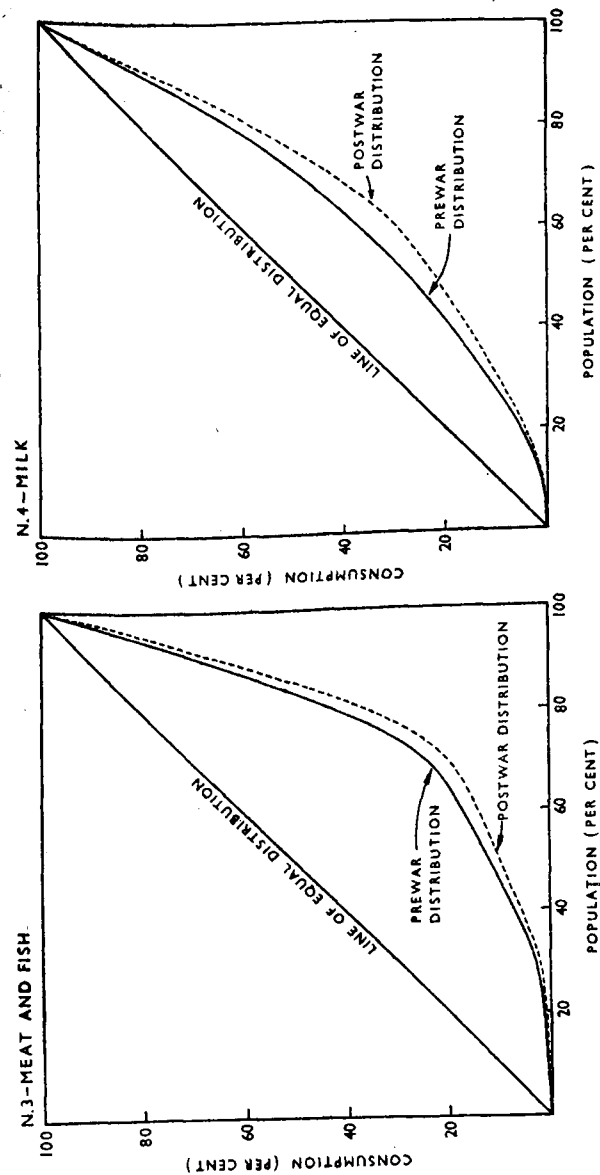


TABLE 1: The horizontal scales measure per cent of the world population and the vertical scales show per cent of world consumption of foods. If shares of consumption were distributed equally all over the world, i.e., if every 10 per cent of the world population absorbed 10 per cent of world consumption, the resulting curves on the charts would be straight diagonal lines. These 'lines of equal distribution' are plotted on the charts. In the (continued on next page)



real world, on the other hand, the lowest-standard 10 per cent of the world population absorb less than 10 per cent of world consumption and the highest-standard 10 per cent absorb more. The actual-distribution curves, therefore, are not straight but sagging, and the degree of sagging indicates the degree of inequality.

parts of the world and that the gap is getting bigger. The latter fact is especially disturbing.

In the past, fortunate and thoughtful people were less directly affected by these differences. They often only heard of the famine when it was long established and the technical problem of arranging anything but palliatives was insuperable. This is no longer so. News of other people's misery reaches us in a few days and by an effort of the same order as that involved in launching a major military offensive we could move the surpluses to the points of need. That, for a brief period, would solve the problem. But hunger would remain and a surplus takes time to build up.

Although there may be general agreement that more food is needed, there may be disagreement about the need for unconventionality in our mode of getting it. The conventional way to get food is to pick it or catch it. We sometimes change the environment a little, as we did when we invented agriculture; or we change the end product, as when we skin, peel, and cook it. The obvious way to get more food is to do these things more intensively. There has been a steady extension of the area farmed; this has saved us in the past and was the main factor that made Malthus wrong; or at any rate premature. The process could go a little further and open up parts of South America, Africa, and West China, but no regions remain that are comparable in area and probable value to those brought into cultivation for the first time during the nineteenth century. As an alternative to farming a greater area we could use better varieties and techniques, and more fertilizer and irrigation water on the existing areas. These things are all being done and they will contribute greatly to the amount of food produced. The case for unconventionality rests on the suspicion that they may not alone prove adequate and that it may be well to explore other methods even although we may hope that they will not have to be used.

To put the problem into perspective, the basic food requirements must first be stated. People need protein, fat, and carbohydrate, in bulk, and minerals in smaller amounts. The vitamins – a chaotic category of substances – are lumped rather than

grouped together because they are only needed in extremely small amounts. The first three types of food are to some extent interchangeable; but not completely, a certain amount of each is essential. There is, therefore, no basis for looking on some components of a diet as more important than others, but, although all are essential, some are cheaper and more easily come by than others. Carbohydrate is generally the most abundant food-stuff so that it is apt to bulk large in the inadequate diets with consequent shortage of protein and vitamins.

All over the world people need much the same amounts of much the same types of food, and the fact that many communities have for generations existed on less should not make us lose sight of this. It is convenient, however, to consider the needs of one country, and Britain will serve our purpose as well as any other. Table II sets these out. It is usual to express human energy

TABLE II

The Power of the People

2,700 kilocalories a day = 130 watts, so
50,000,000 people = 6,500 megawatts.

The Fuel of the People

Foods supply: protein	3.9 K calories per gram
carbohydrate	4.2 K calories per gram
fat	9.0 K calories per gram

An average mixed diet will not therefore contain more than 6 K cal. per gram, so 2,700 K cal. would be supplied by 450 grams. For 50,000,000 people that is 8.2 million tons a year.

requirements in kilocalories per day. There are two disadvantages in this; the units are often called calories and eminent scientists have perpetrated fallacies through not realizing that this careless usage was being followed; the usage obscures the relationship between the amount of energy handled by people metabolically and in the course of using lamps, fires, electric motors, and so on. A person obviously does not run at a steady 130 watts. During sleep and quiet periods the rate falls to 60 watts or lower, and rises above 1,000 during exertion. From

Table II it is clear that each person needs more than a pound of the dry matter of food each day. The actual weight eaten is, of course, greater than this because most foods are more than half water. There are no known, or probable, foods that give more energy per gram than the fats. Whatever success we may have in making new types of food, the vision, or nightmare, of a meal degenerating into the swallowing of a few pills every day, is therefore baseless. The total bulk eaten will remain about what it is now: this bulk is quite impressive, more than 8,000,000 tons of dry matter a year. Similarly, the population of this country metabolizes a substantial amount of energy; the people are running at nearly 6,500 megawatts, whereas the target set for the proportion of our power that is to come from the twelve proposed nuclear stations is only 5,000–6,000 megawatts by 1965. Unconventional forms of production, if they are to supply any significant proportion of the needs of even such a small country as Britain, will necessitate the setting up of major new industries. And Britain contains less than 2 per cent of the world's population. There is, therefore, no reason to set the different unconventionalities that have been proposed in opposition to one another. There will probably be room for every one that is soundly based, for the world's needs are great.

The most unconventional way to get more food would be to make it synthetically. At present no food eaten in bulk is synthesized. Fats have been made on the 2,000-ton a year scale by the partial oxidation of petroleum, or Fischer-Tropsch hydrocarbons, and laboratory scale experiments have been made on the polymerization of crotonic aldehyde ($\text{CH}_3\text{CH}=\text{CH}\cdot\text{CHO}$) to products from which acids with 8, 12, 16, etc. carbon atoms could be made. The difficulty with these processes is not, as is sometimes thought, the unfamiliar flavour of the fats made – that could probably be easily remedied by a little more research – rather it is the scale of the proposed industry. The war-time 8 oz. a week ration for Britain needed 10,000 tons of fat a week. The German plant that produced only a three-hundredth of that cost more than £1 M.

The costs of synthesis could probably be greatly reduced,

but it is still legitimate to wonder whether attention has been focused on the right objects for synthesis. Instead of trying to make the complex substances that supply most of the energy in a normal diet we might think more about the simple substances that could make up a small but useful proportion of it. Some of these are listed in Table III: they are all either already being

TABLE III

Some easily synthesized foods

Acetic acid	CH_3COOH
Alcohol	$\text{CH}_3\text{CH}_2\text{OH}$
Glycine	$\text{NH}_2\text{CH}_2\text{COOH}$
Alanine	$\text{CH}_3\text{CH} \begin{array}{l} \nearrow \text{NH}_2 \\ \searrow \text{COOH} \end{array}$
Beta alanine	$\text{NH}_2\text{CH}_2\text{CH}_2\text{COOH}$
Glycerol	$\text{CH}_2\text{OH}\cdot\text{CHOH}\cdot\text{CH}_2\text{OH}$
Succinic acid	$\text{COOH}\cdot\text{CH}_2\text{CH}_2\text{COOH}$

cheaply synthesized in bulk, or could be. Only one, alcohol, is a familiar food. The rituals that normally surround its production and consumption are apt to obscure the fact that it is a remarkably cheap energy source and in many communities – the coal miners of Fife for example² – it supplies 5 per cent of the energy for heavy work. It is only when addicts raise its contribution to 30 per cent or more of the total calorie intake that the traditional signs of poisoning supervene.³ The other possible simple synthetic foods might be greeted with less enthusiasm and the extent to which they could usefully be included as regular components of a human diet is not known, but it is safe to assume that together they could make up 10 per cent of it, and 10 per cent of our annual food intake is nearly one million tons.

At a certain level of complexity a complication is introduced into synthesis by molecular asymmetry. Simple molecules are symmetrical, as most bottles and chairs are. As complexity increases it becomes more likely that they will be asymmetric like books and corkscrews. When this stage is reached there can be a mirror image molecule just as there can be a left-handed cork-

screw or a book designed to be read in a mirror or from the back. In Table III alanine is such a molecule. The H in the middle must be pictured as lying either above or below the plane of the paper, thus making two forms that are related to each other as the right and left hands are. They are called dextro and laevo, or *D* and *L*. Substances of this type, the amino acids, are generally important because they are the building units of proteins, and for this purpose only the *L* forms are generally used. These are all related to each other as the various types of right-handed screw – wood screws, corkscrews, twist drills, etc. – are related. When an amino acid is made synthetically both forms are made at once and it is difficult to separate them so that the useful *L* would be accompanied by the *D* forms, which are useless for protein-building and may be harmful. When an amino acid has a function other than protein-building, both forms can be used. This is so when alanine is used as a tissue fuel, it is also so with methionine ($\text{CH}_3\text{SCH}_2\text{CHNH}_2\text{COOH}$) probably because one of its roles is to supply methyl (CH_3 —) groups and either form can do this. *DL* methionine is already being synthesized in bulk for improving animal feeding stuffs. As cheap methods for synthesizing some of the other amino acids are developed we may expect to see them also appearing in foods but, because of the probable expense of these syntheses and of the unknown effect of eating unnatural *D* forms for long periods on a large scale, it is not likely that the bulk of our amino acid requirement will ever be met by total synthesis, rather than by some form of natural protein.

The vitamins are already being synthesized in bulk. The scale on which they are synthesized is bound to increase, but improvement in the technique of synthesis is certain to be balanced by the discovery of better natural sources and techniques of isolation. Thus riboflavin is now commonly isolated from cultures of *Eremothecium Ashbyii* and it is nearly economic to isolate the ascorbic acid already present in green walnuts, rather than go through the intricacies of 'synthesis' from easily available natural sugars. The inverted commas indicate an important aspect of synthesis; to be useful it need not be total but may start

with a related product of farm or fermentation tank and convert that by a few changes into the substance required. Steroid production offers several examples; thus ergosterol is made from cheaper sterols, and cortisone from hecogenin extracted from sisal. In this mutable field one confident prediction may be risked; we shall continue, for many years to come, to rely on organisms rather than total synthesis for our supplies of chemical extravaganzas like vitamin B_{12} .

Total synthesis would, or could, start from the carbon of coal or limestone and atmospheric nitrogen, and the energy generally needed for the syntheses would have to be supplied from whatever power supply the country used. The alternative mode of production starts with atmospheric carbon dioxide and nitrogen but gets its energy from sunlight. The different forms of photosynthesis are basically the same; technical convenience controls the decision whether a given illuminated area is better used to grow trees and harvest once a century, wheat or potatoes and harvest once a year, a leafy crop and harvest once a month, or a unicellular alga and harvest continuously. These are the types of organism that have to be used to bring new organic matter into circulation. They must be distinguished sharply from animals, fungi and most of the bacteria, which only shuffle, with varying degrees of inefficiency, the materials the photosynthesizers have made. There is, therefore, nothing unconventional about the process of photosynthesis; any unconventionality we may envisage lies in the conditions under which we let it operate, in the plant species that we use, and in the uses to which we put the products. These distinctions are made in Tables IV and V.

Sunlight is likely to remain the only significant energy source for photosynthesis. Artificial light is useful for altering the physiological rhythms of some plants and animals, but the low efficiency of conversion of energy into light, and of the photosynthetic process itself, makes it likely that, if new energy is being applied to food production, it would be used for the synthesis of substances of the type mentioned in the last section. Everyone knows that Britain is a sunless and ill-lit island. But

TABLE IV

The main vehicles for photosynthesis

<i>Crop</i>	<i>Environment</i>	<i>Interval between harvests</i>
Trees	Unploughed and often unploughable land	50-100 years
Wheat, potatoes, etc.	Ploughland	1 year
Leafy crops	Ploughland	About a month
Algae	Tubes or tanks	Daily or continuous

In spite of these variations, all give about the same return of organic matter per acre per year if warmed, watered, fed, and illuminated comparably.

TABLE V

Two types of useful organism

The primary producers that make new organic matter starting with CO_2 , water, some salts, and nitrogen compounds that can be as simple as N_2 or NH_3 .

Examples: trees, farm crops, algae.

The Shufflers are more diverse in their needs. They cannot use CO_2 as their main carbon source, and some cannot use NH_3 , but they need, to varying extents, preformed organic compounds.

Examples: animals, bacteria, yeasts, fungi.

what everyone knows is not necessarily either true or relevant. No plant is adapted to work efficiently in full sunlight; plants thrive on overcast skies and long days and this, as Halley had already pointed out in 1693, gives Britain an advantage over the short-day tropics. The temperature in Britain is, however, generally too low for efficient growth. By midsummer day a field has had half of the light it will get in a year but, because of the risk of frost, it is necessary to plant many crops so late that at this date the field has only a partial green cover. This difficulty is got round by using frost-hardy species that are always ready to use any spring light that happens to coincide with conditions warm enough for some photosynthesis. An alternative technique is to keep the plants warm in greenhouses; this technique is likely to be used increasingly. Power stations, whether driven by coal or nuclear fission, are only 25-30 per cent efficient. This means that

the 5,000-6,000 megawatts of electricity that was mentioned earlier will be accompanied by nearly 20,000 megawatts coming away as hot water. So long as this is not radioactive it will be the ideal medium for warming glasshouses and the community would be well advised to insist that power station effluents are not radioactive even if they are being wasted in the sea. To be safe from frost an acre of glasshouse should have at its disposal 880 kilowatts (i.e., 3,000,000 BTU per hour), so the new power stations will discard enough heat, assuming it could all be used efficiently, for 35 square miles of glasshouse. Table VI sets out

TABLE VI

Available waste heat

12 new nuclear power stations will generate 6,000 megawatts as electricity.

This will be accompanied by 20,000 megawatts as hot water.

To be safe, an acre of glasshouse needs to have available 3,000,000 BTU per hour = 880 kilowatts.

So the waste heat could warm 35 sq. miles of glasshouse.

these figures. It is reasonable to think that about half the heat could be used, but even that would warm about twice Britain's present acreage of glasshouse. Such an expansion, though very productive, would be expensive and attention is therefore often given to soil warming. This saves the cost of the house but, because cold air still circulates freely, it is less effective for a given expenditure of heat. Furthermore, if electricity is used for the heating, the costs of installation are low but waste heat is not used; to use that a more expensive installation of pipes would be needed. These figures suggest that it will probably be impracticable to increase production by warming any significant proportion of the arable land of Britain. Soil and air are warmed by 4 megawatts per acre when the sun is shining and that is a rate of energy expenditure that will be hard to match.

Similar quantitative objections can be raised against the proposal that unicellular algae, such as *Chlorella*, should be grown instead of normal field crops. The system of tubes or tanks

needed for algal culture would be easier to keep warm than an equal area of glasshouse, but the capital outlay on pumps and separators needed to harvest several acres of culture and keep it moving is intimidating. Furthermore, although the physiology and anatomical structure of *Chlorella* are convenient for getting quick multiplication, relative absence of cellulose, and economical use of water, they make it difficult for these plants to pick up atmospheric carbon dioxide. The added expense of making carbon dioxide and blowing it into the culture medium has, therefore, to be met, whereas a leafy plant is adapted to absorb carbon dioxide unaided. In spite of these difficulties there are still advocates of mass algal culture.⁴ The sceptics, for example Thimann⁴ and Pirie⁵, agree that it is possible to get with algae much higher yields of organic matter than can be got from the same area devoted to normal farming, but argue that the normal plants are equally productive if pampered to a comparable extent and that it would not be feasible in practice to pamper algae to the extent that is possible in experiments. Thatcher and Babcock⁶ set out in detail the various items of probable cost of the various processes involved in the mass cultivation of algae and conclude that, even if it were technically feasible, it would be uneconomic in most environments.

There are, however, a few environments in which algae have a clear advantage. Where water shortage is acute, as in a tropical desert, algae are better than higher plants because it is, in theory at any rate, easier to recirculate the water. Higher plants depend on a transpiration stream, that is, on the evaporation of water from their broad leaves. The algae live submerged and water is not used up. It is, however, contaminated by their metabolic products and it has not been shown that the water can be satisfactorily purified in practice. But this may well prove feasible. It may also be feasible to conserve the water transpired by higher plants in a greenhouse. In polar areas it would probably be easier to maintain the temperature of an algal tank than of a field and so make use of the long summer light. And in a space ship voyaging near enough to the sun to get an adequate amount of light it would be easier to manage algae than any other type

of plant and so absorb the CO₂ exhaled by the crew and make the O₂ that they need. But the inverse square law must be borne in mind. Saturn is nearly ten times as far from the Sun as Earth is, so that the intensity of sunlight is only one hundredth. Photosynthesis there will be sluggish. Finally, there is the sea. Very few higher plants grow well in salt water, but many of the algae do. It is a pity that so few of the algal enthusiasts study the marine forms because these might be very useful. Algae, therefore, have a role in the Sahara or Baffin Land, or within the orbit of Mars or in the oceans, but elsewhere food production is likely to depend on higher plants or on non-photosynthetic processes.

In this argument normal agricultural yields of 2-4 tons per year per acre are often quoted with disdain. These are yields from an actual acre during a whole year and take into account only that part of the crop that is normally harvested. When we consider more specialized conditions, or shorter periods, or the total weight of organic matter produced, the higher plants show greater capacity. Even under the sub-optimal climatic conditions of Rothamsted, in south-east Britain, sugar beet accumulates organic matter at rates up to 44 tons per acre per year during the period of maximum growth. Some unpublished results got by P. C. Owen are set out in Table VII to illustrate this. On poor land without added fertilizer Ovington⁷ finds that pine plantations make organic matter at rates up to 10 tons per

TABLE VII

Rate of accumulation of dry matter by sugar beet in successive fortnightly periods

Date	11/6	25/6	9/7	23/7	6/8	20/8
Ratio of the total area of leaf to the area of the ground on which it is grown	0.5	1.7	5.0	6.3	7.8	7.4
Rate in tons of dry matter per acre per year	13	33	36	44	32	

This crop was watered and fertilized optimally; it was protected from frost but not heated. The final figure is a rate and, as in short-term experiments with other types of crop, it does not give the actual yield in a year.

acre throughout the year, and Rennie⁸ has stressed the increases in forest yield that can be got by the use of fertilizers.

In the warmer parts of the world, or with better cultural conditions, the yields can be still higher. Sugar cane, under ordinary conditions, gives 40 tons and there are claims that 100 tons can be got. The water hyacinth (*Eichornia*) gives 6 tons of dry matter per acre per month and, in 25-square-foot tanks, Arnon grew 106 pounds of potato tubers in 4 months. This is equivalent to 5 tons of dry matter per acre per month for tubers alone; if the leaves and stalks are taken into account the yield would be doubled. Much of the organic matter made in these ways is, of course, of no direct use as human food; like the organic matter of algae it needs sophistication and the methods that could be used for this will be considered later.

If agricultural success could be measured by the amount of organic matter built up on a given area in a given time, and by the physical and financial effort needed to achieve this rate of synthesis, then our search for new crop plants could be guided by simple measurements of photosynthetic efficiency. There may be no case for being so unconventional as to use algae, but that would still leave us about a quarter of a million plants to choose from. Only a hundred of these are used on a significant scale, and these are somewhat improved strains of the plants selected by primitive man. Two paramount considerations controlled his choice; it had to be possible to separate part of the plant by simple mechanical processes from fibrous or unpleasantly flavoured material; in any climate in which plants grow for only part of the year, the edible parts of the plant had to be preservable. These requirements are most often met by seeds and tubers. The plants that have been selected are those that give seeds and tubers that are convenient to handle and these plants are not necessarily the hardiest or the most productive. Modern technology opens up several new possibilities. Refrigeration and other forms of food preservation make it possible to use any foodstuff at any time of year. This change is obvious and need not be enlarged on. Quality can now be assessed so easily that the useful parts of a crop can be selected with certainty. I have

argued elsewhere⁹ that routine fibre and nitrogen determinations, together with feeding trials, could give us the basic information on which to select a very much wider range of leaves and immature flowers as potential foods, than would have been safe for primitive man. One probable unconventionality therefore is an increase in the amount of vegetable material grown for direct use as human food. The biggest change is, however, likely to spring from the development of biochemical engineering.

Biochemical engineering is a new comprehensive term for a subject, some parts of which, brewing for example, are ancient. In the same way that biochemistry is the fusion of chemical skill with biological interest and enthusiasm, so biochemical engineering is the fusion of these with engineering skill. It is the art of studying a biological raw material to find out what useful components could be separated from it and to what useful biological conversions the residue would be susceptible. Often, every component in a natural product would, in isolation, be valuable, but their values conflict so that they cannot be used when in juxtaposition. The problem is similar to the one that confronted Macheath:

How happy could I be with either
Were t'other dear charmer away!

Some separations are traditional, starch and vegetable oils for example, and the only probable unconventionality is the development of a new plant source. The third main foodstuff, protein, was recognized as a component of leaves by Rouelle in 1773. He was demonstrator in the *Jardin du Roi* in Paris and recognized the similarity between casein and the material he was making from hemlock leaves, this he called *la matière glutineuse ou végéto-animale*. The beginning of this century was a period of intensive study of the seed proteins, but the leaf proteins were almost entirely neglected until 1926 when Ereky, who was for a time Minister of Agriculture in Hungary, realized that leaf protein could be a useful human food. He devised a machine to separate it on a technological scale and patented the process

It has been patented at fairly regular intervals ever since. In spite of this, leaf protein remains more a laboratory curiosity than an article of commerce. The separation of leaf protein is a natural extension of the preparation of plant viruses from leaves; I have been engaged on this since 1934 so that a war-time interest in new and, if possible, home-produced sources of food reawakened Ereky's idea. After various difficulties that are of sociological rather than technological importance a production unit was established at Rothamsted and with this we make several hundred pounds of protein a year and could make, if there were demand, that amount every week.

Protein, as has already been said, is no more essential in food than most of the other components but it is less easily come by, as the curves in Table I showed. The main foods of the world, the cereal grains and potatoes, do not contain enough to make a balanced diet; cassava contains hardly any. Some more concentrated protein source is therefore needed. This is generally supplied by the many different forms of peas and beans, or by animal products such as meat, fish, milk, and eggs. The legume seeds contain 25-45 per cent of protein and the animal products, if not unusually fatty, contain even more. If a third or less of the food eaten is in these forms, protein balance can be maintained. It is the official policy of many countries, and of the international organizations such as the Food and Agriculture Organization, to increase supplies of animal products and of soya beans and ground nuts so as to meet the need. This is a commendable first step; but there are difficulties.

The high-yielding legumes will not grow in all parts of the world and many communities do not relish the necessary heavy intake of beans. In China, for example, soya is grown predominantly for oil and much of the protein is used as fertilizer although there is protein deficiency in many areas. It may be argued that this use of an edible protein as fertilizer is not wasteful because in this way the nitrogen is returned to the soil. But it would have been returned to the soil just as efficiently if, in a community without sophisticated sanitary arrangements, it had been eaten. The incorporation, in the diet, of a sufficiently large

proportion of peas and beans has proved difficult in most regions. There is no similar difficulty with animal products; people, unless inhibited by religious taboos, eat readily as much as is available. The standard of living of a community can indeed be assessed by the role that animal products play in the diet. If ample meat, fish, and milk products were available throughout the world there would be no problem. Table I showed clearly that they are not available. It may be legitimate, therefore, to look on protein deficiency as the world's main nutritional problem and, as an example of one approach to its solution, devote some more space to leaf protein.

The general course of the separation is shown in Table VIII

TABLE VIII

Pulped green leaves are separated into:

Juice, which gives after coagulation	coagulum containing	{ proteins fats starch	} food for man and other non-ruminants
	fluid containing	{ amino acids amides sugars salts etc.	} medium for the growth of micro-organisms
Fibrous residue containing	most of the	{ cellulose hemicelluloses lignins pectin	} Still a fodder for ruminants and a substrate for microbial fermentation
	some of the	{ proteins fats starch	

and the character of the main items of equipment in the photograph (Inset 9). The arrangement we use is more elaborate than would be necessary for routine production, and we are experimenting with simpler units. Protein is separated from the juice by heat coagulation; it is then filtered off, washed, and preserved under refrigeration or in cans.

The product contains 70-80 per cent protein and some starch

and lipids including chlorophyll. The yield varies with the quality of the leaf used, but with a good starting material such as a young cereal, clover, or sugar beet leaves, representative figures would be: 1 ton of leaf contains 400 lb. of dry matter and this contains 80 lb. of protein, of this we extract half or 40 lb. The only satisfactory way to assess the quality of a protein is to use it for the purpose for which it has been made and see how good it is. The requirements of rats, pigs, hens, and people are not necessarily identical; and people may have different requirements according to whether they are infant, adult, pregnant, or lactating. The assessment of quality, therefore, involves quite an elaborate research programme, and it is important to remember that most of the protein eaten throughout the world has never had its quality assessed. It is safe to assume that much will be gained by the introduction of any palatable new protein source, and it would be foolish to dismiss one because it does not appear to be quite so good as the two 'ideal' proteins, casein and egg white. Experiments have not yet been carried out on the value of leaf protein in human food, but in the rations of growing chickens it is as good as soya bean protein. This is precisely what would have been expected from its amino acid composition.

At present a great deal of the leafy material that grows in Britain every year is wasted and the part of it that is not wasted is mainly fed to cattle. Cattle, already referred to in Table v as shufflers, do not separate the components of the leaf into a more and a less useful fraction, but subject the whole mixture to total conversion. The advantages of avoiding such a conversion are simply quantitative. The process need not introduce the 85-95 per cent losses that are associated with the conventional use of animals as converters of plant material, but there is always some loss, and if we are going to make an unconventional product by using a more efficient converter, such as a yeast, fungus or bacterium, we might as well go the whole way and avoid conversion completely. If the advantages of doing this are accepted, a radically new approach to the selection of economic plants will become possible. Instead of deciding what conventional

foodstuff is wanted and then organizing agriculture so as to produce it abundantly, we would decide what plant a given area can produce most abundantly and the biochemical engineer would then study what can be done with it.

However efficient extraction procedures may become, crop residues and crops that are difficult to extract are likely to remain. These will be the raw materials for microbial conversions and they may well supply the most unconventional of future foods. Molasses, sulphite liquor from the wood pulp industry, and a number of other vegetable extracts are used as substrates for the cultivation of micro-organisms – especially yeasts. The dominance of research on bulk yeast cultivation is clear from a glance at the literature, but it is not clear that the yeasts offer any advantages over other micro-organisms; they generally grow more slowly and the proteins and fat that they make, though useful, have not been shown to be better than those of organisms such as *Bact. coli*. Tradition is probably important here, and the yeasts have played so many roles in nutrition in the past that they excite less opposition than organisms that, at least in popular opinion, are associated with disease.

Earlier in this article these biological converters were dismissed, perhaps a little cavalierly, as merely shufflers. This shuffling is important and there is room for an immense amount of work on the bulk cultivation of non-photosynthetic micro-organisms, but it may be worth while reiterating that they do not make new organic matter from inorganic sources. The most they can do is to give us more valuable compounds when they are fed on carbon and nitrogen compounds that are either made synthetically or are present in wastes. Microbial production is not, therefore, a substitute for agriculture or the chemical industry though it is a valuable supplement to them.

The most important problem raised by research on the unconventionalities remains: 'How will they be used?' The answer is simple: 'Slowly.' No time need be wasted on those who sniff and say 'I prefer beefsteak.' Their reaction is as brainless as the baby's noisy reaction to the drying up of its mother's milk. But we become reluctantly reconciled to food not associated with

the charms of the mother's breast. The problem is: 'What shall we eat when there is less beefsteak?' Some at least of the unconventional foods discussed here are likely to play a part. There are two obvious steps to be taken in deciding which: laboratory scale experiments must demonstrate that the material made is as nutritious, when fed in conjunction with the other components of a normal diet, as theory leads us to expect: approximate costing must show that there is a reasonable chance that it could be produced economically. With these points established, the scale of work should immediately increase to one production unit large enough to give measured costs (recent experiences must have convinced most people that economics is still one of the experimental sciences) and an adequate supply of material for detailed experiments on handling and compounding with other foods.

The palatability of a novelty cannot always be determined by eating a pinch of it out of the scientist's bottle; many conventional foods might seem unattractive if eaten in this way, conversely, things that seem passable in small quantities taken once, may be less so when eaten regularly. But in the long run palatability will probably not seriously restrict the use of an otherwise valuable novelty. The human appetite is plastic and diverse, as a moment's thought about the things eaten in different parts of the world shows,¹⁰ and skilful processing can greatly alter flavour and texture. There is no more reason to think that, for these, primitive man achieved perfection, than to think that the best music can be played on a tom-tom or the best pictures painted with ochre and charcoal.

The real difficulty in an unconventional approach to an old problem is that projects are not selected for test on any objective basis. Instead, all are at first woodenly opposed; later a few get tested, not because they are more plausible than the others, but because of the vehemence, obstinacy, or 'pull' of their protagonist. There is a risk that, during the phase of obstruction and argument, people may get so committed that they will be unwilling to see that a project is in fact proving as unsuccessful as its critics had correctly but baselessly predicted it would be.

The actual test is then made unnecessarily expensive and prolonged because of the initial delay and obstruction.

Maximum productivity from an area will be attained when we have studied the possible plants to grow on it and chosen the one that grows best and not the one for which we have the most obvious use; when we have fertilized the area optimally for that crop and have prevented at least some of the pests and diseases from attacking it; when we have explored the alternative uses to which the crop could be put and chosen the least wasteful; and when we have collected the by-products and residues and found uses for them too. Such a programme has never been carried out and has probably never even been attempted. It would be prudent to start on it before increasing population and insolvency make the need too acute.

REFERENCES

1. Food and Agriculture Organization Commodity Policy Study 10 - *Functions of a World food reserve: Scope and Limitations* (Rome, 1956).
2. Garry, R. C., Passmore, R., Warnock, G. M., and Durnin, J. V. G. A.: *Studies on expenditure of energy and consumption of food by miners and clerks, Fife, Scotland 1952*. Med. Res. Council Special Report Series No. 289. (London, H.M.S.O., 1955.)
3. Nutrition Society Symposium, 1955. 'Alcohol and its nutritional significance', *Proc. Nut. Soc.* 1955 14 93.
4. Proceedings of the World Symposium on Applied Solar Energy. (Stanford Research Institute, Menlo Park, California, 1956.) This contains the papers by Fisher, Myers, Tamiya, and Thimann.
5. Pirie, N. W.: 'The efficient use of sunlight for food production', *Chem. & Ind.* 1953 442.
Pirie, N. W.: (1956 a) 'Power from leaves.' *Proc. UNESCO Symp. on Wind and Solar Energy*, 216.
6. Thatcher, F. S., and Babcock, H.: 'The mass culture of algae', *J. Solar Energy Science and Engng.* 1957 1 37.
7. Ovington, J. D. 'Some biological considerations in forest production', in *The biological productivity of Britain*, Inst. Biol. 1958.
8. Rennie, P. J.: 'The uptake of nutrients by mature forest growth', *Plant and Soil* 1955 7 49.

9. Pirie, N. W.: (1956 b) 'Unexploited technological possibilities of making food for man and animals', *Proc. Nut. Soc.* 1956 **15** 154.
10. Nutrition Society Symposium, 1953. 'Unusual Foods for Human Consumption', *Proc. Nut. Soc.* 1953 **12** 32.

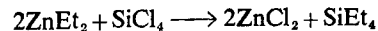
SILICONES

M. H. THORNDIKE

SILICONES are synthetic polymeric compounds with a structure of alternate silicon and oxygen atoms, containing organic groups (usually methyl or phenyl) attached to the silicon atoms. The fundamental siloxane structure, —Si—O—Si— , confers on the molecule great thermal and chemical stability, while the organic groups contribute to such properties as water-repellency, flexibility, and solubility in organic solvents. These properties, together with others such as good electrical insulation characteristics, ability to prevent sticking, and to suppress foaming, result in these compounds finding a great diversity of industrial applications. Their domestic uses in polishes and for waterproofing textiles are well known, but less familiar, perhaps, are their use in electrical engineering, and to varying extents in mechanical engineering, in paper, leather, glass, pharmaceutical, and confectionery manufacture and in many other industries and trades which utilize some of the properties described above.

HISTORY AND DEVELOPMENT

About 1840 Dumas predicted the existence of organo-silicon compounds. Some twenty years later Friedel and Crafts prepared the first compound in which an organic group was attached to the element silicon by the reaction of diethyl zinc with silicon tetrachloride.



During the period 1899–1944 the late Professor F. S. Kipping of University College, Nottingham, published over fifty papers on organo-silicon chemistry mainly in the *Journal of the Chemical Society*. It was he who coined the word *silicone* to cover the range of polymers he succeeded in isolating. Because of their chemical inertness he described them as 'uninviting', but as time

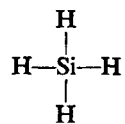
has shown this inertness has proved to be a very useful characteristic of these compounds.

In the 1920s the development of polymer chemistry and the growth of plastics led to the possibility of making hybrid polymers containing organic polymers (plastics) and inorganic polymers (glasses). By the 1940s much development work was under way in America. Although efforts were being made to produce a heat-resistant dielectric resin to use with glass-fibre tape in electric motor insulation, the first silicone materials produced commercially were in fact fluids. By the end of the war a variety of uses had been found for these fluids, and gradually silicone lubricants and polishes were put on the market, and additionally resins and rubbers developed.

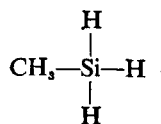
Silicone products began to be used in Britain about 1945 when small quantities were imported from America. Two British chemical companies then began to distribute American materials, but subsequently built plants to manufacture silicones themselves. They were Imperial Chemical Industries Limited, and Midland Silicones Limited. During 1956/57 both companies extended their plants and their combined capacity is now more than capable of meeting British demand at home. Although detailed figures are not available, it seems likely that about 200 tons of silicones were used in Britain during 1953. By 1957 consumption had probably reached 800 tons, and it has been estimated that in the early 1960s the market in Britain for these products may reach between 1,200 and 1,500 tons.

THE CHEMISTRY OF SILICONES

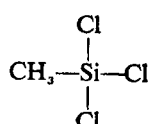
A systematic nomenclature has been applied to silicon compounds, according to which the simpler compounds are regarded as derivatives of silicon hydrides, called silanes. For example,



Mono-silane



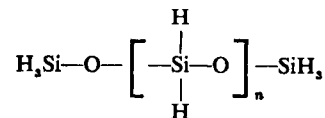
Methylsilane



Methyltrichlorosilane

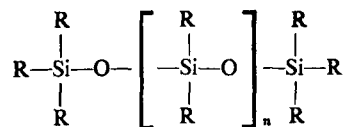
Compounds containing two silicon atoms are known as disilanes: $\text{H}_2\text{Si}-\text{SiH}_3$, and if an oxygen atom is inserted between the silicon atoms the resulting compounds are called disiloxanes: $\text{H}_3\text{Si}-\text{O}-\text{SiH}_3$.

Siloxanes often form long chains and may be regarded as polymers, thus,



Siloxane polymer

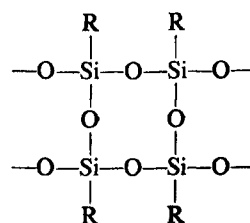
If the hydrogen atoms in these polymers are replaced by alkyl or aryl groups (denoted by R) polyorganosiloxanes are obtained containing the unit $-\text{RHSiO}-$ or $-\text{RSiOR}-$, the latter being known as silicones. A typical chain structure found in a silicone fluid is



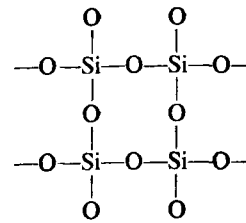
Silicone fluid

The viscosity of the fluid increases with increasing chain length, and very long chain high molecular weight polymers are viscous gums.

Silicone resins are formed by suitable modification of the chain polymer to form a cross-linked, three-dimensional lattice structure similar to that of quartz (silica).



Silicone resin



Quartz

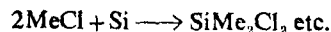
These resins vary in hardness and rigidity according to the degree of cross-linking: their chemical characteristics depend rather more on the nature of the substituents.

METHODS OF MANUFACTURE

Silicone compounds are the result of hydrolysing chlorosilanes, and there are four ways of making chlorosilanes industrially; the first of those given below is the most important.

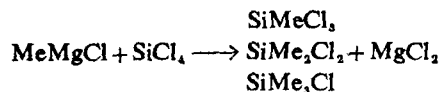
(a) Direct Process

Elemental silicon is converted directly into chlorosilanes containing both an organic radicle and chlorine. For example, methyl chloride is passed through a mixture of heated powdered silicon and a copper catalyst. The resulting gas, consisting of a mixture of chlorosilanes and unreacted methyl chloride, is condensed and the condensate fractionated.



(b) Grignard Process

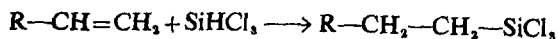
The Grignard Reagent, consisting of alkyl or aryl halides and magnesium chips in ether suspension, is treated with silicon tetrachloride to give a mixture of chlorosilanes.



The products are filtered and distilled. This method is very flexible and enables a variety of organic groups to be attached to silicon, but in industry the use of ether is undesirable.

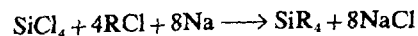
(c) The Olefin Addition Method

Trichlorosilane is reacted under pressure with an unsaturated organic compound. Heating is required and a peroxide catalyst is sometimes used.



(d) Sodium Condensation Method

This method is based on the well-known Wurtz reaction, but it is not of industrial importance because of low yields, and the hazards associated with the use of metallic sodium.



The technology of manufacture is complex, but three main types of product are obtained from the above reactions. They may be divided into fluids, resins, and rubbers.

The fluids may be conveniently sub-divided into (a) dimethyl silicone fluids, and (b) other compounds. The former are prepared from dimethyldichlorosilane with the addition of a small amount of trimethylchlorosilane as a 'chain-stopper'. The other compounds consist of polymers having units in which some of the methyl groups are replaced by, for example, phenyl radicles. Both types are produced by blending chlorosilanes in the required proportions, followed by hydrolysis and purification.

The resins are normally prepared by hydrolysing mixtures of dialkyl or diaryl dichlorosilanes, or both, and similar trichlorosilanes, to give a cross-linked structure of the type already described. The product is dissolved in a suitable solvent and sometimes 'bodied' by heating in the presence of a catalyst to give the desired viscosity.

There are several kinds of established industrial silicone rubbers, but two of the main types are based on (a) a dimethylsiloxane gum, and (b) a gum in which phenyl groups have replaced some of the methyl groups.

The first step in the preparation of dimethylsilicone gums involves the treatment of the hydrolysis product of dimethyldichlorosilane with suitable equilibration catalysts such as ferric chloride, sulphuric acid, etc., to promote formation of high molecular weight linear molecules without cross-linking.

The second stage is to mix intimately finely divided silicas or diatomaceous earths with the gum on mixing rolls similar to those used for processing natural rubber. At the same time a catalyst such as benzoyl peroxide is added. At this stage the compound is a plastic material looking like bakers' dough.

The third stage is the moulding or extrusion, to give the desired shape, followed by 'curing' or 'vulcanizing' by heating, to effect cross-linking between the molecules.

SILICONE PRODUCTS

Fluids

Silicone fluids are colourless or straw-coloured liquids available in a wide range of viscosities of from a few to a million or so centistokes. They are odourless, non-toxic, and practically non-volatile. They are characterized by their stability at high temperatures and constancy of physical properties over a temperature range from approximately -70°C to 200°C .

In general, dimethyl silicone fluids are readily soluble in aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons, and higher alcohols, but totally insoluble in water and the lower alcohols. They allow the passage of water vapour and so cannot be used as rust preventatives. They are, however, non-corrosive to metals, and are in general unaffected by them.

Silicone fluids are very stable when exposed to air at high temperatures for long periods. For example, the dimethyl fluids when heated to about 150°C will last almost indefinitely, but in the presence of air at temperatures of 200°C and above, they lose weight and increase in viscosity until gelation occurs.

Physiologically the fluids are practically inert. Tests have shown that they do not irritate the skin, but, although they cause no corneal damage when dropped into the eyes, they may, in some cases, cause a delayed temporary irritation.

Resins

Silicone resins are characterized by their three-dimensional branched-chain structures, some of which are only fully developed after they have been applied to the appropriate surface and cured by heating. Their main properties are their heat stability, water-repellency, dielectric properties, and resistance to chemical agents.

Resins are normally supplied by the silicone manufacturer as a solution in toluene or xylene. The solution is applied by brush

or spray and the solvent allowed to evaporate: many require subsequent heat treatment to drive off any residual solvent and to complete the cross-linking polymerization of the resin.

Silicone resins have found the following applications: (1) surface coatings, including paint formulations, (2) water-repellent resins, for use on concrete and masonry, (3) release agents for rubber, plastics, and sticky foodstuffs, (4) electrical resins, e.g., impregnation and coating of glasscloth, (5) laminating resins for paper, asbestos, etc., (6) moulding resins, for electrical equipment, and so on.

Rubbers

Silicone rubbers are based on linear polymers of very high molecular weight. It will be remembered from the outline of the method of manufacture given earlier, that inorganic fillers are added to impart mechanical strength. The characteristic elastic properties are thought to result from intermolecular cross-linking in the presence of an oxidizing catalyst when the shaped materials are cured by heating. (Inset 1.)

Where flexibility at extremes of temperature is required these rubbers are widely used. Flexibility at temperatures as low as -80°C can be obtained by using a gum in which some of the methyl radicles have been replaced by phenyl groups. The silicone rubbers can easily withstand temperatures of 200°C ; some as high as 300°C . At normal temperatures, however, physical properties such as tensile strength and tear resistance are poor compared with natural rubbers.

In their resistance to ozone they are greatly superior to natural rubbers and they have a certain degree of resistance to weak acids, bases, salts, and hydrocarbon oils, although prolonged exposure results in swelling and deterioration of physical properties. As a class, they combine the characteristic silicone properties of heat resistance, inertness, water-repellency, and non-sticking with an elasticity similar to that of natural rubber. As a result they find uses in engineering for gaskets and seals subject to high or low temperature operation. Their non-sticking and heat-resisting properties make them specially suitable for use in refrigerator

door gaskets, for seals on engines or other hot equipment, and for non-sticking valve seats. They also make good anti-shock mounts especially at temperatures where natural rubber would lose its elasticity, or decompose. (Inset 8.)

Miscellaneous Products

Emulsions. There are a number of situations where it is not convenient to use a pure silicone fluid, sometimes on technical grounds, on other occasions because of economy, especially where only a low silicone concentration is required. Under such circumstances aqueous emulsions of silicones are used. They are, of course, attractive in that they may be diluted with water.

Greases. There are two main types of greases made by compounding certain fillers with the silicone fluids. In the first type the filler is usually finely divided silica. This type of grease does not flow with heat, has excellent water-repellency, and good dielectric properties. It is used as a valve lubricant, for the impregnation of pump packing, particularly for high-temperature or corrosive conditions. It may also be used as a release agent for heat sealing equipment, and as a waterproofing seal in electrical systems such as motor-car ignition apparatus. The second type of grease is prepared from the fluids by the addition of carbon black or special soaps. This is a non-flowing lubricant intended for use at very high or particularly low temperatures, and as a 'permanent' lubricant in sealed bearings.

Fluid containing free chlorosilanes. When applied to glass, quartz, or similar products, a silicone fluid containing some unhydrolyzed methylchlorosilanes, forms a tightly bonded, microscopically thin, water-repellent film. These fluids are used as a rain repellent for aircraft windscreens, on manometer tubes to give more accurate readings, and on vials used in medical work to facilitate complete drainage.

Bouncing Putty. This is a putty-like substance which has a high elastic rebound, flows in the cold and yet shatters if struck.

It is ductile if slowly drawn, but brittle if pulled suddenly. When pressed on to a newspaper it will pick up an accurate impression of the printing. Bouncing putty is of little industrial importance, but makes a fascinating toy.

APPLICATIONS OF SILICONES

The properties of the main types of silicone compounds have been described, and now ten of the more common applications will be discussed to illustrate the varied uses of these materials. The first two, release and anti-foaming applications, are of general industrial interest, the remainder are selected from industries and trades that use silicones in their day-to-day work.

Release Agents

People who wear false-teeth are not always eager to eat sticky sweets, nor do housewives enjoy cleaning dirty frying pans. This is because, where inherently sticky substances are involved, or when different materials are brought into contact under conditions involving heat or pressure, they are always liable to adhere to some extent. The moulding techniques used in the rubber and plastic industries are typical examples of situations where heat and pressure are encountered, and consequently where 'release' problems arise.

It is common practice to interpose substances known as release agents, parting agents, or mould lubricants, between the surfaces that are liable to stick. These parting agents provide a relatively weak interface which enables the two surfaces to be separated.

Various substances are used to prevent sticking, for example, the builder wets his trowel with water when spreading cement, the cook greases baking pans, and so on, and in industry various oils, greases, and proprietary materials have been used, but most of them possess serious defects in one or more respects.

Silicones, however, approximate closely to the ideal release agent. The properties that commend them are: (1) They facilitate separation from complex moulds. (2) They are chemically inert, and do not attack either the moulds or most substances

being moulded. (3) They can be applied easily by spraying or brushing, and work in very thin films. They neither burn nor carbonize at normal moulding temperatures, and even after prolonged use build-up is not evident. Thus the mould does not require frequent cleaning and the moulding is a faithful replica of the mould. (4) Silicones have very low volatility and do not cause smoke or unpleasant fumes when applied to hot mould surfaces. (5) Liquid silicones have low surface tensions and readily wet the mould surface. They tend to be retained on the surface, and one application is often sufficient for several releases. (6) Silicones are stable at much higher temperatures than those at which purely organic compounds can be used. (7) Although, by weight, silicones are more expensive than other materials, they are more economical to use because only small quantities are required. Labour costs are cut and the number of faulty releases is reduced. (Inset 2.)

Silicone fluids, emulsions, resins, and rubbers have all found applications in preventing sticking of one sort or another. The silicone fluids are diluted with solvent, and the emulsions with water, before application. Both these types of liquid are widely used in the plastic and rubber industries. If a rather more permanent type of release agent is required, then a silicone resin can be deposited from its solvent and cured to form a hard film: this practice is used in the baking industry.

Foam Prevention

Beer drinkers expect just the right amount of 'head' on their beer, children enjoy blowing bubbles, but on the industrial scale the development of foam is a serious problem. It may mean that oversize vats or reactors have to be used, some of the product may be lost, or there may be undesirable oxidation and even risk of fire.

Foam is a concentrated dispersion of gas bubbles in a liquid, stabilized by traces of impurity such as proteins, detergents, or fine suspensions of solids. Whether they are soluble or not, these impurities tend to concentrate at the air/liquid interface and form a film on the surface of the bubbles, thus stabilizing the

foam. If the liquid is being boiled or mechanically agitated the tendency to foam will increase. (Insets 3 and 4.)

There are many mechanical methods for breaking foams including centrifuges and rotating discs which aim at physical destruction. There are also additives available such as alcohols, castor oil, and many proprietary compounds, most of which aim to prevent the formation of foam rather than to destroy foam already created. Silicone antifoams fall into the second category, and although they are not effective in all situations they possess several advantages. Perhaps the most striking is the very small quantity of silicone required – from 1 to 25 parts per million.

Wherever synthetic detergents or wetting agents are used there is a tendency for foam to form, consequently silicone anti-foaming agents are frequently used in dyebaths, bottle-washing plants, and sewage disposal units. Silicone antifoam agents have also been used successfully in the manufacture of synthetic resins, the process called 'beating' in the paper industry, the cooking of varnishes and linseed oil. The fluids are also used to suppress foaming where hydrocarbons are carried in bulk, for example in seagoing oil tankers.

Polishes

Car and furniture polishes containing silicones are already familiar. They are easy to apply and develop a high gloss with the minimum of effort. This is because silicones and waxes are in general incompatible and instead of plasticizing the wax the silicones act as spreading agents for it, and by acting as a lubricant between planes of the wax crystals facilitate the formation of a uniform thin film of wax. Although their protective action against water and dirt is sometimes exaggerated, the water-repellent and anti-stick properties of silicones do assist the polish to give more lasting protection.

Silicone polishes are formulated either as aqueous emulsions or solutions in a volatile organic solvent. In both cases the polish consists essentially of a mixture of waxes containing a dimethyl silicone fluid. Solvent type polishes are prepared by dissolving silicone fluid and wax in a solvent such as white spirit. Emulsion type

polishes are generally prepared by emulsifying a silicone/wax solution with a suitable emulsifying agent. The whole is then homogenized and small quantities of other chemicals added to stabilize the emulsion. For household purposes straight solvent or emulsion polishes are used, but for car polishes a mild abrasive is usually added. The compositions of commercial polishes vary considerably: the wax content may vary from 1 to 30 per cent, but a silicone content of from 1 to 4 per cent is usually sufficient.

Paints

Both silicone fluids and resins are used in the paint industry. The addition of a small quantity of low viscosity dimethyl silicone fluid to paint during manufacture assists the grinding and dispersion of pigments, and inhibits their flotation.

Some manufactured articles are painted by dipping, and it has been found that a small amount of silicone fluid in paints used this way eliminates flow lines and 'silking', and in finishes that are stoved the additive minimizes the characteristic mottled finish known as 'orange peel': the gloss of the paint film is also improved.

Silicone resins are often incorporated into paint formulations particularly where resistance to corrosive or wet conditions is required, especially at high temperatures where organic films would break down. In order to achieve sufficiently rapid drying and desirable consistency for handling, organic film formers can be blended with silicone resins, either in the cold or by cooking. Unfortunately compatibility of the usual run of silicone coating resins with many organic resins is limited, but new silicone resins are being developed especially for use in the paint industry. Typical applications of siliconized paints are the treatment of chimney stacks and similar structures, but they are also gaining increased popularity for decorative work where improved water-repellency is desirable.

Water Repellents for Buildings

It has been estimated that on the average in England 100 tons

of rainwater fall on a house in one year. Most building surfaces are porous to some extent and consequently moisture may penetrate to the interior of the building unless certain precautions are taken. Bricks, stonework, and concrete contain many pores or capillaries through which gases and liquids may pass. Water is sucked into brickwork by capillary action, but fortunately it may be opposed by coating the exposed ends of the pores with a water-repellent silicone resin.

There are many materials on the market which waterproof buildings by forming a continuous film over the surface, thus sealing the pores. These include preparations based on aluminium stearate, wax, or silicates. They stop the ingress, of course, but they also prevent the egress of moisture and the flow of air through the brickwork even where a building has cavity walls. Structures should be able to breathe, hence a water-repellent treatment, such as that conferred by silicones, rather than a water-proofing treatment, is desirable.

A water-repellent solution contains from 2 to 5 per cent silicone depending upon the nature of the resin. The solvent carries the resin into the pores and then evaporates. A fine deposit of resin is left in the pores to a depth of about 0.25 inches, and experience has shown it to remain effective for 5 to 10 years, and maybe more.

An advantage of using a silicone treatment on brickwork that is not always realized is fuel economy. As wet walls dry the latent heat of evaporation required cools the building, and this is one reason why buildings that have been empty for some time are particularly chilly.

Textiles and Leather

The main properties conferred by the silicone treatment of textiles and leather are water-repellency and resistance to water-borne stains such as tea or ink. Treated textiles are also found to have improved handle, and the treatment is resistant to dry cleaning. (Insets 5 and 6.)

Fabrics may be made resistant to water in two different ways. In the first, the true waterproofing process, the interstices of

the fabric as well as the surface of the fibres are covered with a film so that the material becomes impermeable to water and air. In the second, the water-repellent process, the fibres of the material are made water repellent through coating with a hydrophobic (water-hating) substance, which allows the fabric to remain porous to air and water vapour. Silicone treatments fall into the second category.

Although there are a few silicone products that can be brushed or sprayed on to finished textile and leather goods to give a surface water repellency, the processes are normally carried out before the garments are made up. This is done by the textile finisher and leather tanner. The silicone is supplied as special fluids and applied from organic solvents, or as aqueous emulsions, a catalyst being required in both cases.

The textile finisher begins by removing all traces of wetting agents from the fabrics by thorough washing with hot water, and then feeds the cloth through large baths of the silicone liquor and passes it through rollers to squeeze the liquor into the fabric which is subsequently dried in hot air and baked for a few minutes at about 150° C. Silicone-treated raincoats are very well known, and the demand for them and treated curtain and furnishing fabrics is growing steadily. (Inset 6.)

If the leather tanner uses an emulsion technique, the silicone emulsion, with appropriate additives, is placed in a drum which can be rotated. The pieces of leather are then tumbled over and over, at room temperature, as the drum rotates for some 15 minutes. The skins are then removed, struck out and processed normally. A silicone emulsion can also be applied to leather along with dyestuffs at the normal dyeing temperature. A solvent process may also be used by brushing, dipping, or spraying the solution. This method may be used on finished articles such as golfing jackets.

Paper Industry

One of the latest developments in paper finishing is a silicone treatment which confers freedom from sticking and some water repellency. The methods of treatment are similar to those used

in the textile industry, both emulsions and fluids, with appropriate catalysts, being used. The silicone is applied by dipping, spraying, or roller coating, followed by drying and baking for a minute at about 120° C.

Paper treated with silicone remains permeable to air and water vapour, while water in the liquid phase runs off without penetration. Blotting paper or filter paper so treated illustrates this phenomenon most convincingly. Organic liquids like benzene pass through unhindered but, of course, they tend to dissolve out the silicone.

Because silicones are non-toxic it is quite safe to use treated paper to wrap sticky foodstuffs, and cakes baked in shaped paper cases come out quite cleanly. Silicone-treated papers are widely used in the packaging of waxes, bitumen, and other sticky materials.

Glass Industry

Silicone emulsions are used in the glass industry as mould lubricants on the machines which form the glass mouldings, and also as coatings on glassware.

The use of a silicone as a mould lubricant avoids the evolution of the oily smoke and fumes given off by hydrocarbon oils at the high temperatures used in the glass industry. This not only results in better working conditions for operatives but reduces plant maintenance and fire risks. The good cooling capacity of a silicone lubricant enables the plant to operate faster, and the clean release of mouldings gives the ware a smoother appearance.

Newly made glassware is easily damaged and articles are liable to seize together or scratch each other. As well as spoiling the appearance of ornamental ware, scratching may reduce the tensile strength of glass to one-tenth of its inherent value. Treating glassware with the appropriate silicone emulsion reduces subsequent damage to a minimum by giving the glass surfaces better lubricity, improved appearance and feel, and in medical and similar ware, when the interior is so treated, cleaner and more complete drainage.

Medicine, Pharmacy, and Cosmetics

Silicone fluids are used in barrier creams, where water-repellency assists the protection of the skin, and also in other cosmetic preparations. The fluids have also been used as inert carriers for antibiotics and as stable fluids for sterilizing baths.

Silicone rubbers are used in the manufacture of stoppers, babies' feeding-bottle teats, and blood transfusion tubing. They can withstand repeated sterilizations long after conventional rubbers would have failed. They contain no plasticizers that can be leached out, are inert, and non-toxic. The new rubbers which cure at room temperatures are being used in dentistry as a moulding material to take impressions.

The treatment of glassware, syringes, and needles with silicones helps to prevent blockage during blood transfusions, and enables vessels to drain rapidly, thus helping to promote accurate dispensing and to eliminate waste. Pills and capsules may be coated with silicones to prevent them sticking together, to repel moisture, and thus reduce the proportion of breakages.

Electrical Industry

Most of the silicone resins and rubbers absorbed by the electrical industry are used as insulating materials. Of the traditional materials, paper and cotton, bonded with organic varnishes, could only withstand temperatures of about 105° C (Class A), and glass, mica, and asbestos about 130° C (Class B), whereas the latter substances treated with a silicone resin varnish can withstand temperatures of 180° C (Class H), or even higher for short periods (Class C.) (Inset 7.)

Silicone insulation is therefore used where electrical equipment has to operate near furnaces, for example, or where abnormal overloads may occur and overheat the apparatus. These resins may be used to varnish wire or glass-cloth, or impregnate windings and laminates. They are applied from a solvent which is driven off, after which the resin is cured by heating.

Silicone rubbers are used where a flexible insulating material is required, and to extrude over wire and cable insulation. They

are also used as structural components where organic rubbers would fail because of extreme heat or cold. Other properties that make silicone rubbers attractive for cables are good electric strength over a wide temperature range, and resistance to ozone and corona discharge. For a given degree of insulation, silicone rubber cables have smaller diameters than conventional rubbers, thus providing an important saving of space and weight. In the event of fire, silicone rubbers leave no carbonaceous matter but are burnt to a residue of silica which is itself an insulator. Silicone rubber pastes are available for coating glass-cloth, or fabrics such as Terylene, which are subsequently wrapped round the material to be insulated.

Various forms of silicone insulation are used in the manufacture of electric motors, dynamos, and transformers, some of which are in use, for example, in nuclear power stations, and also in domestic appliances such as steam irons and immersion heaters.

CONCLUSION

There are now about twelve silicone manufacturers throughout the world, and considerable research and development work has been carried out to evolve techniques to make the best use of these compounds. Although silicones are more expensive than many conventional materials, where their particular properties are desirable, they are likely to be used in increasing quantities for many years to come.

FURTHER READING

- Rochow, E. G.: *An introduction to the Chemistry of the Silicones* (London, Chapman and Hall, 2nd Edition, 1951).
 McGregor, R. R.: *Silicones and their Uses* (London, McGraw-Hill, 1954).

BUBBLE CHAMBERS AND NUCLEAR RESEARCH

J. R. ATKINSON

THE experimental nuclear physicist requires, as one of his essential tools, efficient detectors of particles such as electrons, protons, and neutrons. Today many such detectors are available, and broadly speaking they can be regarded as falling into either of two categories – visual or electronic. The expansion chamber is an example of the first group, and the Geiger counter is the best known member of the second. The bubble chamber is a recent addition to the visual group and the purpose of this article is to explain, not only its mode of operation, but, also, some of the purposes for which it has been developed. In order to understand the reasons for the extraordinarily rapid development of the bubble chamber, it is first necessary to discuss, in a little more detail, the operation and use of the cloud chamber in nuclear physics.

The expansion or Wilson cloud chamber makes it possible to see and photograph the tracks of atomic particles and by these means to elucidate the mechanisms of interactions of known particles, e.g., electron-electron scattering. The chamber can also be used to reveal the existence of new particles as in Blackett's work on the positron. It should be emphasized that when a physicist inspects a cloud chamber photograph and states that he 'sees' a certain particle causing some reaction, he means that he sees the track of the particle and interprets its behaviour by postulating that a particular type of interaction has taken place. The situation is rather similar to that when the vapour trail of a very high flying aircraft is seen; the existence of the aircraft is assumed by virtue of the track it leaves – the plane itself may be far too small to be seen.

In recent years a new branch of nuclear physics has emerged known as high energy physics; these studies arose from the discovery in cosmic rays of the meson. It is in order to make possible the controlled production of mesons within physical laboratories that large accelerating machines such as synchrotrons and cyclotrons have been developed. In carrying out experiments with high energy particles it is found in many cases that the chance of a given reaction taking place (such as a meson colliding with a carbon nucleus) is so small that very many photographs of meson tracks passing through a methane-filled expansion chamber, say 12 inches in diameter, must be taken before an event is seen.

It is true that by increasing the pressure to 100 atmospheres, which is about the practical upper limit of pressure for an expansion chamber, the probability of observing an event in a given number of photographs is increased; nevertheless, it is clear that if the working gas could be replaced by a liquid this would increase the density by slightly more than a factor of a thousand, i.e., compared with gas at atmospheric pressure. Is this possible?

The basic physics of the processes of 'seeing' tracks must now be considered. In the Wilson chamber an expansion is used to cool the gas, e.g., methane, and if the latter were saturated with some vapour, e.g., alcohol, at the initial temperature, it would be supersaturated after cooling. Professor C. T. R. Wilson showed that under these conditions, and in the absence of dust and foreign matter, the charged ions that are produced from the neutral gas atoms when a charged particle passes through the gas act as condensation centres. This means that the ions become thousands of times larger, and eventually visible, because of the vapour that condenses upon them – i.e., the minute ion (about 10^{-8} cm. diameter) becomes a liquid drop (about 10^{-2} cm.).

If now we are to consider how a liquid could be used instead of a gas, to produce tracks, one possibility is to see whether under conditions of superheat (instead of supersaturation), ions will act as centres for bubble growth and thereby reveal the position of these ions. In this case the process is one of changing liquid to vapour, i.e., evaporation as opposed to condensation.

DEVELOPMENT OF THE BUBBLE CHAMBER

According to the inventor of the bubble chamber, Professor D. A. Glaser of Michigan University, the actual experiments that he carried out with such startling success owed their origin to a study he made of the bubbles contained in a glass of beer.

After preliminary experiments in which he showed that a

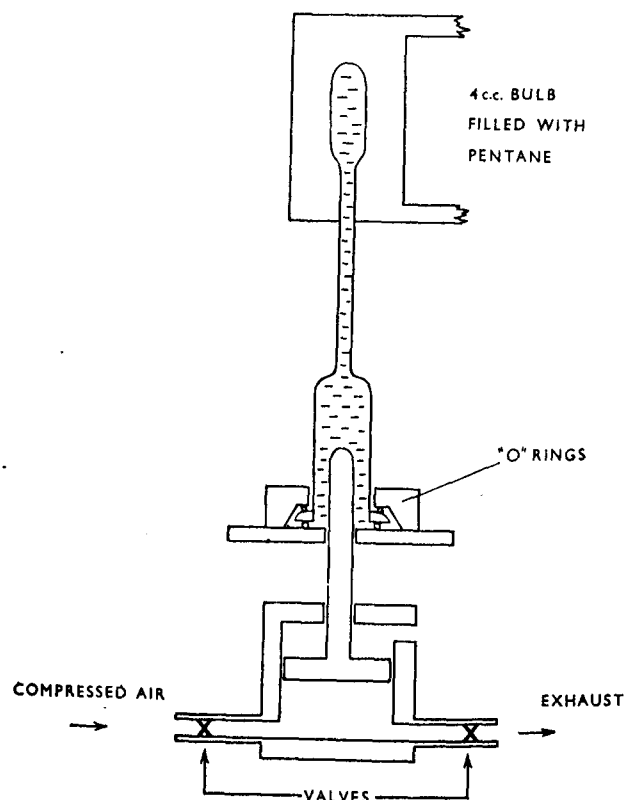


Fig. 1. Schematic diagram of the type of early bubble chamber built by D. A. Glaser.

clean superheated liquid could be made to boil by bringing a strong radioactive source near to the liquid, Glaser constructed a bubble chamber in which he was actually able to observe and photograph the tracks of the particles from the radioactive source. A diagrammatic sketch of the type of apparatus used and a reproduction of one of Glaser's early photographs are shown in Figure 1 and Inset 12 respectively.

The principle of operation is straightforward: the glass bulb contains pentane, which is heated to a temperature of about 130°C . At atmospheric pressure pentane boils at 28°C and at 130°C the vapour pressure is about 12 atmospheres, i.e., about 170 lb./sq. inch; in order to prevent the pentane boiling at this high temperature, the pressure is increased by loading the piston until the pressure is above 170 lb./sq. inch. If now the piston is suddenly made to fall so that the pressure is reduced to near atmospheric, a state of superheat is set up in the pentane. If the liquid is very clean, and there are no sharp edges or corners on the inside of the glass container, boiling will not occur for a period of time up to about one second. Under these conditions the chamber is said to be 'sensitive' because, if a charged particle passes through the chamber during this period, boiling will

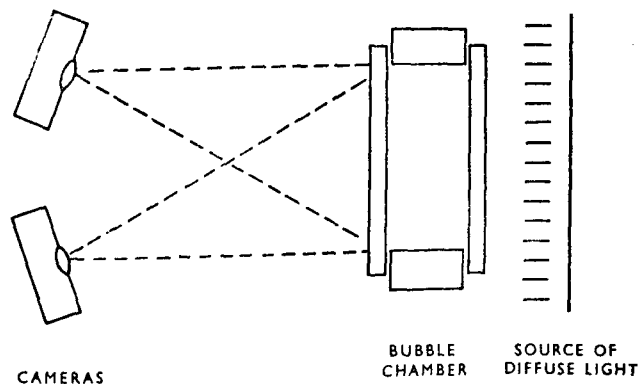


Fig. 2. Diagrammatic representation of a method of illumination and stereoscopic photography of tracks in a bubble chamber.

start as a result of small bubbles forming on the ions that are liberated by the particle on its passage through the chamber. At an appropriate moment a flash of light behind the chamber allows the bubbles to be recorded on a photographic negative. Figure 2 shows a schematic arrangement whereby images may be recorded from two different positions, thereby allowing stereoscopic reprojection to be made which will give the actual position of the tracks in space. It must be emphasized, however, that whereas in the case of drops forming in an expansion chamber the process is a relatively slow one (about 200 milliseconds), in this type of bubble chamber the rate of bubble growth is very fast – of the order of a few millionths of a second. For this reason the correct time relationship between the passage of the particle and the moment of the illumination flash is very critical.

Types of bubble chamber

The type of chamber described above became known as a 'clean' chamber. Because of the high pressure in the chamber, and because the glass walls could not be made too thick for accurate photography, the size of such a chamber is limited to a few hundred cubic centimetres.

Chambers were therefore constructed using metal as the main material, e.g., copper, brass or stainless steel, and glass windows were fitted as 'ports' for viewing and photographing the bubbles. At first it was thought that the immediate boiling that takes place at the edges of the glass/metal surfaces would prevent bubbles from growing upon the ions. It was found, however, that provided the expansion was fast enough, the edge effects did not prevent tracks of particles from being rendered visible in the main body of the chamber – but the rate of bubble growth was much slower (1 or 2 milliseconds).

This second type of chamber was called a 'dirty' chamber because of the pre-boiling that takes place on any sharp edges or corners in the interior. Figure 3 gives a schematic diagram of a 'dirty' chamber. In order to separate the working liquid from the rest of the chamber a diaphragm is used. The pressure necessary to compress the liquid is applied below the diaphragm –

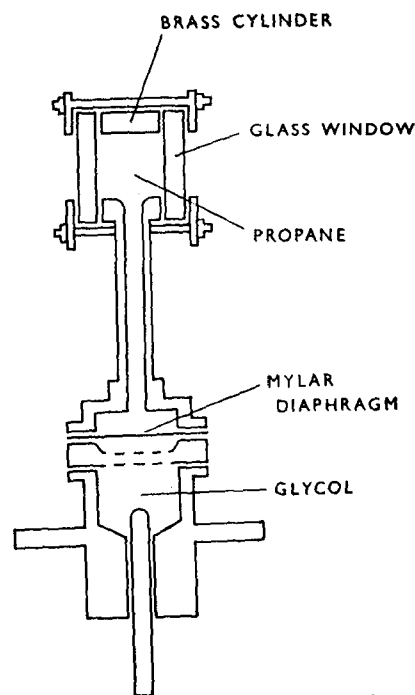


Fig. 3. Diagram of small 'dirty' chamber.

either by using a gas (e.g., compressed air) or a liquid as shown. Today the qualification 'dirty' is frequently omitted as most of the chambers in use with particle accelerators are of the 'dirty' category. Inset 13 shows a 5-litre 'dirty' chamber in use at Glasgow University. Experiments continue, however, in some laboratories with 'clean' chambers for the purpose of elucidating the precise mechanism by which bubble growth commences – and on how it depends on the physical properties and operating conditions for different liquids. Perhaps it is worth while recording that, as one might expect, a 'clean' chamber subjected to a very intense burst of radiation shows the same characteristics of slow bubble growth as a 'dirty' chamber.

The chambers so far described employ a hydrocarbon as working liquid; although pentane was used in the earlier chambers, it has generally been replaced by propane. This enables lower working temperature, about 60°C , to be used and is much more convenient than the 150°C required for pentane.

For reasons that will be discussed later, liquid hydrogen, deuterium, and helium chambers were rapidly developed after the hydrocarbon chambers. The principles of operation of these 'low temperature' chambers are essentially the same as for the hydrocarbon chambers, but since the whole chamber must work, in the case of hydrogen, at a temperature of approximately -250°C , the actual design is rather different and more complicated. Figure 4 shows a schematic diagram of a small liquid hydrogen chamber. The mode of operation is as follows:

The chamber itself, *A*, consists of a copper cylinder sealed at the ends by two circular glass plates. One plate transmits the light from the flash source into the chamber and the photograph is taken through the other plate. Part of the outer wall of the chamber is connected by a copper block, *B*, to a vessel *C* which also contains liquid hydrogen. A radiation shield *D*, which is maintained at liquid nitrogen temperature, surrounds both the chamber *A* and vessel *C*. A final jacket *E* surrounds the whole assembly and is connected to a vacuum pump. The expansion pipe runs from the chamber up the side of the vessel *C*, and out through the vacuum jacket; at *F* the expansion and recompression valve system is fitted. For simplicity, a number of filling pipes, safety valves, etc., have been omitted from the diagram.

The principle of operation is straightforward. An electrical heater embedded in the block *B* controls the temperature of the chamber which is, of course, at a higher temperature than the vessel *C*. Operation of the expansion valve *F* produces the superheat condition within the chamber after which the recompression is applied. A chamber of this type of design, 4 inches diameter and 2 inches long, has been constructed and used in California with the 184-inch synchrotron and also with the Bevatron.

While discussing the types of chamber available it is appropriate to mention the 'gas' bubble chamber. In this device a gas, e.g., methane, is 'dissolved' in the propane by application of considerable pressure (30 atmospheres), and large amounts

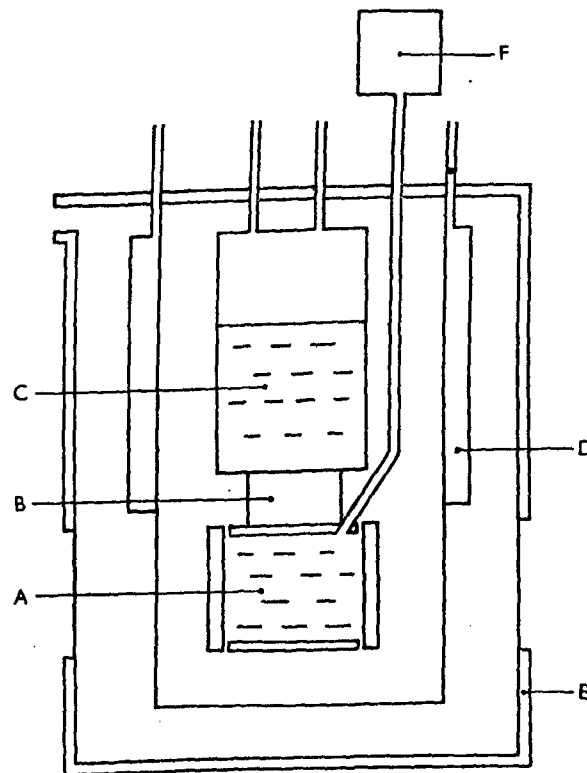


Fig. 4. Schematic representation of liquid hydrogen chamber.

(about 30 per cent by weight) of gas can be absorbed. The process can be carried out at room temperature and, therefore, no specific heating or cooling jacket is required. If the pressure is suddenly released, the dissolved gas will try to 'boil out' of the liquid and hence any ions that may be present will promote this process. Tracks of particles can, therefore, be recorded in the same way as for the chambers in which the bubbles arise from the condition of superheat.

Bubble chamber 'cycle'

Before discussing the kinds of physical investigation for which the different types of bubble chamber may be used, it is important to say a little more about the sequence of operations that should be applied to the chamber. It has already been explained that after the pressure has been reduced suddenly, the chamber will be in its so-called sensitive state. In the 'dirty' chamber, bubble growth at the walls will begin immediately following the pressure reduction and the pressure will begin to rise. After a relatively short time the chamber will, therefore, become insensitive to track formation and ready for recompression. There is, however, good reason for applying rapid recompression after the chamber has been 'sensitive' for only a limited period; if the bubbles that start to form at the walls (as soon as the expansion takes place) are allowed to grow too large and rise to the top of the chamber, the process of recompression and condensation of the vapour is a relatively slow process and the heat 'cycle' becomes both slow and inefficient.

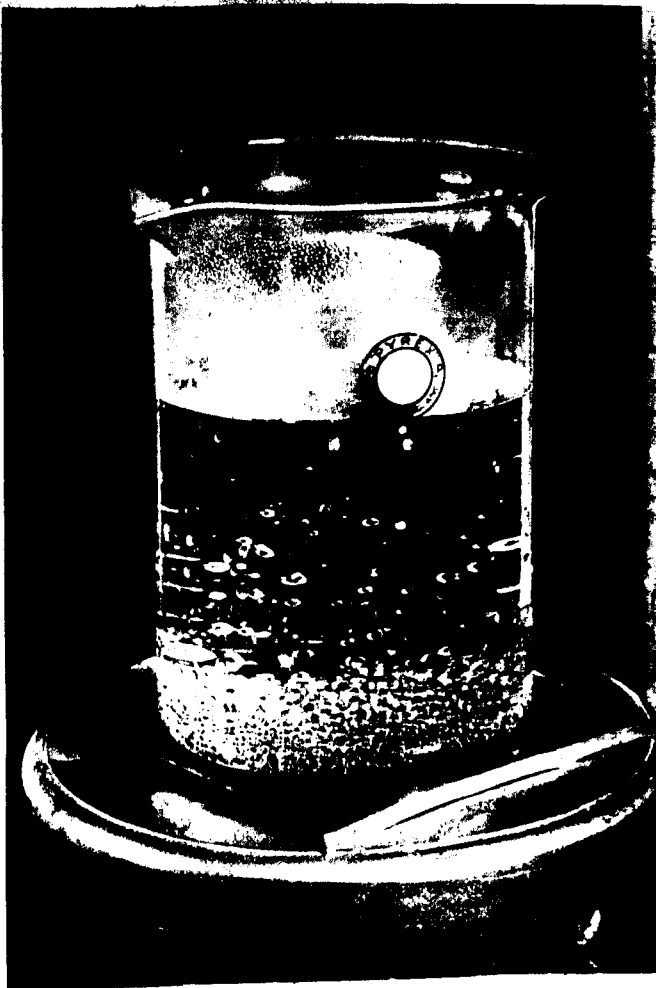
This is particularly important in low-temperature chambers where, in addition to the expense caused by loss of coolant material, the temperature stability within the chamber itself may be upset. Generally speaking, therefore, it is important that the processes of both expansion and recompression should be rapid even though it is only required to take photographs at relatively infrequent intervals.

It is naturally difficult to specify a unique sequence of operations – for each chamber there will be a correct 'cycle' and this will depend not only upon the particular experiment for which it has been designed but also upon the nature of the working fluid and physical dimensions of the chamber. A typical cycle of operation for a hydrocarbon chamber is shown in Figure 5.

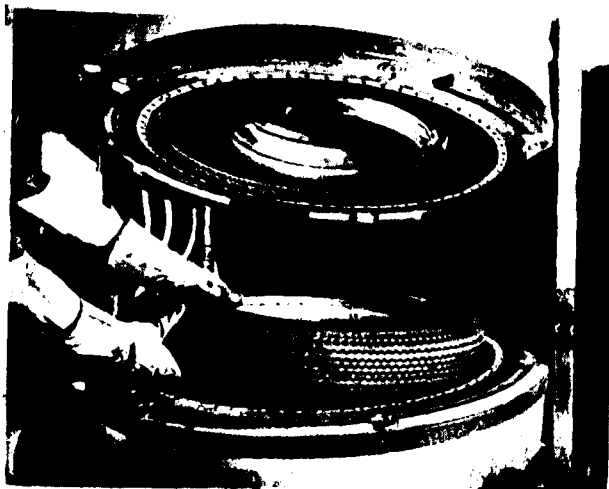
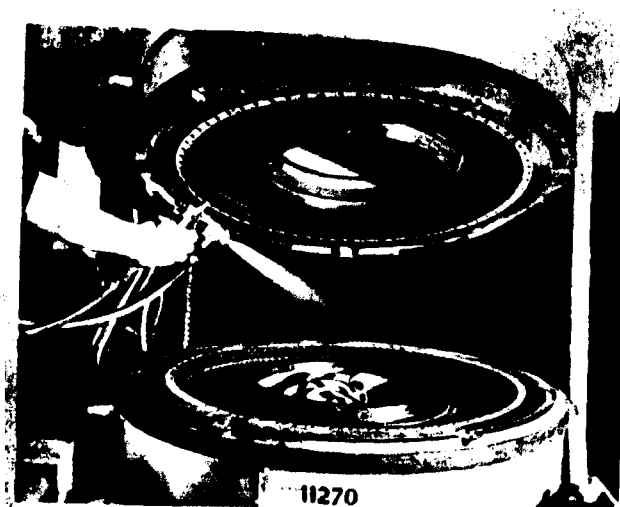
A represents the moment at which the expansion mechanism (hydraulic or mechanical) is made to operate. *B* represents the point at which the minimum pressure is reached.

The time *AB* may be about 2–3 milliseconds for a small chamber but will be longer for a large chamber – say 10 milliseconds.

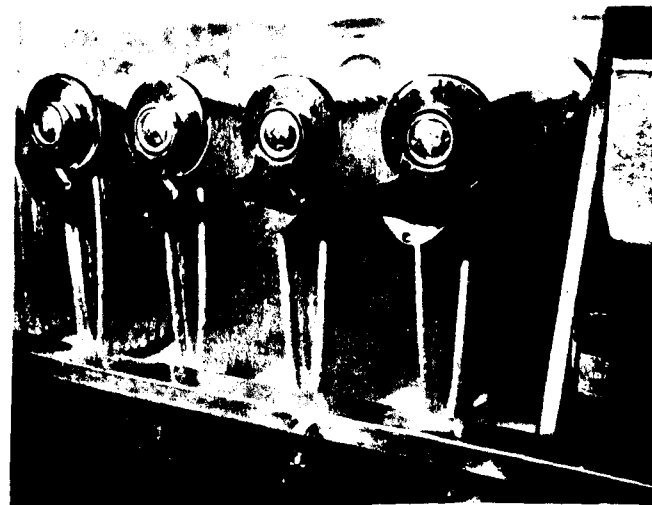
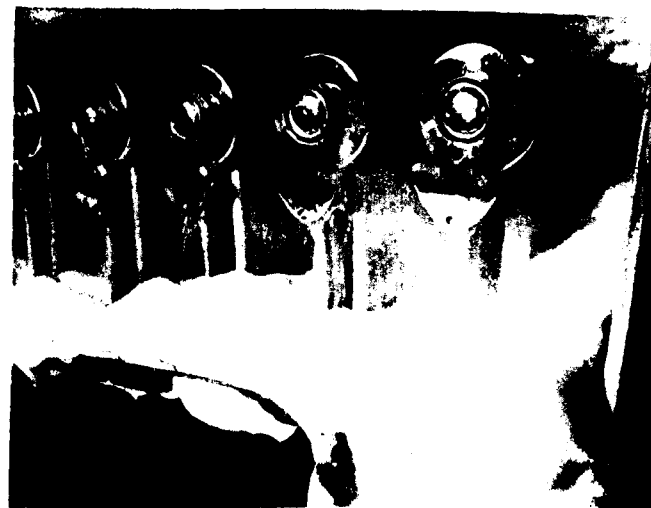
SILICONES



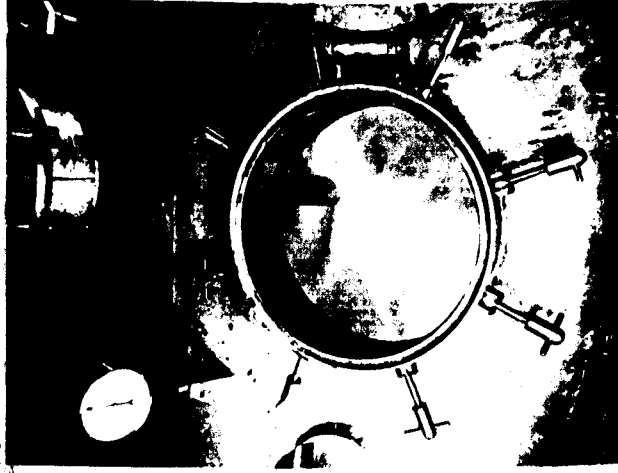
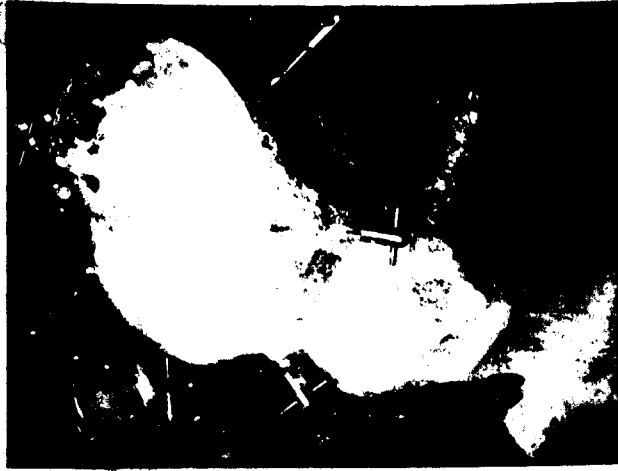
1. Water boiling in a beaker separated from an electric hot-plate by a sheet of silicone rubber which can withstand a temperature of 300° C. (Courtesy of I.C.I. Ltd.)



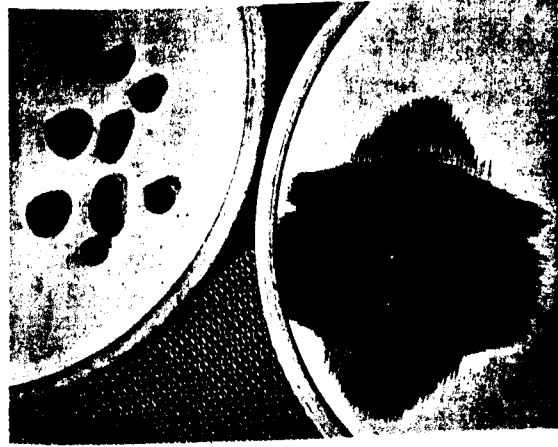
2. Silicone release agents are widely used in the rubber and plastics industries. The upper photograph shows a mould being sprayed with silicone, and the lower, a rubber tyre being removed from the mould. A silicone concentration of between 0.5 and 2 per cent is normally used. (Courtesy of India Tyre and Rubber Co. Ltd.)



3. The foaming occasioned during a hank dyeing process, shown above, was eliminated by the addition of 0.5 ounce of silicone in 100 gallons of dye solution, as illustrated in the lower photograph. (Courtesy of Weldon and Wilkinson Ltd.)



4. The foaming that accompanies a yeast fermentation has been suppressed by the addition of a few parts per million of silicone anti-foaming agent. (Courtesy of I.C.I. Ltd.)



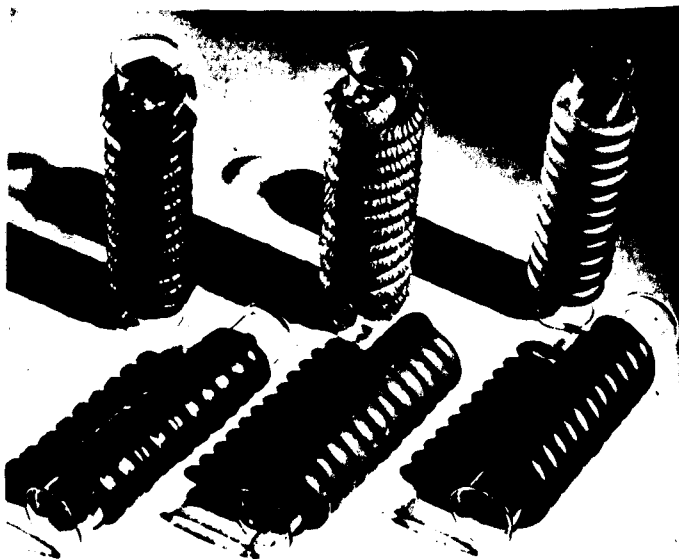
5. (left) Ink spilt on acetate rayon. The lower sample is untreated and easily stained; the upper specimen was treated with silicone and displays a high degree of repellency to water-borne stains. (Right) The untreated brick on the left has absorbed large quantities of water. The brick on the right has been treated with a silicone resin and displays a high degree of repellency like the treated rayon. (Courtesy of I.C.I. Ltd.)



6. Silicones also impart water repellence to leather. The untreated leather on the left is absorbant while the material treated with silicone emulsion does not 'wet'. (Courtesy of I.C.I. Ltd.)

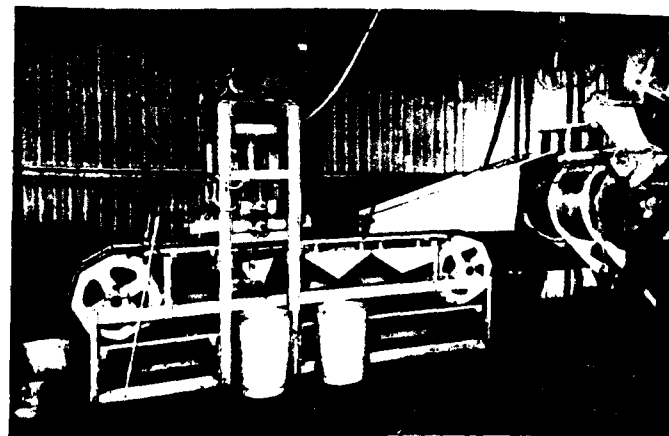


7. Engineer assembling the windings of an electric motor. The wires are sheathed with silicone rubber, and the glass cloth wrappings impregnated with a silicone resin. (Courtesy of I.C.I. Ltd.)



8. The effect of a high concentration of ozone on different rubbers. The front specimens show the materials before exposure, and the back, after. From left to right, Neoprene, natural rubber, and silicone rubber. (Courtesy I.C.I. Ltd.)

UNCONVENTIONAL FOODSTUFFS



9. The production of leaf protein. Green unwithered leaves go up the elevator on the extreme right, fall into the hopper, and thence go into the horizontal drum, where they are pulped and thrown out on the continuous press. This is an endless belt that moves forward intermittently under a ram whenever this is lifted. The action is fully automatic. A little to the left of the middle of the photograph, and working from top to bottom, are the oil pump, the hydraulic cylinder that operates the unit, the ram, the main juice-collecting funnel, and the bin in which the juice collects. Fibre collects at the extreme left.

THE STUFF OF BONES

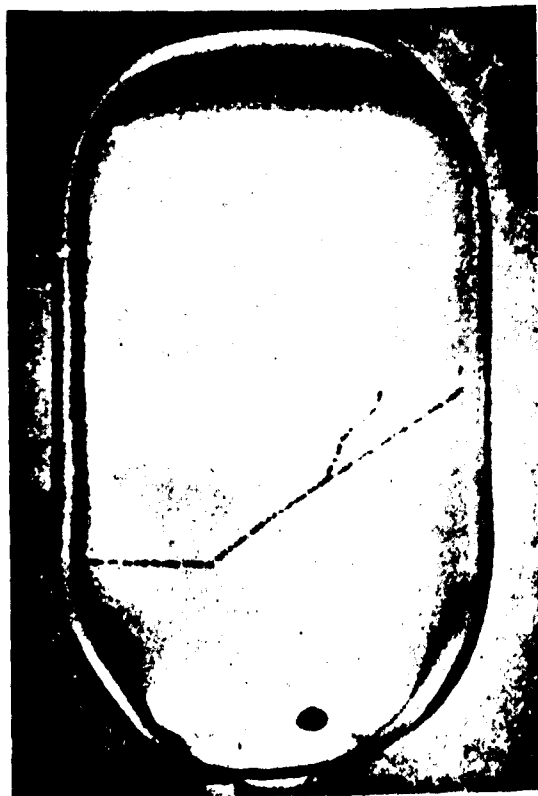


10. A specimen from the Hunter Anatomical Collection (1718-83). Human breast bone just before birth to show bony centres in cartilage model. $\times 2$.

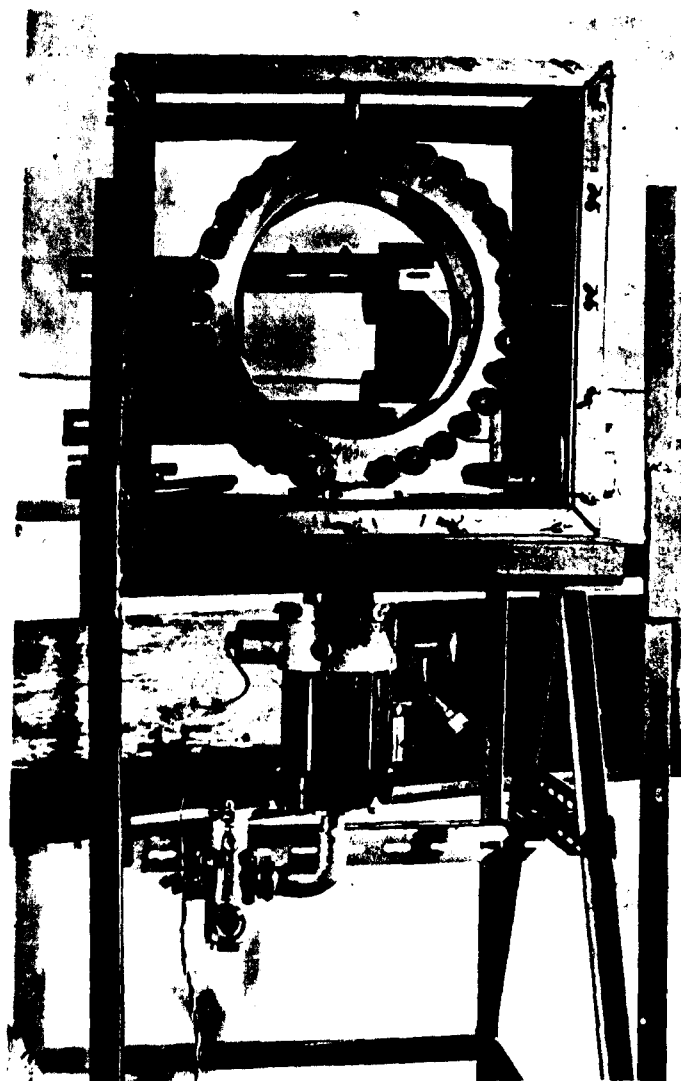


11. Also a Hunter specimen. Vertical segment through the end of long bone (thigh bone) to show meshwork of bony trabeculae. In the living bone the spaces are filled with marrow. $\times 2$.

BUBBLE CHAMBERS



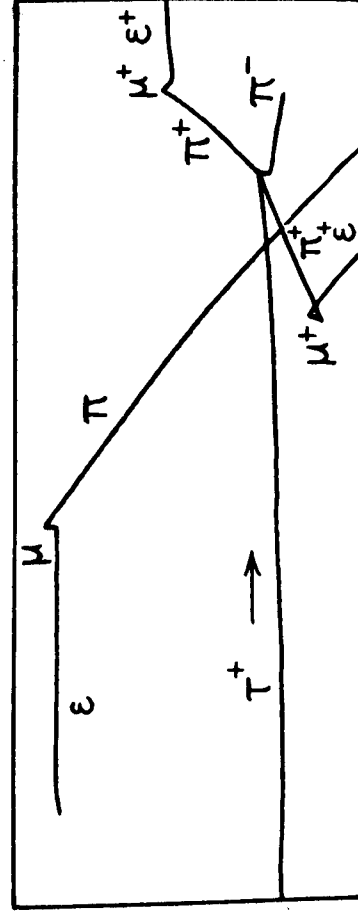
12. One of the first bubble chamber photographs taken by D. A. Glaser, showing tracks produced by the passage of charged particles.



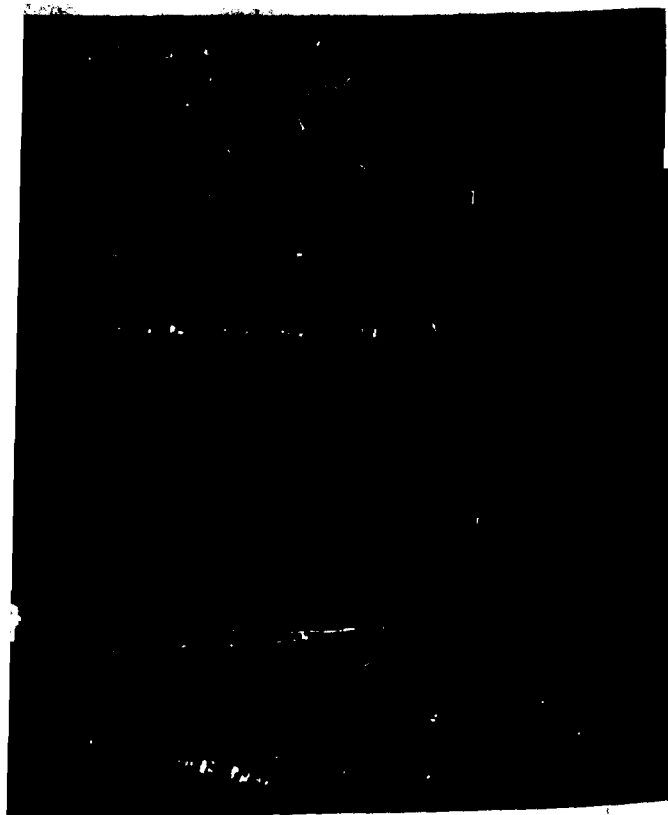
13. A five litre (10-in. diameter) propane bubble chamber.



14. The decay of a τ (tau) meson into three π (pi) mesons, and the subsequent decay of two of the π (pi) mesons.



15. Key to the opposite bubble chamber photograph.



16. Stereoscopic photographs showing the process of decay of π (pi) and μ (mu) mesons. The π (pi) mesons enter the chamber from the left; the μ (mu) mesons are shown by the short tracks of slightly higher bubble density.

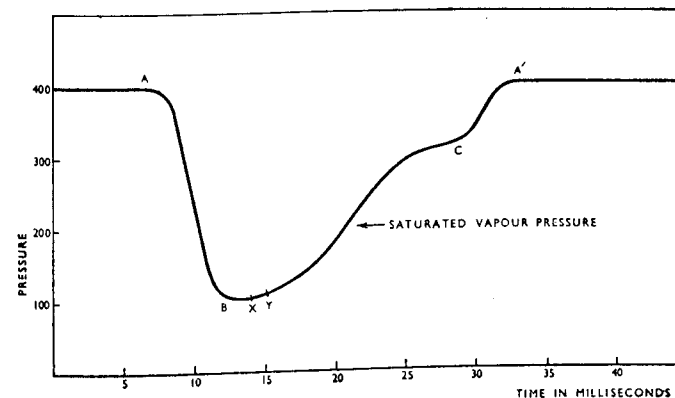


Fig. 5. Order of events in a bubble chamber cycle.

After about 10 milliseconds the 'wall' bubbles will have grown and the recompression should be applied at C; A' represents the moment at which the initial pressure is regained and in principle the chamber is ready for operation again. The time interval CA' will depend on the speed of the recompression mechanism. In practice it may be necessary to wait for a short time until A' before recycling – but since the whole sequence may only have taken about 25 milliseconds it should, therefore, be possible to run the chamber at about 40 times per second.

Two further points X and Y are shown on the time graph. If a particle or group of particles was allowed to enter the chamber at X, then the lamp flash would be triggered off at Y after sufficient time (about 1 millisecond) had been given for the bubbles to grow to the requisite size for photography. Naturally in practice a group of particles may not all reach the chamber at the same moment and the point X must be regarded as representing the region of time (when the chamber is used with an accelerator this 'region' will be the width of the output pulse).

USES OF THE BUBBLE CHAMBER

It has been shown that, in principle, the bubble chamber can be

regarded as equivalent to a 'liquid' expansion chamber; this gives not only the increase in the density of the working medium, as we have already mentioned, but also the very fast rate of operation if it is required.

It has also been pointed out that in the field of high energy physics new particles called mesons have been discovered, and it is essential that, in attempting to understand the structure of matter, the physicist must endeavour to determine the properties and behaviour of these new particles. One of the difficult – and at the same time exciting – aspects of meson work is that many different types of meson are found in cosmic radiation. It is clearly important that attempts be made to produce all the different mesons in the laboratory with the use of high energy accelerators which are either in use or in the process of being developed. One fact that characterizes mesons is that they are unstable particles; this means that after a certain period they undergo a transformation from which different particles emerge – frequently with high energies themselves.

The task of the 'high energy' physicist can, therefore, be summarized as follows:

- (a) To investigate interactions in which mesons are produced; a most important reaction of this sort is one in which high energy protons collide with other protons.
- (b) To determine the properties of the mesons and the nature of the 'decay' process which takes place at the end of the life of a given meson.
- (c) To determine how these mesons interact with other nuclei – particularly protons.

The bubble chamber can play a very important part in these investigations. The liquid hydrogen chamber is effectively a proton chamber – the fact that the hydrogen exists in the form of molecules with appropriate electrons does not in most cases affect these investigations of high energy phenomena.

Meson Production

Consider first the experiment in which protons collide with protons. This is one of the fundamental reactions of nuclear

physics because from it may be derived information concerning the nature of the forces that hold nuclei together. Although this article is intended to confine itself to a description of what bubble chambers are and for what purposes they can be used, it is necessary to describe here, in a very elementary manner, some of the problems of nuclear physics.

It is accepted that a nucleus consists of an assembly of both protons and neutrons; although the latter have no charge they nevertheless exert a strong force upon a proton or another neutron when either of these come close enough to the neutron. If these attractive forces did not exist, the neutrons would not remain within a nucleus and every element except hydrogen would be unstable – if it existed at all! Similarly there must be proton-proton forces of an attractive nature: this may seem at variance with Coulomb's well-known law that like charges repel since both protons have a positive charge. The explanation seems to be that when one proton approaches another, at large distances apart the Coulomb repulsive force certainly is present; if, however, the protons are approaching each other with considerable energy they can come very close together in spite of this mutual repulsion, and at a certain critical distance the, so-called, nuclear forces come into play. One of the theories of these nuclear forces has $\hbar$ as its basis, the assumption (based on experiment) that the magnitude of the forces between proton and proton, proton and neutron, neutron and neutron, are all approximately of the same order of magnitude.

To return to the proton-proton collision – or as it is usually called—scattering experiment, this can be carried out by firing protons from an accelerator, e.g., a cyclotron, into a liquid hydrogen bubble chamber. From the statistics of the number of protons scattered through different angles, information can be deduced about the nature and strength of the proton-proton forces. The experiment should be repeated at different values of the energy of the incident proton.

If the energy of the incident protons is high enough, it will be possible to observe within the chamber tracks which show that, in addition to the proton-proton scattering process, in some of

the collisions a meson has been *produced*; it is from the kinetic energy of the protons that energy is 'deducted' to manufacture the meson (according to the Einstein Law $E=mc^2$) and give it some kinetic energy. As the energy of the incident protons is increased still further, different types of mesons with higher mass values can be produced, and details of the processes can be found from analysis of the tracks.

The beam of high energy protons could also be directed into a bubble chamber filled with liquid deuterium. In this case the protons can also interact with the neutrons contained in the deuterium (deuterium is an isotope of hydrogen which is formed by adding one neutron to the proton, the nucleus of ordinary hydrogen). Since it is impossible to have a target consisting only of neutrons, the physicist frequently relies upon such a 'difference' method in which the experiment is carried out first with hydrogen as the target and then with deuterium.

Again, if a hydrocarbon target is used, there is clearly the possibility that the incident protons can interact not only with protons of the hydrogen but also with *any* or *all* of the protons and neutrons, i.e., nucleons, which make up the carbon nucleus (6 protons, 6 neutrons).

We have seen how mesons are produced when charged particles interact under certain conditions, but this is not the only way of making them. There is, for example, the phenomenon of meson production when the incident 'missiles' are not particles at all but high energy gamma rays, i.e. photons. Here again the bubble chamber can be, and has been, used to give information on the mechanism of the process. With a liquid hydrogen bubble chamber, we can look for the tracks of the meson, and since the gamma rays do not themselves give ionizing tracks it might be thought that the experiment would be a very easy one compared with the proton-proton one. Unfortunately, this idea of a photograph showing a clear chamber except for tracks of mesons (originating from the point where the gamma rays interacted with protons), is not right. Gamma rays interact with atoms in a number of different ways and by one type of interaction – called 'pair production' – produce with

comparative ease, electron pairs, i.e., positive electrons and negative electrons. Hence the bubble chamber will contain many tracks of these electron pairs but, nevertheless, it is still possible to carry out the experiment in such a manner that the meson tracks can be distinguished from the electron and positron tracks. By replacing the liquid hydrogen chamber by a hydrocarbon chamber the interactions of the gamma rays with carbon nuclei can be investigated.

Early in 1958, American scientists proposed to use a liquid hydrogen chamber in an extremely interesting and important experiment. The chamber is placed in the beam of the negative protons (usually called anti-protons) that can be produced in the very large accelerator known as the Bevatron. By these means the interaction of an elementary nucleon with its own 'opposite' will be observed for the first time under controlled conditions.

Meson Decay

The different varieties of meson have been given names taken from the Greek alphabet. The first meson was discovered by C. F. Powell and his collaborators at Bristol after an examination of photographic emulsions that had been carried high up into the atmosphere by balloons. For a period of some years there was an awkward but interesting disagreement between theory and experiment concerning the properties of the meson. This was resolved when it was found that the meson discovered by Powell, now called the μ meson, was a secondary particle – it was the product of the decay of a primary meson, now designated as the π meson. It is the π meson that is produced in the proton-proton collisions or the photon-proton interactions, and it was for the π mesons that theoretical physicists following the work of Yukawa were interested in predicting various properties. The properties of the π meson are very different from the μ meson and it was because of this that the confusion arose. The μ meson is itself unstable and decays into an electron and two other particles called neutrinos. The latter do not give ions when they pass through matter, and therefore they do not yield tracks in either expansion or bubble chambers. Inset 16 shows a π meson

decaying into a μ meson, which in turn decays to an electron. This photograph was taken in Liverpool by Dr Evans and his colleagues, working with a propane chamber.

Naturally the elucidation of the mode of decay of given types of meson is of prime importance – both from experimental and theoretical considerations. The bubble chamber has already played a part in contributing to our knowledge of how mesons decay. Thus in Inset 14, taken by Dr Glaser, a τ meson enters a hydrocarbon bubble chamber and after coming to rest decays into three π mesons. Other mesons decay in different ways – it is not unusual to find that a given meson may have several different modes of decay, and again a measurement of the relative probability of these modes is essential before a comprehensive theory can be formulated.

Meson Interactions

It has been shown above, in a very elementary and condensed form, how meson production and decay may be observed with the use of the bubble chamber. If the link between the mesons and nucleons is as close as has been suggested, it is not surprising that the physicist will also want to know what happens when a meson interacts with a nucleon, e.g., a proton, or with a whole nucleus, e.g., carbon. Again the bubble chamber can help in yielding this information. In many laboratories possessing high energy proton accelerators, a beam of π mesons may be extracted from the machine, focused, collimated, and then allowed to pass through a hydrogen or hydrocarbon chamber. The most important reactions that may be observed, apart from decay, are either scattering or capture. In scattering the meson bounces off the proton or carbon nucleus and the angular distribution of the scattered meson is measured; this gives information about the nature of the force between the two particles when they come sufficiently close to one another. If the meson energy is very low, it is possible to observe capture of the meson (when it has a negative charge) by the nucleus before decay to a μ meson takes place. After capture of a π meson, the rest mass of the meson must be disposed of in the form of energy: usually this

results in the ejection of a number of particles from the nucleus, each of quite high kinetic energy.

Although of a quite different nature, a meson interaction that attracted considerable attention and publicity, was recently reported from U.S.A. Negatively charged mesons were passed into a bubble chamber containing a mixture of liquid hydrogen and liquid deuterium. Some of the photographs showed that when the meson had apparently come to rest, after a short but finite time, it was apparently supplied with additional kinetic energy. A few of the photographs showed that this process could take place more than once for the same meson. The only explanation that fits the observed facts is that, under certain conditions, the negatively charged meson tries to behave like an orbital Bohr electron and form a molecule consisting of a hydrogen atom and a deuterium atom – as distinct from the ordinary hydrogen molecule which consists of two hydrogen atoms. Since the mass of the meson is much higher than that of an electron, the orbit will be much smaller; this brings the proton and deuteron close enough together so that the nuclear attractive force is brought into operation which results in the formation of a new nucleus, an isotope of helium. The energy release of this process is considerable – with the result that the μ meson is re-ejected with considerable kinetic energy. The extraordinary feature of the reaction is that it is a 'fusion' process – a process that is usually associated with thermonuclear reactions requiring very high temperatures (millions of degrees). Yet in this case the temperature is not far removed from absolute zero! It will be noted that the μ meson is acting as a sort of catalyst and, in principle, one might expect to be able to develop a controlled fusion power source along these lines. Calculations have shown, however, that this is in fact not feasible.

PRESENT STATE OF BUBBLE CHAMBER DEVELOPMENT

Evidence of the important part that bubble chambers are expected to play in the field of high energy is shown by the amount of technical effort that is being directed to their construction and

development in practically every country in the world where nuclear research is in progress.

In U.S.A., hydrocarbon, liquid hydrogen, deuterium, and helium chambers are being employed in current experiments of the types already discussed. In addition, there are many chambers under construction, and it is of interest to mention a few of them. In California a liquid hydrogen chamber 6 feet in length and over a square foot in cross section is the largest of the new projects. This chamber is fitted with a high field electromagnet and requires as accessories not only a large generator for the latter and a high capacity liquid hydrogen plant but it has also necessitated the erection of a separate building to house it. The chamber will be used to study the mechanism of production and the properties of the particles resulting from very high energy proton-proton collisions. Dr Glaser himself is building a liquid xenon chamber in which it is expected to be able to observe and elucidate complicated meson interactions and decays. The xenon class of chamber comes into a category called 'heavy liquid' chambers, i.e., they contain a liquid of relatively high atomic number and density. This will mean not only that particles will be slowed down more easily but also that there will be a high gamma-ray conversion (into electron pairs) efficiency. In addition, where a particle possesses strong coupling with nuclei, interaction lengths will be comparable with the dimensions of a large but practicable size of chamber. The xenon chamber has many advantages, but nevertheless it is very expensive and the rate of production of xenon is limited. In small chambers alternative liquids, such as tungsten hexafluoride, have been used and a large chamber containing this material is being constructed also in California.

In Britain there are a number of hydrocarbon chambers in operation at various Universities, and four hydrogen chambers are either ready or nearly ready for use. In view of the considerable manpower required for the design and manufacture of large low-temperature chambers, it is likely that a number of Universities and Government Establishments will co-operate in the construction of such a chamber, one of the uses of which will be

in conjunction with the new high energy accelerator under construction for the Nuclear Institute at Harwell. At a later date it is proposed to build, also by joint co-operation, a large heavy-liquid chamber.

In Russia, several hydrocarbon chambers are in operation, and at least one hydrogen chamber. Further chambers, particularly hydrogen ones, were reported at a recent Conference in Italy to be in the process of design or construction.

In France and Italy chambers are in operation and in these countries, as well as in Germany and Switzerland, design and construction of various types of advanced chamber is in progress.

It should also be added that, owing to the rate at which the chambers can be made to operate, the problem of rapid analysis of large numbers of photographs is a formidable one. In some countries, particularly U.S.A., considerable thought and manpower is being directed to the development of automatic, i.e., electronically controlled, scanning linked with computers. If the full contribution of bubble chambers to nuclear physics is to be realized this technique will almost certainly be used eventually.

Summing up, therefore, it seems clear that the bubble chamber is a most powerful addition to the techniques available to the nuclear physicist. Already problems in meson interactions and decay have been solved by its use, and when the larger chambers, some of which have been mentioned, are linked with the existing or planned high energy accelerators, results should be obtained which should clarify to an appreciable extent an understanding of how mesons fit into our concepts of the structure of matter.

APPENDIX

A note on the theory of operation of a bubble chamber

Although it is not intended to present here any mathematical treatment of the relevant theory, it is only fair to point out that, as in the case of condensation, no exact theory of bubble formation has yet been developed. It is not at this stage possible to calculate precisely how many bubbles per centimetre will be

observed when a given type of particle passes through a given liquid under specified conditions of superheat. From the point of view of an experimental physicist who is proposing to use a bubble chamber two questions are of particular concern: (1) At what temperature and pressures should the liquid be operated in order that bubbles will be formed along the track of an ionizing particle? (2) From the observed bubble density can the velocity and the rate of change of velocity of the incident particle be deduced safely? If a full and exact theory were available then, as has been already stated, the answers to both these questions would be known.

In practice, the situation is rather interesting. Glaser developed a formula that expressed the degree of superheat required for bubble formation as a function of the surface tension and the dielectric constant of the liquid: in addition this formula contained a quantity n which represents the number of electronic charges associated with a given bubble. Physically the formula stated that for a bubble to grow (no matter how small it was initially), either n had to be larger than a certain value for a fixed value of superheat, or for a given value of n , the superheat must be greater than a certain value. From experimental observations on the value of the superheat necessary before bubbles can be observed, the value of n may be calculated and for the hydrocarbon chamber a value of about 6 is obtained. Thus we have a picture in which one imagines that when the liquid is in its state of superheat, by statistical fluctuation, bubbles of microscopic size are forming and collapsing rapidly throughout the volume of the liquid. This means that a charged particle in passing through the liquid develops a cluster of six or more charges at a point where a small bubble is forming and instead of collapsing as an uncharged bubble would do (this can easily be proved to be the case), the concentration of charge enables it to grow and thereby reveal that part of the track of the particle. The difficulty with this theory, from a quantitative point of view, is that in certain cases very large and unlikely values of n seem to be required. Nevertheless, when a completely new liquid is to be considered for use in a bubble

chamber, the formula, with a value of n chosen to be about 6, frequently predicts values of working pressure and temperature that are near those actually observed in experiments.

The idea of clusters of charges leads immediately to a qualitative answer to the second question stated above, which to the experimentalist is very important. A mechanism by which a charged particle deposits clusters of charges is well known – the phenomena of delta rays; this is the name given to low energy electrons which are ejected from an atom by the charged particle as it passes through matter. To form an ion, an electron has only to be detached from an atom, but if given, in addition, some kinetic energy by the interaction, it will in turn cause ionization as it comes to rest. For a low energy electron in a liquid, the range is very short and therefore this secondary ionization will be contained within a very small volume. Hence we have an explanation for the production of clusters which we have seen can lead to the production of a bubble of microscopic size.

Now the number of delta rays lying within certain energy values is known to be inversely proportional to the square of the velocity of the incident particle. Therefore, if this qualitative picture is correct, the number of bubbles per centimetre, i.e., the bubble density, should be proportional also to the inverse square of the velocity. This is found to be approximately the case, but until recently different workers who were investigating this problem have not reported full agreement and it was not immediately obvious where the discrepancy lay. It now seems that the mechanism of the coalescence of bubbles plays an important part, particularly when the velocity of the incident particle is low and, therefore, the bubble density high. The next and immediate step is to carry out experiments that will show to what extent the coalescence mechanism is operative right at the start of the bubble forming process and to what extent it is operative during the process of growth.

THE STUFF OF BONES

G. M. WYBURN

'I FEEL it in my bones' conveys a sense of the inevitable, the preordained, and the immutable. Yet bone is not a static and unchanging structure. Like any other tissue, it is a living milieu with a constant movement of its molecules and an interchange of ions between its elements and the blood circulating through it. For instance, radioactive material, such as P^{32} , appears in young bones five minutes after being injected into the body. Given proper feeding, the bones lengthen and thicken as the child grows, and they may soften or harden with variations in the quantity of secretion poured into the blood by certain glands. There is also the daily wear and tear and replacement and, like all living matter, they pay toll to the ageing process – old bones are brittle and break where the more resilient bones of youth would bend. The stuff of bones is cells, a matrix composed of fibres with cementing substance, embedded in which are minute crystals of the mineral 'apatite' which is responsible for the characteristic hardness that enables the skeleton to act as the supporting framework of the body. Although to the naked eye, bone looks decidedly solid, one-fifth of it by weight is water, and a section of bone seen with the microscope is porous, its substance permeated by spaces filled with bone cells and large and small canals containing blood vessels.

While today we know a great deal about bone, its biological structure, its chemistry, and physical properties, there are still a number of puzzling things about it. Why should the inorganic ions circulating in solution in the blood be deposited as an orderly arrangement of crystals at the selected sites where bone is being formed? Or again, why under certain conditions should tissues outside the skeleton change into bone? If, for example, a small piece of bone is grafted under the skin, into a muscle

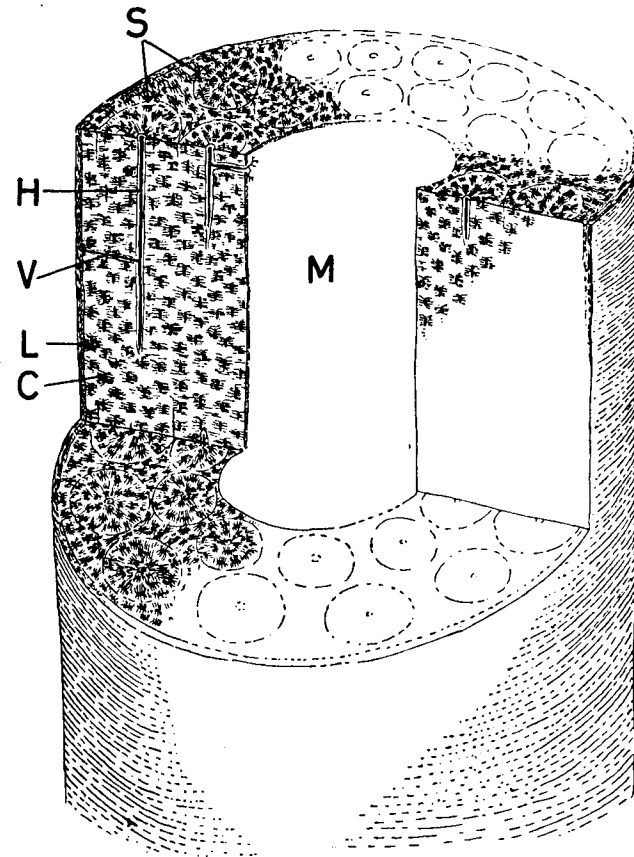


Fig. 1. Schematic drawing of a segment of the shaft of a long bone, showing centre marrow cavity, and microscopic structure of cut vertical and transverse surfaces. H=Haversian canal, V=Volkman's canal, L=lacunae (bone cell spaces), C=canaliculi, S=Haversian system, M=marrow.

or into the space behind the cornea of the eye, within a few days the surrounding soft tissues have formed new bone. In this respect, bone is quite unique and is the only tissue or organ which, when grafted, can induce the host tissues to change into those of the graft.

CELLS OF BONE

While there are those who belittle the importance of the cells in bone, there is no real reason to suppose that bone is any different in this respect from other tissues of the body where the cell is the organizing centre of activity. Bone cells are named according to the work they do, osteoblasts, osteoclasts, and osteocytes – the builders, demolishers, and maintenance cells.

Osteoblasts

Where new bone is forming, e.g., growing or healing bone, there are always plenty of osteoblasts present. These are filled with substances like ribonucleic acid, glycogen, and enzymes, such as alkaline phosphatase, indicating the active manufacture of the protein and carbohydrate substances for the organic part of the bone matrix. If a growing animal is given an injection of radioactive carbon (C^{14}) or sulphur (S^{35}) the labelled material accumulates in the osteoblasts within a few hours, and only later is found in the matrix. When new tissues are being laid down, the building cells usually multiply by (mitotic) division. Osteoblasts, however, do not divide, but increase in number by recruiting 'precursor' cells, and one of the questions asked is where do these cells come from? Are they a special brand of cell, a race apart like the blood-forming cells, and endowed with potential qualities of bone formation, or can other cells, such as the fibroblasts of soft connective tissue, change into osteoblasts? Generally speaking, growth, and renewal of tissues and organs after birth, is carried out by the specific cells of the particular tissues or organs concerned. One of the fascinating puzzles about bone is that it can be formed outside the skeleton – 'ectopic' bone – e.g., in the sheaths of muscles or organs, in the soft tissues round joints – places where it has no business to be, and where, indeed,

it can interfere with normal duties. Ectopic bone can be produced experimentally and there is strong evidence that in such conditions the local connective tissue cells become converted into osteoblasts.

Osteocytes

When the osteoblasts have finished their work many of them become imprisoned in spaces (*lacunae*) in the matrix they have produced. They are now osteocytes. The change from osteoblast to osteocyte is irreversible. There is an inter-communicating network of fine canals between the lacunae, and the osteocytes push fine spidery processes into these minute channels. Each cell is responsible for the maintenance of the surrounding territory of matrix, and when they die the bone dies. To carry out their job the cells require to get raw materials from the bloodstream. In even the hardest type of bone no cell is more than a fraction of a millimeter from the nearest blood vessel.

When a piece of bone is grafted into a new situation, many of its cells die because of the physical difficulty of getting a new blood supply quickly enough. The living cells that are present in the graft when it is examined two or three weeks later are new osteocytes derived from osteoblasts.

Osteoclasts

Young bones grow in length and thickness, but at the same time the fully grown bone preserves the shape and form of the infant model. This means that new bone formation must be accompanied by a process of remodelling by selective resorption and formation. The job of the osteoclast is bone resorption, working in co-operation with the osteoblasts. The internal architecture, at first a random arrangement of thin sheets (*trabeculae*) is finally determined in weight-bearing bone by the local mechanical requirements – a beautiful example of this is the pattern of bony struts and stays in the inside of the weight-bearing heel bone, or of the neck of the femur which is transmitting the body weight to the lower limbs.

Osteoclasts vary in size and shape, and are often large enough

to qualify as one of the body's giant cells with up to a hundred nuclei. When at work, osteoclasts can be seen wrapped round a spicule of bone, pressed flat against its surface or in a large space in the bone that the cell itself has excavated. They have been watched at work in a transparent tissue chamber in a rabbit's ear destroying a spicule of bone 0.04 mm long. The spicule had disappeared within twenty-four hours.

Osteoclasts are mobile and can protrude their substance in elongated processes like the pseudopodia of amoebae. It is a grim picture to see an osteoclast pushing an exploratory tentacle along a canaliculi into a bone cell space seeking out the tenant osteocyte. The surface of an osteoclast in contact with the bone has a 'brush' border of tiny processes like those found in the free surfaces of the lining cells of the intestine or the kidney tubules. The osteoclasts presumably first soften the bone by a secretion of some kind, and then push these tiny protrusions of their substance into the softened bone. Softening, or decalcification, implies dissolving the hard mineral part of the bone which is then removed in solution in the body fluids. One difficulty is to account for this 'solution' at the normal pH of the tissues. A number of 'chelating' agents are now known that have an affinity for calcium, and decalcify by attracting the calcium from the bone and so break up the mineral. It is possible that osteoclastic activity is a form of physiological chelation.

We still argue about the origin of the osteoclasts. They are not seen in normal adult bone, but seem to be mobilized in response to some altered condition within the bone, the precise nature of which is unknown. They appear, for example, in the jaw at the time of shedding the milk teeth, obviously in connexion with the loosening process, and also after an injection of parathormone (the secretion of the parathyroid glands in the neck) large numbers of osteoclasts are found in the bones. During the egg-laying season in birds there is a marked and quite rapid decrease in bone density caused by the absorption of calcium used to form the hard egg-shell, and again we find many osteoclasts in and around the bones.

In the body there is a type of cell whose duty is to deal with

dead or foreign material. These are the phagocytes, some of them very big cells, e.g., foreign body giant cells. Most likely the osteoclast belongs to this class of cell, and specializes in bone destruction.

The Bone Matrix

The great bulk of the substance of bone – the material in which the cells are embedded – is bone matrix. The tissues that are used for packing, holding together, supporting and taking strains and stresses, like joint ligaments and the tendons that attach muscle to bone, are grouped together as the connective tissues. The matrix or intercellular ground substance of connective tissue consists of collagen fibres and mucopolysaccharides (substances made up of a varying proportion of protein and carbohydrates). The organic part of bone matrix is also collagen fibres and mucopolysaccharides. Because of their optical properties, collagen fibres are not normally visible under the microscope in bone sections and have to be unmasked by special treatment which removes the mineral salts and mucopolysaccharides. The younger the bones the easier it is to show up the collagen fibres. A collagen fibre is an aggregation of smaller units packed side by side, the fibrils, visible with the electron microscope. These fibrils have a pattern of cross banding at regular intervals of 640 Å and there is evidence that they can be still further resolved into thinner longitudinal units, the protofibrils. The tendency to fibre formation is a characteristic property of collagen, and fibres can be precipitated from a solution of collagen by a variety of non-specific chemical procedures. The mechanism appears to be an aggregation in length and breadth of elongated particles and the pattern of banding of such reconstituted fibres varies according to the procedure adopted. Altering the pH, for instance, produces a 'fibrous long spacing' type of fibre with the bands at intervals of 3,000 Å.

While the gross chemistry of collagen is more or less known, at any rate in terms of analysis of the relative quantities of essential constituents, there is still some doubt about how these constituents are packed together to form its molecule, so we

cannot yet be too certain about the interpretation of the visible structure, however fine, in terms of physical chemistry. Collagen is a fibrous protein which means that the molecule is made up of amino acids linked together to form polypeptide chains, and the characteristic of a particular fibrous protein depends on the kind, proportion, and sequence of the amino acid groups in the chains.

Chemists believe that the collagen macromolecule is made up of three such polypeptide chains coiled round one another. One suggestion is that the microfibril is an end-to-end linking up of collagen macromolecules each 3,000 Å in length, and that the repeating sequence of regions of bands and inter-bands represents differences in the disposition and interaction of the side groups of the main polypeptide chains in these regions.

In newly formed bone, the fibres of the matrix are coarse, and interlace in random fashion with no ordered pattern. In mature bone there are sheets of parallel running fibres, and although the matrix is a continuous structure, a section of bone seen with the microscope has a layered appearance as though it were made up of lamellae. This is in part due to the different direction of the fibre bundles in the neighbouring lamellae, e.g., in the concentric lamellae of the Haversian systems (Figure 2), but in addition there are quantitative differences in the composition of contiguous areas, one type of lamellae having more cement and mineral substance, while another type has more collagen fibres. The fibres are formed in the bone cells, passed into the matrix where they undergo further development.

The remainder of the organic matrix (but a much smaller part) consists of mucopolysaccharides – protein-carbohydrate substances, with a very little protein which is, however, quite distinct from collagen. The precise chemical relationship of the protein and carbohydrate is not known; they may be loosely linked or more firmly bound together to form a macromolecule. The carbohydrate part consists of polysaccharides, i.e., sugar units joined together (polymerized) to form a large molecule.

There are mucopolysaccharides in the ground substance of all connective tissues. The main mucopolysaccharide of carti-

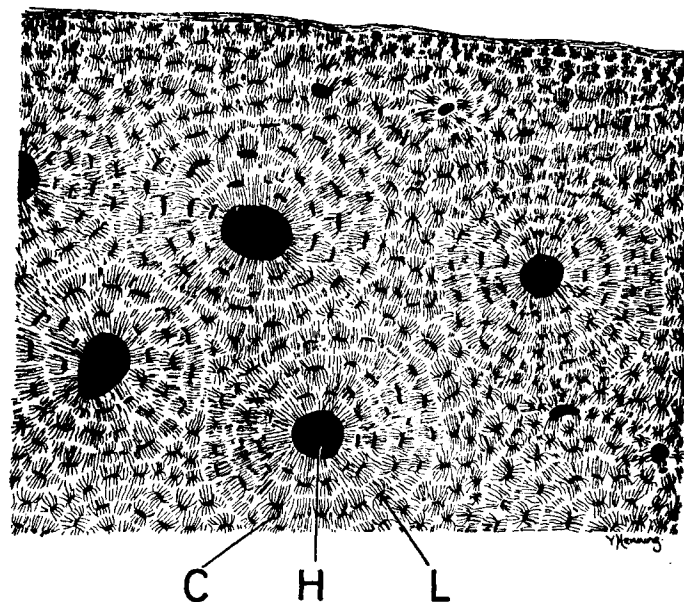


Fig. 2. Drawing of a transverse section of shaft of bone to show the canal system. The pattern of lacunae indicates the layered (lamellar) arrangement of the matrix, e.g., the concentric lamellae of Haversian systems.

lage, chondroitin sulphate, is also found in bone; mucoitin sulphate is the mucopolysaccharide of the corneal ground substance; and hyaluronic acid is the most abundant mucopolysaccharide in the soft connective tissues, e.g., under the skin. The purpose and physical form of the mucopolysaccharides differs in the various tissues. The most direct way of evolving bulk and viscosity is by polymerizing simple sugars and sustaining them in water to form either a transparent refractive medium such as the cornea of the eye, or a lubricating fluid (synovial fluid) for the movable joints. The mucopolysaccharides are concerned with the regulation of tissue permeability, with the transport of substances from the blood to tissue cells, and they are

necessary for the proper nutrition of avascular structures like cartilage and cornea. The mucopolysaccharide cannot be entirely exempt from blame in the rheumatic conditions today grouped together as the collagenous diseases, and it may be that in the sudden onset of 'stiff neck', or the true lumbago, there is an equally sudden change in the polysaccharide molecule associated with the collagen fibres. In densely fibrous tissues the mucopolysaccharides are the cement between the fibrous units, and there may be a more intimate union of collagen and the mucopolysaccharides, associated with the extra-cellular maturation of the organic matrix.

The polymerization of sugar units begins in the cell. Injected S^{35} (radioactive sulphur) accumulates first in cartilage cells before appearing in the ground substance incorporated in chondroitin sulphate. We have no knowledge of the relationship in time and place of the intracellular events concerned with the formation of the collagen and mucopolysaccharide of the bone matrix.

MINERALIZATION OR CALCIFICATION OF THE MATRIX

More than half the bone by weight is inorganic substance in the form of minute crystals (10^{-7} cm. in length) of the mineral group known as the apatites. The main ions of these crystal particles are calcium, Ca^{+2} , and phosphate $(PO_4)^{-3}$ and OH^{-1} . The ratio of Ca and P is about 1 : 5, but this can vary in different bones in the same individual, and at different ages in the same bone. In addition there are small amounts of Na^{+1} , K^{+1} and Mg^{+2} , Cl^{-1} , F^{-1} , and Cit^{-3} , and together with water these inorganic ions make up what is known as the bone salt. An important physical characteristic of the bone crystals is the high proportion of surface area to mass, so that a large percentage of the ions are on the surface and thus in a favourable position for rapid and free interchange with the ions of the body fluids. Ca^{+2} and $(PO_4)^{-3}$ are incorporated in the crystal lattice as well as on the surface and in this position ionic interchange is probably restricted to the process of recrystallization associated with bone

remodelling. The size of the crystals is limited by the supply of minerals in the tissue fluids and the ratio of Ca/P ions in the bones can be altered with changes in the diet. The mineral element is not a continuous structure throughout the matrix. Seen with the electron microscope the crystals are discrete and appear to form rings round the collagen fibres at intervals of 640 Å, i.e., corresponding to the bands, and possibly positioned by the activity of the side groups of the collagen molecule in these regions.

The presence of Cit^{-3} and F^{-1} is of topical interest. Mammalian cells can generate energy from the oxidation of carbohydrates, fats, and proteins by a complicated chemical procedure known as the tri-carboxylic acid cycle (Krebs cycle), and citrate occupies a key position in this process. The skeleton contains about 90 per cent of the total citrate content of the body, but it is not clear whether this is in the form of free ions on the surface of the crystal, or linked with Ca. It is known that citrates form complexes with Ca and that these calcium citrate substances are soluble at the normal pH of body fluids. The Cit^{-3} , therefore, may be involved in the deposition and absorption of mineral crystals and the bone cell could exercise some control over the mineral state of its territory of matrix by varying the amount of citrate available locally.

Fluorine in bones

Fluorine is taken into the body mostly in drinking water, and is either excreted in the urine, or deposited in the skeleton as fluorine ions on the surface of the crystals, and later in the crystal lattice. The amount of fluorine in bones increases with age and the consequent change in the physical nature of the crystals may be to some extent responsible for the greater density of old bones. The topical interest in fluorine is the belief that added to drinking water it will prevent dental caries, a form of tooth decay, and recently an expert committee of the World Health Organization has stated that 'the effectiveness, safety and practicability of fluoridation as a means of preventing dental caries, ... is now established'. Too much fluorine,

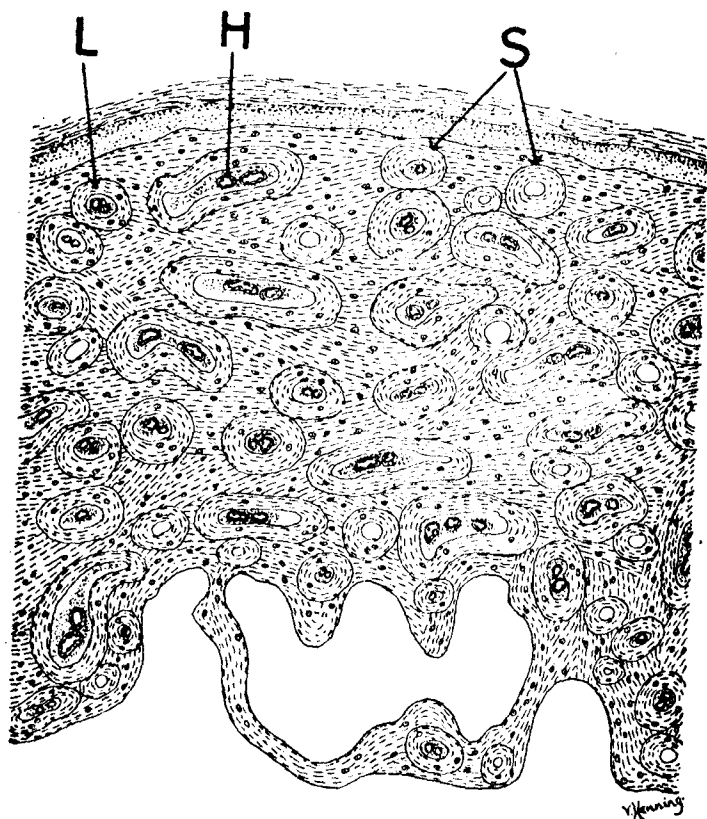


Fig. 3. Drawing of a transverse section of decalcified bone.

however, can affect the tooth enamel, giving mottled teeth, and there may be other as yet unknown low-level toxic effects.

When fossil bones are embedded in a porous deposit, such as gravel, containing fluorine ions, in the course of time they take up the fluorine ions which become incorporated in the bone crystals. One of the tests that helped to expose the Piltdown hoax was the analysis of the fluorine content of the so-called

fossil bones, which showed that they were relatively recent remains, and not an archaeological 'find'.

Another method of estimating the age of fossil bones is by measuring the content of radioactive carbon (C^{14}). C^{14} is formed in the atmosphere by the action of cosmic rays and there is a continuous but limited exchange with the carbon atoms of living tissues, including bones. This ceases at death and thereafter there will be a gradual diminution in the amount of C^{14} in the bones. The extent of this diminution gives an indication of the age of the fossil bones, provided they are not too old, because C^{14} has a half life of 5,600 years.

Bone mineralization

One of the perplexing and at the same time intriguing puzzles about bone is to explain why ions in solution in the body fluid should form crystals in its substance. For a long time it was assumed that calcification – the hardening process by deposition of bone salts – was the work of special enzymes, but there is now considerable experimental evidence against this. When new bone is being laid down the first step is the formation of the organic matrix, i.e., the collagen fibres and the mucopolysaccharides, which is thereafter calcified by the deposition of the mineral crystal in its substance. Collagen and mucopolysaccharide are, however, common to the ground substance of all connective tissues so that presumably in bone there is a special physico-chemical state of the organic matrix which constitutes a 'calcifiable' tissue. Another point to be considered is the solubility of inorganic ions at the pH of the tissues, and it is possible that some mechanism affecting the local pH is also involved in the process of calcification. The problem is not yet settled, although there is some recent promising work on the subject.

When growing animals are fed on diets deficient in phosphates and vitamin D the bones continue to grow in length, but do not harden and remain as cartilage or soft osteoid tissue. This is the condition found in rickets. If slices of such rachitic cartilage are incubated *in vitro*, i.e., outside the body, in a solution containing the necessary ingredients of a calcifying fluid,

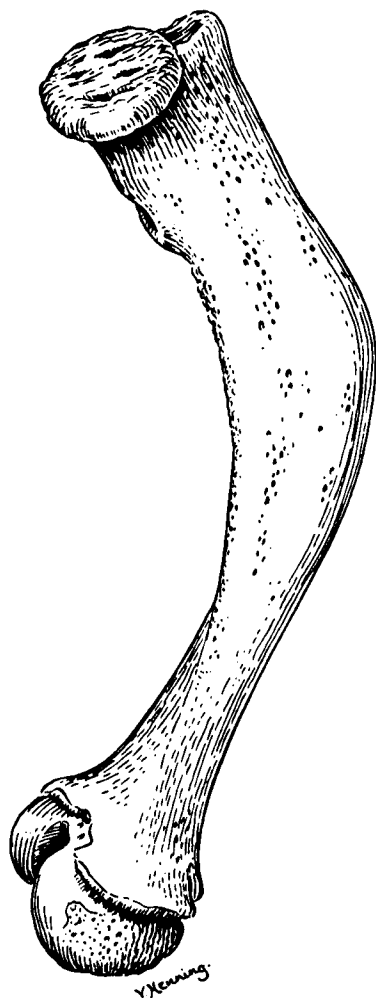


Fig. 4. A Hunter specimen. Deformity of the thigh bone (femur) of young subject due to rickets.

calcification will take place. If the rachitic cartilage is first shaken up in a solution containing strontium which competes with Ca for the P no calcification occurs, but if the tissue is now placed in solution containing only calcium and no strontium, further treatment with the calcifying fluid will result in calcification. This so-called reversible inactivation of calcification has become a useful technique to get more information about the mechanism of mineralization, and so far points to some special linkage of bone collagen and mucopolysaccharides as the critical factor.

Containing so many inorganic ions – some labile, others more or less immobilized in the crystal lattice – bone is a natural target for many radioactive elements. Of these the most dangerous is strontium (Sr^{90}) which along with barium (Ba^{140}) is readily absorbed from the intestine. Strontium has a half life of 20 years, emits beta particles and has the ability to replace calcium in the bones. The harmful effects are due in the first place to the destruction of the blood-forming elements in the bone marrow, and interference with growth in the young bones, but more ominous is the possibility of initiating cancerous growths of bone. Since environmental contamination from the fallout of Sr^{90} has only commenced in recent years the Sr/Ca ratio in a human skeleton will depend on the degree of bone remodeling and re-formation of crystals, plus the surface chemical interchange. To this will be added, in growing bones, a further proportion of strontium, replacing the calcium in the formation of new bone.

To produce bone needs something more than just getting together the ingredients, the cells, the collagen, the mucopolysaccharides and the minerals. The vitamins A, C, and D, and the hormones of certain glands are all necessary items in the recipe. Proper growth and remodeling of bone requires a balanced amount of vitamin A in the diet. With too little, irregularities and deformities occur in the skeleton, while with excess there is unrestrained activity of the osteoclasts which resorb much of the bone and leave it fragile. Vitamin A is required for the well-being of most of the tissues and sense organs of the body, and

perhaps the best known effect of vitamin A deficiency is night blindness. Vitamin C (ascorbic acid), the scurvy vitamin, appears to be necessary for the production and maintenance of the ground substance of connective tissues in general, including the organic matrix of bone. In scurvy the bones produce a type of matrix which is not calcifiable and thus they remain soft. This effect is reversible with adequate supplies of vitamin C.

The important job of vitamin D – the rachitic vitamin – as far as bone is concerned, is to maintain the level and ratio of Ca/P in the blood needed for calcification, and it probably does this by regulating the absorption of minerals from the intestine. In the absence of vitamin D no calcification takes place and the new bone in the growing infant remains soft and bends with weight bearing. Adult rickets, osteomalacia, occurs where there is malnutrition with a lack of vitamin D, particularly when associated with pregnancy and the additional demands on body calcium and phosphorus.

Of the endocrine glands whose secretion has an influence on the state of the skeleton, the two most directly concerned with bone are the parathyroids and the pituitary.

One would expect to find that the amount of calcium in the blood was in equilibrium with the labile calcium in the bones, i.e., the Ca^{+2} on the surface of the crystals accessible to free interchange, but in fact the blood calcium level is higher than this equilibrium figure – it has to be, if the needs of certain other tissues such as muscle are to be satisfied. It is said that this higher level is possible because of the action of parathormone – the secretion of the parathyroid gland. Experimental injection of parathormone is followed by the appearance of large numbers of osteoclasts in the bones, indicating bone resorption with breakdown of the mineral crystals, and so the liberation of the immobilized Ca^{+2} . If it is true, as has been stated, that there is a complete turnover of blood calcium every minute, then presumably Ca^{+2} and parathormone normally form a two-way control system, when the level of one rises the other lowers, and vice versa. Where there is an abnormal state of hyperactivity of the parathyroid gland with the production of an

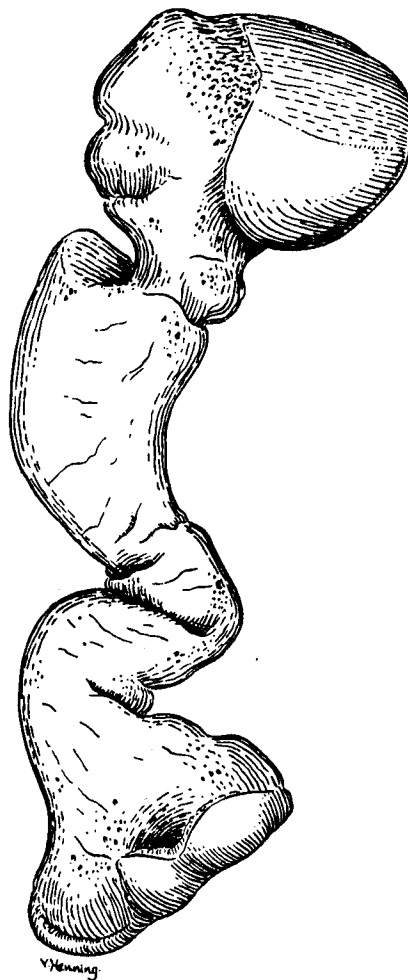


Fig. 5. A Hunter specimen. A deformed arm bone (humerus), of 'a man who died at Wapping in 1766, with remarkable softness of the bones'. This specimen is labelled osteomalacia, but from the history the deformity might well be due to osteitis fibrosa from excess secretion of the parathyroid gland.

excess of parathormone, calcium is drained out of the bones which then become soft and flexible, a condition known as osteitis fibrosa.

Many of the giants and dwarfs of the circus and the fair-ground owe their occupation to unusual behaviour of their pituitary gland, an insignificant-looking structure about the size of a pea, nestling unobtrusively on the under surface of the brain, yet through its secretion wielding a vast influence on both the permanent form and the day-to-day activity of the tissues and organs, including a special interest in the growth rate of the skeleton. Various other conditions affecting both child and adult skeletons are due to some upset in the normal work of this 'master' gland.

In what way individual molecules of hormones and vitamins bring about acceleration, retardation, or change in direction of the various activities within and without the cell to achieve this overall effect, is at the moment largely surmise.

*

Scattered throughout the civilized world there are groups of biochemists, biophysicists, crystallographers, and all manner of biologists and medical men working on the problems of bone. Already in the present century there have been rewarding results. Today there should be no rickets, causing deformities in our child population, and some of the 'incurable diseases' of twenty-five years ago, e.g., osteitis fibrosa, can now be put right by dealing with the offending gland. Our nosology, however, still includes a long list of abnormal states of ossification, including that mysterious condition of muscle 'dystrophy' where over a period of years groups of muscles in the body become progressively ossified from the deposition of mineral salts in their substance until, like Lot's wife, the unfortunate victim becomes literally transformed into a pillar of (bone) salt.

Sooner or later we will get the right answer to most of these problems and be able to prevent or cure many crippling conditions affecting the skeleton, so that it need no longer be said of us that 'The good is oft interred with their bones'.

COMMUNICATION IN THE FIELD OF SCIENCE*

R. H. MACMILLAN

THE ability to communicate by means of speech distinguishes man from the animals, and the ability to communicate, through the medium of the written word, with the past and future is the key to civilization. Human knowledge, and particularly scientific knowledge, is cumulative: the present is built upon the past, and the future upon the present; if each generation had to establish the fundamentals anew, only very limited progress would be possible.

Recently there has been an immense increase in the volume and importance of communication in the world. The number of learned societies multiplies and, with the rate of publication of all types of literature at a record level, the number of books in the world's libraries is doubling every fifteen years. The same is true of periodicals, both learned and ephemeral. Meanwhile, the number of documents that pass from hand to hand is mounting daily. This is so in all phases of modern life, but most particularly in industry, where even a minor executive finds his desk inundated with floods of reports, minutes, instructions, and so on.

This situation, in which paper work occupies so much time, has come about because of the increasing complexity of industrial society today. Almost every activity is necessarily a co-operative one, calling for contributions from specialists in many fields, often remote from one another. To design a nuclear power station, or the launching rocket for a satellite, calls for co-operation between electrical and civil engineers, metallurgists, mathe-

*Part of the Inaugural Lecture given by Professor Macmillan at University College, Swansea.

maticians, thermodynamicists, chemists, physicists, and instrument technologists; their activities may well be co-ordinated by a mechanical engineer. All these specialists inevitably have different backgrounds, and to some extent use different technical vocabularies, yet they must communicate with each other concisely and without ambiguity if they are to collaborate effectively.

Ideas and information may be conveyed verbally as well as through the written word: in fact oral communication predominated until the invention of printing. Every industrial executive spends many hours each month in conference, and committee meetings of every sort wield an immense influence in the ordering of all our affairs. Is it not extraordinary then that so little thought is usually expended on the all-important problem of expediting committee business, by ensuring that ideas are expressed clearly and briefly? The reason for it lies, I believe, in a very general lack of appreciation of the existence and nature of the problems that face us.

Those ideas with which we are primarily concerned convey knowledge or information. Now, knowledge is one of the basic resources of mankind, every whit as important to nations as are their natural resources of power. But unlike the fossil fuels, such as coal and oil, knowledge is not consumable: it is available in unlimited quantities, like thermonuclear energy, if only we can tap its sources. It must be realized, then, how important is the issue at stake, and it is suggested that we ought to bestow on our means of communication the same care as we lavish on the design of a machine: a passage in a report or a phrase in a discussion that fails to convey its message clearly and concisely can be compared with a machine that is hard to use or control.

For a general statement of the correct principles of communication, I cannot do better than quote Professor Kapp, formerly Pender Professor of Electrical Engineering at University College London. He wrote that

The best expositor . . . designs [his vehicle of information] so as to ensure that the person addressed will remain receptive for the whole of the time that it takes him to impart the information, that

this person may be ready to receive each point at the moment when it is presented to him, to see emphasis where it is intended. To do this the expositor must know, so far as it is humanly possible to know such things, what is likely to be happening in the recipient's mind from moment to moment; he must assess every passage for its characteristic qualities; he must recognize which of his statements will be difficult and which easy to understand, which will be known to the recipient already and which will be new to him, which items are for information only and which for action, which may safely be soon forgotten and which must be remembered, which will be welcome to the recipient and which highly unwelcome.

What I have been saying so far has applied generally to the communication of any sort of ideas whatever. Let us now, however, focus our thoughts on the communication of scientific ideas in particular and, since many of the problems of oral and written communication are similar, I shall restrict my remarks to discussion of the written word.

First of all, I feel we should be clear in our minds why it is that a scholar or research worker may wish to communicate his ideas. Presumably it will be for one of two reasons: either he thinks his work so interesting he is certain that others will wish to hear of it, or he believes it to be so important that they ought to know about it. In either case there is, or should be, an active desire on his part to communicate, and this, of course, is the first step towards success in its achievement.

It is important, when he comes to put pen to paper, for the writer to bear in mind his primary reason for writing, and also the type of individual by whom he intends his words to be read, because scientific ideas are often complex and their proper understanding usually demands a certain background of knowledge. Naturally, this applies also in other fields; but with science a special difficulty arises in that very many persons lack almost entirely the necessary basic information, divorced from everyday experience as much of it is.

Because of the importance of scientific background, the communicator of scientific ideas must express them differently, according to the person to whom they are directed. His reader

will probably be a member of one of four main classes. Firstly, there are co-workers in the same scientific field. It may then be assumed by the writer that they are completely familiar with the special vocabulary that it is customary to use, and that they are aware of all important work that has been done in the field, apart perhaps from some of the most recent contributions. In many respects, writing for this group presents the least difficulties to the scientist.

The second group comprises other scientists, who have the necessary scientific background and outlook but are unfamiliar with the particular subject in question. In addressing this group, it is necessary to define carefully any peculiar vocabulary used and to fill in a certain amount of special background information. It must be remembered that because scientific knowledge is cumulative, any individual publication must fit into a general scheme.

The next class includes readers with intellectual capacity but without scientific training. This category would, I suppose, include the majority of those present. Although the writer may assume that a member of this group will be willing to read with care and concentration, making a real attempt to understand unfamiliar ideas, he must make a continuous and conscious effort to help this process of assimilation. It has been suggested that there are too few good scientists for us to expect them to spend valuable time in learning to write for the ordinary reader, and that we ought therefore to employ specially trained intermediaries to do this job. In the United States the 'technical ghost-writer', as he is called, has come during the last few years to fulfil just this function; but it is to be feared that the emergence of such an individual is a retrograde step and could lead to an even greater separation between the scientist or technologist and the ordinary man.

Finally, we must consider the type of writing needed to impart some grain of scientific truth to those who are either unable or unwilling to make any considerable effort at understanding difficult ideas and who read uncritically, if at all. This class unfortunately constitutes a very high proportion of the population.

Some decline in scientific accuracy is inevitable in attempting to communicate with persons from this group, and I would suggest that although such writing is of great importance, it should be the province of 'science-writers', not of scientists.

It has been maintained that the difficulty of scientific communication rests principally or even solely upon the unfamiliarity of the language used to convey scientific ideas. Undoubtedly some authors load the scales against the comprehension of their work by the use of special and esoteric words that are often unnecessary. Pure scientists are more prone to this fault than are technologists. Consider this authentic extract from a botanical source: 'The foliage is usually persistent. The leaves are linear, linear-lanceolate, acicular or squamiform and have simple venation. The leaf surface is often glabrous or lustrous.' Translated into plain words, by means of Flood and West's *Dictionary of Scientific Terms*, this becomes: 'The leaves usually last for several years. They are straight and narrow, thin spear-shaped, needle-shaped or scale-like and the veins are simply arranged. The surface of the leaf is often smooth or shiny.' This scientific habit of not calling a spade a spade has little to commend it, as it leads to a loss in clarity, and often in brevity too.

An incidental source of difficulty to the layman reading scientific material is the fact that a number of words in common use have a precisely defined scientific meaning, that often differs somewhat from the popular usage. Obvious examples are such words as *power*, *work*, and *energy*. The same situation arises with legal terminology, only in a far more acute form.

Nevertheless, I cannot support the view that we can lay the blame for the reader's lack of interest in, or comprehension of, scientific writing at the door either of the scientific vocabulary of the authors, or of their frequently obscure and sometimes even illiterate style. I have already stressed that the ideas to be conveyed are often new to the reader, and they are set against an unfamiliar background – this is the fundamental difficulty. Doubt has lately been expressed as to whether it is really possible for scientists to put some of their discoveries into terms

comprehensible to the layman. Examples that spring to mind concern the radiation hazards attendant on the testing of nuclear weapons, and the precession of a satellite's orbit. Yet this same man is expected to take decisions, as a voter, on the assumption that he *can* understand these and related phenomena. My own view is that although a few issues of importance may not be entirely intelligible to somebody without scientific or mathematical background, their number at present is certainly small.

That the communication of scientific ideas to the layman *can* be achieved without a sacrifice in accuracy has been proved time and again, both by means of lectures and the written word. But we may be certain that success has only been attained because the author or speaker was aware of the problems he faced and exerted himself to make his meaning absolutely clear and his line of argument easy to follow. Among the successful exponents of scientific writing for the general reader, one recalls such names as Julian Huxley and Fred Hoyle. In addition, many scientific talks and lectures have been models of clarity: from the *Science Lectures for the People* given in Manchester, by the nineteenth-century chemist Roscoe, through the many illustrated Lectures at the Royal Institution, to *Science Survey* and other scientific matter presented by the B.B.C. A proportion, though a regrettably small one, of the lectures at the Annual Meetings of the British Association match up to the standard I have in mind.

That there is a growing demand on the part of the public in this country for authentic and up-to-date information about current developments in both pure and applied science is proved by the appearance, and continued success, of periodicals such as *The New Scientist* and *Technology*. It is easy to be critical of some of the contributions to these publications, but for the most part they are adequately fulfilling a valuable and necessary function. The *Scientific American*, since its rejuvenation a few years ago, has gone from strength to strength, as is evidenced by the fact that some of the material published in it is now being made available in book form.

We see, then, that the popularization of science has a rela-

tively long and often honourable past, while there has recently been a greater appreciation of its importance and possibilities. Let us consider now how intelligible specialists succeed in being when they are addressing other scientists. Sir William Bragg, in his final Presidential address to the Royal Society, made a plea that contributors to the *Transactions* should make their abstracts intelligible to all other Fellows of the Society. The proposal evidently fell on deaf ears, as the current abstracts can still be understood only by specialists in the particular field. Again, it has been proposed that research workers seeking financial support be required to explain the objects of their work in plain words before being permitted to proceed. Since the men who fill the purse, even if they do not hold its strings, are scientific laymen, there is much to be said in favour of this suggestion, and I do not doubt that in all but exceptional instances the exercise would be entirely practicable. Furthermore, expressing his ideas in terms intelligible to the general reader can be a valuable experience to the scientist. In this connexion, Albert Einstein allowed himself to be quoted as having once made what he later described as a 'slightly exaggerated statement'. It was this: 'Whenever I get a new idea, I do not feel I fully understand it until I can express it in plain words.'

It is now time to be more specific about the means by which the scientific writer is to express himself, and I wish to detail a few of the principles that can be applied to help resolve the difficulty of communicating scientific ideas. For the most part, my remarks apply equally to technical report writing and to scientific writing for the general reader. The techniques I shall advocate are generally accepted and have been described at length in such excellent books as *The Presentation of Technical Information* by Professor Kapp, whom I quoted earlier from another source.

Now, whether he is writing for colleagues or for the public, the scientist must always remember that communicating ideas demands the co-operation of the reader, if it is to be successful. In the process of transfer, the consumer of ideas is just as important as their producer, and the effectiveness of a document

depends as much on the willingness of the reader to understand as on its own intrinsic clarity. It follows that ideas cannot be thrown out as though they were bullets that must meet their mark, when they are fired at a target, provided the aim is good. The process of communication has been compared more aptly with feeding a fastidious cat: only with skill and effort can the animal be persuaded to partake of the fare set before it.

The primary method of obtaining the reader's co-operation is to enlist and retain his interest. If he can be persuaded that the matter before him contains material of importance to himself, he will take great pains to extract it, just as a detective is willing to spend hours deciphering the scribble on a charred scrap of paper provided he is convinced of its value to his investigation. Once gained the reader's attention must be held. Two factors are all-important in achieving this: pace and length.

The rate at which new ideas are introduced must not be too slow or the reader's attention will wander, nor must it be too fast or he may be unable or unwilling to follow the argument. Judicious repetition combined with subtle variation can be invaluable in helping the reader to understand and in giving him time to assimilate. Illustration and the use of simile and metaphor are other means of varying the pace and of holding attention by arousing interest.

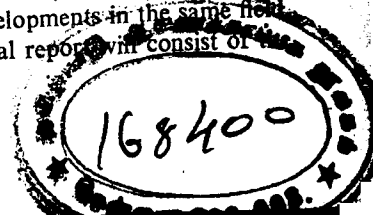
Closely associated with pace is length. I have already pointed out that the amount of explanation needed must depend on the extent of the reader's background in the field covered. Naturally, any piece of writing should be as short as possible consistent with clarity and with covering all the ground. It will be more serviceable if it is like a ballet dancer's skirt, short but full: one that is long and voluminous is better adapted to conceal the subject than reveal it.

The process of assimilation to which the reader must subject the new ideas presented to him consists mainly in associating them with the framework of ideas already stored in his mind; the closer the association achieved, the greater will be his understanding of them and the more vividly will they be retained in his memory. To assist the reader's associative process, the writer

must plan the logical framework – the skeleton – of his work with the utmost care. In the main argument of a technical paper, or in any piece of scientific writing for the general reader, this broad framework may vary so greatly that it is impossible to lay down a standard approach to the problem, except to stress that it is always desirable to proceed from the familiar to the unfamiliar – from the old to the new. This matter of organization is one of the main themes of that admirable book by Professor Nelson entitled *Writing the Technical Report*. The structure of a report should be planned not only to provide a balanced division into main sections and sub-sections, but also to have a suitable succession of paragraphs and sentences. Even the arrangement of the phrases and words within the sentences must be such that the whole forms a single logical unit. This is clearly a counsel of perfection, but it is always useful to have a target at which to aim.

Since the reader is not assisted by the variation in pace and emphasis with which the able speaker will naturally enliven his words, it is all the more important for the writer to marshal his ideas in the best possible sequence, and to construct his sentences in such a way as to avoid all ambiguity. If a truly logical sequence can be achieved, the reader is led imperceptibly from idea to idea until the whole becomes plain and memorable to him, with the least conscious effort on his part. It would not be appropriate to attempt here to go into the detailed techniques that are useful in constructing the logical framework – such devices as comment words, logical bridges and theme sentences – as an adequate treatment would demand a whole series of articles; so I must be content with the comment that, if carried out completely, the logical composition of any piece of writing calls for considerable ingenuity and effort.

A technical report must usually attempt to cater for two main classes of reader. There is the specialist in the same field and there is the busy man who wants to know the results and be persuaded of their accuracy and who may also wish to seize the relevance of the work to other developments in the same field. Bearing these two in mind, a typical report will consist of



Title, a Summary and List of Contents, the Introduction and Main Argument, followed by the Conclusions, References and Appendices. Many readers will study only the Title, Summary and Contents, the Introduction and the Conclusions, and Diagrams. To assist them, a special effort must be made with these parts, particularly in ensuring that the Summary, Introduction and Conclusions are complementary rather than virtually identical, as so often happens. The Introduction should be used to put the problem in perspective, and the Conclusions may point to further work. Care is always needed to decide what material should be included in the Main Argument, and what can be safely relegated to the Appendixes: there is often a temptation here to allow the tail to wag the dog.

A typical argument in applied science runs somewhat along these lines. It starts with the basic equations, each expressing a physical relation or condition, or an assumption or approximation. These equations are then solved to express the unknowns in terms of known quantities, and a new formula is thus reached and interpreted physically. To develop such an argument one must start by stating briefly what is to be done, one must enumerate clearly all the assumptions and approximations that are used, one must show clearly the physical significance of each basic equation, and one must take particular care to explain any difficult steps in the analysis.

I have left till last a matter which, though of importance, is often given far too great prominence in discussions of scientific writing. I refer to its English style, a matter on which I can strongly recommend Sir Ernest Gower's book *Plain Words*. The object is to use those words that will best convey the ideas to the reader's mind. Such English has aptly been called Functional. Circumlocution is clearly not functional, it wastes the reader's time and dissipates his attention. To obtain brevity a sentence or paragraph may well need recasting. Jargon also must be shunned for the same reasons. To make writing vivid, the active is preferable to the passive and the concrete to the abstract.

Consider the following sentence, which perpetrates every

practice that I have been warning you against, yet might well have appeared in a newspaper leading article. 'A comprehensive reassessment of Collegiate financial policy is necessitated by the currently unsatisfactory economic situation and it is anticipated that during the forthcoming quinquennium there will inevitably be a consequent reduction both in recurrent and capital expenditures.' Some of you, through years of practice, may have understood this sentence; but I am sure that the idea it contains is expressed far more clearly and memorably, when it is rewritten like this: 'We fear events will force Colleges to spend less in the next five years, both on salaries and equipment.'

Of course, brevity can be overdone. Witness the celebrated headline in a New York newspaper: 'OYSTER BARS JAM PROBE.' Only an initiate could be expected to divine from this that the chief of police would not allow an investigation into traffic delays, but declined to give his reason. The English spoken by Russians often exhibits the same excessive terseness; this is because of the peculiarities of the Russian language, which omits some of the verbs and prepositions that are essential in English. The growing practice of using strings of nouns as adjectives is ugly – and unnecessary, too, as the increase in brevity is negligible. Moreover, an addiction to this bad habit may antagonize sensitive readers. 'Oil storage tank depth measuring equipment', for example, is better written 'Equipment for measuring the depth in tanks for storing oil.' Note that the order of the words has been reversed, and that only now is it clear that the depth to be measured is that of the oil rather than of the tank.

It is during the process of revision that the writer must check that the structure of his work is really satisfactory, and that only truly functional English is being used. Reading work aloud is a fine way of highlighting its faults, as they become magnified when spoken. If time permits, it is best to leave each draft for a few days after completion before undertaking revision, as a fresh eye will reveal faults that familiarity had concealed; it is even more valuable, when it is practical, to enlist the help of an independent and critical reader, preferably drawn from the

same category of person as those for whom the work is designed. While tediously revising, one realizes how true it is that only a genius could write successfully without taking great pains: but if writing is done carelessly, the reader must spend *his* time extracting the meaning, and it is arrogant of the writer to assume his own time is more valuable than his reader's. Anyway, the satisfaction to be had from a lucid piece of exposition amply repays the labour that must be expended upon it.

RESEARCH REPORT

A. W. HASLETT

PROGRESS WITH ZETA

THE most recent news about Zeta – Harwell's zero-energy thermonuclear assembly – has cleared up the chief point of general interest left uncertain by the initial experiments published in January of this year, but leaves many more questions unanswered. Some of them may have been answered by the time that these notes appear in print. The substantial results at the time of writing are that temperatures of the order of 5 million degrees centigrade have been measured in a ring-shaped, pulsed, discharge tube filled with heavy hydrogen (deuterium) at low pressure; that instabilities in the discharge column have been controlled for durations of some thousandths of a second, compared with millionths of a second in other published experiments; and that fusion reactions between deuterium nuclei have been detected, but have been shown not to have been caused in the main by high temperature. Most of them were the result of collisions between deuterium nuclei raised to much higher energies than could be accounted for on the basis of temperature – probably during the initial pulse of current – and other deuterium nuclei of lower energy. A comparatively simple modification to Zeta – which has already been completed at the time of writing – should enable temperatures roughly twice as high to be reached during the present summer. In these conditions, many more neutrons should be produced, which should make it possible to get more detailed information than at present about the course of events in the discharge column. Other experiments are being done with different forms of discharge tube, and by the time that the Geneva Atomic Conference opens in September, it may be hoped that a more complete picture will be possible.

In principle, Zeta is a pulse-operated, iron-cored transformer, of which the secondary circuit is the discharge tube. The pulse in the primary of the transformer is obtained by discharging a bank of 25,000-volt condensers. The gas in the discharge tube is made slightly conducting in advance, so that any disturbance resulting from having to establish a conducting channel from scratch is avoided. Also, the pulse in the discharge tube is limited to its original direction by short-circuiting the primary at the right moment – that is, when current in the secondary would begin to be reversed. In this way, current pulses of the order of 200,000 amperes have been induced in the discharge tube at 10-second intervals. This was in the initial experiments with Zeta.

The essential advance that made it worth while to design and build Zeta was the discovery from earlier research at Harwell that instabilities in a ring-shaped (toroidal) discharge column could be controlled effectively by comparatively small magnetic fields, applied along the axis of the tube. The control field in Zeta is derived from current-carrying coils placed round the outside of the discharge tube.

A second advance was the use of a discharge tube of wide diameter – one metre, compared with ten centimetres or less in contemporary American experiments. Since the need to control the discharge column arises from the requirement that it must be restrained from contact with the walls of the tube, it might seem obvious on general grounds that there was an advantage in having a reasonable margin to play with. But this was not so in practice until the possibility of control during reasonable lengths of time had been realized. In other words, the second advance stemmed from the first.

Yet a third advance stemmed similarly from the second. A tube diameter of one metre, combined with a ring diameter of three metres (as in Zeta), implies a sizeable job of construction which made it necessary to use metal in place of glass or ceramic as the material of the tube. It followed in turn that there had to be short insulating sections in the tube walls; otherwise the walls would have short-circuited the interior of the tube, through

which current was wanted to flow. Four such sections were provided. But it was realized that eddy currents would flow in the conducting quadrants between them, and that these would provide an additional means for the control of instability in the tube. In this way, the use of a metal – aluminium – which was selected in the first place as a matter of necessity, turned out to offer an advantage in design.

It may be useful at this point to go back to the beginning and consider what were the objects of the experiment, and some of the processes that may be supposed to operate in the discharge tube. The setting up of what has been described as a unidirectional pulse of current means, in the first place, that there is a flow of electrons round the gas inside the tube, which is soon constricted into a discharge column. The electrons, as they circulate, may collide with deuterium nuclei from which they have parted company and transfer energy to them. It is also possible that some of the deuterium nuclei may be directly accelerated by transient electric fields, arising during the early stages of the pulse. Finally, there may be some general or mass movement of the gas.

In any case, various of the deuterium nuclei will collide with others. Most of these collisions will do no more than contribute to the more even distribution of energy among the different particles; they are part of a warming up process. But in some of the collisions – those taking place at higher energies – one nucleus will penetrate the other, a fusion reaction will occur, and a neutron will be emitted. The fusion reaction will be correctly described as thermonuclear only if the colliding nuclei owe their energy to random or thermal movement, the result of repeated collisions. It will not be thermonuclear if one or other nucleus has been accelerated to a high energy by a different process.

The objectives of such an experiment are, first, to produce high temperatures and to measure them; secondly, to hold the temperatures produced for a long enough interval for thermonuclear reactions to be brought about on a detectable scale; and thirdly, to demonstrate that such reactions have, in fact, occurred, and to measure the rate of their occurrence. It is not

enough for this last purpose merely to show that neutrons have been released, and that they have been released in fusion reactions; it is necessary also to discover the pattern of energy distribution among the reacting nuclei. In practice this leads to a fourth objective: to discover in some detail the course of events in the discharge column.

The measurement of temperature is itself difficult; it amounts in the end to finding out how the energy imparted to the current pulse is distributed among the particles in the gas column – electrons, deuterium nuclei, and atoms present as impurities – at different stages of the discharge; and this has not yet been possible. Alternatively, if the problem is approached as one of measurement in the usual sense, then there are again difficulties. The only methods that can be used at these high temperatures are those of spectroscopy; and the temperature of the deuterium nuclei – which are the main objects of interest – cannot be measured by spectroscopy after quite an early stage of the discharge. Nearly all of them have by then parted company with their one electron, and there are not enough electrons left to jump from one energy-level to another with respect to the nucleus and, in so doing, to emit radiation of characteristic wavelengths. It is therefore impossible to measure the spreading out of these wavelengths – otherwise the broadening of spectral lines – due to the movement of some atoms towards the spectroscope and of others away from it.

To obtain spectrographic measurements of temperature, it is necessary to make use of atoms, present as impurities, which start with a larger number of electrons and do not lose them all. Those used so far have been mostly nitrogen and oxygen. The best measurements of peak temperatures in Zeta have been based on the broadening of two lines in the ultra-violet emitted respectively by nitrogen atoms that have lost three electrons, and by oxygen atoms that have lost four. The distribution of intensity with wavelength across these lines shows that, in the atoms concerned, there was a random distribution of energy; in other words, that they had undergone enough collisions for there to be something to be measured which could be called tempera-

ture. Also, the temperatures so measured increased at higher peak currents, and there was reasonable, though not perfect, agreement between the temperatures obtained for these two kinds of atoms. The highest temperature measured – one of about 5.5 million degrees centigrade – was for oxygen atoms in conditions such that the peak current reached 178,000 amperes.

In the original experiments, temperatures were also estimated from the number of neutrons that were released on the supposition that they came, all of them, from thermonuclear reactions. This is now known not to have been the case, and the theoretical calculations were admitted to be suspect. There was reasonable agreement none the less, especially with the temperatures measured for oxygen atoms in experiments giving the highest peak currents. This agreement, as it now seems, must in part have been misleading.

It was thought impossible at this time – without going to higher currents – to measure the distribution of energies or directions of the emitted neutrons; and hence to work back from these to the energies and directions of the deuterium nuclei that gave rise to them. In the experiments now reported, this has been done with an expansion cloud chamber. This does not show directly the tracks of the neutrons – since they have no electric charge – but does show the tracks of ions in the gas with which the neutrons have made collisions. In this way, it has been shown the directions of the emitted neutrons have a bias in the direction of the current-flow in the discharge tube; and that, if the direction of current-flow is reversed, so also is this directional bias of the neutrons. In about 90 per cent of collisions giving rise to neutrons, it appears that one nucleus, but not the other, has acquired an energy some 50 times as great as the mean energy corresponding with the highest measured temperatures. It has been suggested that this energy may be acquired by stages during successive early circuits of the discharge tube. But whatever the mechanism, it appears that, while fusion reactions have been produced, not more than about 10 per cent of them can be thermonuclear. Some of them must be, but they have not been proved to be. This has been a disappointment for obvious

reasons. Another way of looking at it is that the measurements of high temperature still hold, and that the problem of finding out what happens in the discharge column has been defined more clearly. Since this must affect future stages of design, it has become the chief present interest.

Beyond the immediate modification already mentioned, a bigger programme has been planned, of which the most important part is an increase of 10-fold in the amount of energy stored in condensers for release into the discharge column. In this way, it is hoped to increase the peak currents to a million amperes; the time that the discharge column is restrained from contact with the walls to about a tenth of a second; and the temperature reached to somewhere above the 15 million degrees of the Sun's interior. That this is still not enough to be within striking distance of releasing more energy than is consumed is a good measure of the difficulty of what is being attempted. It is hoped, none the less, to proceed in one step to this final stage – for which temperature of more than 100 million degrees will be necessary.

The members of the Zeta team at Harwell – now constituted as a division – who contributed to the original publication were Dr P. C. Thonemann, E. B. Butt, R. Carruthers, Dr A. N. Dellis, Dr A. Gibson, G. N. Harding, D. J. Lees, R. W. P. McWhirter, R. S. Pease, Dr S. A. Ramsden and S. Ward, together with Mr D. W. Fry, now deputy director of the establishment. The more recent measurements described in these notes were by Dr B. Rose and A. E. Taylor of the cyclotron group.

Experiments using pulsed, heavy-current discharges through deuterium gas were first described in a now well-known lecture given by Academician I. V. Kurchatov at Harwell in 1956. Straight, i.e., cylindrical, discharge tubes were used, fed through electrodes. This approach has been followed also at the Los Alamos Scientific Laboratory and at Princeton in the United States, and in other countries, including Britain. Temperatures of up to five million degrees centigrade have been produced, for times of the order of microseconds.

The use of the torus form, with energy supplied through a

pulsed transformer, appears to have originated in Britain. As well as at Harwell, it has been used in recent experiments with an apparatus known as Sceptre III in the Associated Electrical Industries research laboratories at Aldermaston, where temperatures of up to about three million degrees centigrade were produced. The torus form has been used also at the Los Alamos Scientific Laboratory, and in Sweden and France. In the Los Alamos experiments, which followed directly from the work at Harwell, temperatures of three million to five million degrees were produced and held for a few microseconds – a result comparable with that obtained at the same laboratory with a straight discharge tube. In France, at the Fontenay-aux-roses centre, temperatures of a million degrees have been produced. According to a recent statement by Kurchatov, some recent work in Russia has been 'very similar to that being done in Britain'.

Use of a wide-diameter tube is significant in relation to the time during which high temperatures can be sustained. There is a theoretical limit – which for a tube of one metre diameter is about a second – to the time during which a discharge column can be restrained from contact with the walls. The time needed for a useful release of energy is also estimated to be of the order of a second. It appears, therefore, that the dimensions of Zeta are such as to permit substantial progress. But with both cylindrical and torus-shaped tubes, there are many more points to be cleared up, and it is known that research in quite different directions is proceeding. Some of this will, it is hoped, be described at the Geneva conference.

In ultimate use, it is envisaged that the reactions employed will be those between deuterium nuclei and deuterium, since heavy hydrogen is both a common and accessible material. The reaction between deuterium and tritium – radioactive hydrogen of mass 3 – is apparently being disregarded in British work. Although the temperature needed would be lower, there is a difficulty about raw materials; production of the tritium needed depends ultimately on lithium-6, which is of the same order of abundance as uranium. This by-passing of the deuterium-tritium reaction represents a change of attitude compared with many

earlier discussions, including one by the Atomic Energy Authority. A further point of interest is that the possibility of direct generation of electricity – without the intermediary of a heat-engine – is to be examined during the next stage of development. A recent estimate of time-scale by Sir John Cockcroft is 'at least twenty years and perhaps much longer'.

A group of papers summarizing British and American research on the controlled release of thermonuclear energy was published in *Nature*, 1958 **181** 217–33. A discussion of the general conditions necessary was given by R. F. Post in *Reviews of Modern Physics*, 1956 **28** 338, and summarized in *Science News* 1957 **43** 108–11.

STRUCTURE OF A PROTEIN

The working out of the three-dimensional structure of a protein by the methods of X-ray crystallography has been so long an objective at the Cavendish Laboratory, Cambridge, that it is difficult to believe that it has now been achieved. It has been accomplished in the case of the muscle pigment, myoglobin, by Dr J. C. Kendrew and his colleagues of the Medical Research Council Unit for Molecular Biology. The choice of myoglobin is itself of interest. Dr M. F. Perutz worked for many years at Cambridge on haemoglobin, and five years ago discovered that heavy atoms – those of mercury – could be attached to its surface, this gave the possibility, in principle, of obtaining a 'view' through the molecule. But it turned out that so many different features, lying at different depths, were superimposed, one on the other, that the 'view' could not be interpreted.

Myoglobin is a simpler equivalent of haemoglobin. It has one haem group instead of four; a molecular weight of 17,000 compared with 68,000. It serves the same biochemical function of combining reversibly with oxygen, but does this in tissue cells instead of in red cells, specialized for oxygen transport. It serves in muscle to provide a local reserve of oxygen; and there is more of it than usual in the muscles of diving animals, such as whales, seals and penguins, whose dark red tissues have been the source of most of the myoglobin used at Cambridge.

The myoglobin molecule, although small compared with haemoglobin, yet contains 1,200 atoms, not counting hydrogen. To obtain the positions of all of them by the X-ray method, it would be necessary to make use of some 20,000 reflections. To arrive at the over-all structure it has been enough to use about 400. The result is a true synthesis, or reconstruction, in the form of 16 parallel sections, which must be piled on top of each other to give a model in three dimensions. What is shown in the model is the repeating unit of the crystal, which contains two molecules. It is possible that the boundary between molecules may have been drawn wrongly in some places, and also that some of the minor features shown may be spurious. But the general features are described as 'undoubtedly correct'. The model is more complicated than had been predicted by any theory of protein structure, and appears 'totally lacking in the sort of regularities that one instinctively expects'. A malformed worm, contorted by profound emotion, is perhaps as good a picture as can be conveyed shortly in words.

The investigation – which is being continued – has become almost an international exercise. It has been supported by the Rockefeller Foundation, the U.S. National Science Foundation, and the Merck Fellowship Board. Those responsible for it have been J. C. Kendrew, G. Bodo, H. M. Dintzis, R. G. Parrish, and H. Wyckoff of the M.R.C. Unit, and D. C. Phillips of the Davy Faraday Laboratory, of the Royal Institution; essential assistance was given also by 'Edsac', the Cambridge electronic computer, and (as a partial check) by 'Deuce' at the National Physical Laboratory, Teddington. In the next stage, it is planned to double the resolution using more reflections. This will suffice, it is hoped, to show something of the intermediate level of structure – that represented by local folding and coiling of the amino-acid chain – as well as disposing finally of any doubtful points in the main structure. The possibility of proceeding to the ultimate stage of resolution, when individual atoms would be distinguished, is not excluded – although, merely as an effort in computing, it would be without precedent in this field.

Kendrew, J. C. *et al.* *Nature*, 1958 **181** 662.

ROYAL SOCIETY EXHIBITS

Among the exhibits at the Royal Society's annual conversations at Burlington House was one by Dr D. C. Burke and Dr A. Isaacs, of the National Institute for Medical Research, London, illustrating research on an inhibitor of virus growth, to which the name interferon has been given. While its significance is considered for the present – and for some time ahead – to lie entirely in research, it is impossible to ignore even at this stage the fact that no antibiotic active against true viruses has yet been discovered. On the other hand, it has been known for some time that one virus interferes with the growth of a second unrelated virus, and the discovery of interferon was the result of research on what has become known as the interference reaction.

The exhibit brought out three points: that interferon can be readily produced on a laboratory scale; that the activity of preparations can be measured effectively by their ability to prevent the growth of influenza and related viruses in pieces of chick tissue in test tubes; and that, when concentrated about 10 times, they reduce greatly the growth of viruses such as vaccinia and cowpox in fertile hen's eggs.

They have been shown also to be active, not only in test-tube experiments, but also in animals, in which interferon does not appear to cause obvious damage. The prospect looks encouraging thus far. But it is not difficult to think of possible valid reasons for caution, apart from the proper desire of those responsible to avoid premature claims. One of them is that interferon does not kill the virus, and so would not necessarily stop its spread. Another – more fundamental – is that until its mode of action is understood, it will be difficult to be certain that there will be no unwanted side effects.

Proceeding upwards from viruses in the scale of organization, electron micrographs of the nuclear membrane of *Amoeba proteus* were shown by Dr E. H. Mercer, of the Chester Beatty Research Institute, London. The membrane is shown to consist of a thin double-layered outer structure, backed by a honeycomb-like inner formation. The latter is most impressively dis-

played in the micrographs. Its suggested function is to support and give shape to the comparatively large nucleus. Within the nucleus, the chromosomes are shown to consist of masses of small spirals (presumably nucleoprotein) clustering in small stellate groups. Apart from the particular examples shown, Dr Mercer points out that, by following an individual amoeba in the light microscope, it should be possible to fix it for electron microscopy in any chosen functional state.

Insects were represented by some studies of American butterflies, carried out by Dr L. P. Brower and Dr Jane Van Zandt Brower, of the Genetics Laboratory, Oxford. Apart from experiments showing the effectiveness of mimicry – using caged scrub jays as predators – they had an exhibit illustrating the importance of colour in the courtship of Tiger Swallowtail butterflies. On the one hand, males of two yellow species were found to waste 23 per cent and 16 per cent of their time respectively in courting tethered females of the wrong species. On the other, when confronted with females of a geographically alien species that has two colour forms (yellow or black), they would ignore a black female and court a yellow one. And they were found, too, to ignore females of a white species.

Much interest was attracted by the enveloping 'knitted insulated-wire underwear' – shown by H. S. Wolff, of the National Institute for Medical Research – that was developed for use during the recent Transantarctic Expedition with the object of obtaining integrated skin temperatures taken under working conditions. The wire used is 0.039 inches in diameter, and contains 60 strands of 0.00166-inch silver-plated copper wire; it is insulated with a coating of polyvinylchloride containing a non-migratory plasticizer. Apart from its immediate purpose, the Royal Aircraft Establishment, Farnborough, has been showing interest in it for use as heated clothing.

For the botanist, there was demonstration of the use of radioactively labelled carbon dioxide, supplied to a single leaf, to study the contribution made by it in materials to the subsequent growth of the plant as a whole. This was from the Research Institute of Plant Physiology, the Imperial College of Science

and Technology, and was shown by Dr H. Jones, R. V. Martin, and Dr Helen K. Porter. The plant used was the tobacco plant. The chief vehicle for the movement of carbon from the leaf was found to be sucrose, and only some leaves above the treated leaf received it. This is the equivalent in plant physiology of the biochemical research on routes of carbon fixation initiated by M. Calvin and A. A. Benson in the University of California.

For the remainder, the place of a model of Zeta (away at the Brussels Exhibition) was honourably taken by one of the Associated Electrical Industries torus 'Spectre III', which has been used also in research on controlled thermonuclear reactions; Dr B. J. Mason and his colleagues of the Imperial College of Science provided well-produced experiments on the nucleation and growth of ice crystals; and the demonstrators of a co-operative exhibit on radio observations made on Sputniks I and II found their attention diverted by requests – successfully met – for early information on Sputnik III.

ROCKET MOTORS

The Americans have had so hard a time with satellites that one hesitates to throw objects that might be taken for brickbats. Rockets are, however, difficult devices to work with, and the following quotation may be found illuminating: 'Combustion instabilities in liquid-propellant rockets have plagued scientists and engineers since the beginning of modern rocket development. A review of the available information reveals that combustion instability (also referred to as rough burning, chugging, humming, groaning, oscillations, unstable combustion, oscillatory combustion, etc.) can occur in every kind of liquid-propellant rocket engine, regardless of the size and shape of the combustion chambers, propellants used, or feed system employed. To date, after more than 10 years of concentrated work in the United States, no complete theory or explanation exists, although significant contributions have been made to our understanding of some instability phenomena. This situation is particularly embarrassing since the design of larger units than those

currently investigated, and even slight modifications of existing units, may necessitate extended and costly trial-and-error development programmes. Although some empirical rules for correcting the difficulties are recognized, it is generally agreed that these are inadequate and have relatively low probabilities of success.' The author is Professor S. S. Penner, who holds the Chair of Jet Propulsion in the Daniel and Florence Guggenheim Jet Propulsion centre of the California Institute of Technology. The quotation is from his book *Chemistry Problems in Jet Propulsion*,* the preface of which is dated December, 1956. He goes on, it is true, to distinguish between 'high frequency' oscillations of 1,000 cycles per second or more which are almost always confined to the combustion chamber, and oscillations of below about 600 cycles per second which generally reflect simultaneous variations in the feed system, and gives some qualitative discussion of each. He also gives empirical rules for scaling-up, some of which he himself developed. But when all that may be has been added in qualification, the quotation already given appears to afford explanation enough of the recurrent failures of a high-performance rocket developed specifically for use in the satellite programme and tested in the full blaze of publicity.

THE MICROTRON

The completion of a 29 MeV microtron at University College London marks a new stage in the development of a type of electron accelerator that has some general claim to interest. What is unusual about it is the simple way in which the increase in mass of the electrons with speed is allowed for – a relativist effect which is of engineering importance in such machines.

The microtron is one of a group of cyclic accelerators, in which the particles accelerated are constrained to follow a circular or spiral path between the pole pieces of a circular electromagnet and, during each revolution, are accelerated by localized differences of potential, so applied as to synchronize with the

*International Series of Monographs on Aeronautical Sciences and Controlled Flight. London, Pergamon Press. pp. 200. 90s.

passage of the particles. The first and simplest type of design – Lawrence's cyclotron – runs into the difficulty that, as the mass of the particles increases, so also does the time that they take to make successive revolutions. In the higher energy machines it is therefore necessary to adopt pulse operation and to reduce the electrical frequency during each pulse so as to keep in step with the particles. This solution is known as the synchrocyclotron. The microtron, on the other hand, starts from the fact that, if energy can be imparted to the particles in big enough steps, it can be arranged that the gain in mass at each acceleration is equal to the mass of the particle when at rest. Its mass after successive accelerations will be 2, 3, 4, 5 etc. times its rest mass, and the time taken for corresponding sections of its path will be increased in the same proportion. Hence, if the particle is accelerated only once in each circuit, and the electrical frequency is arranged to be twice that needed for the first complete circuit, the time for all subsequent circuits will be an exact multiple of the frequency, which need not therefore be varied.

For an electron, the potential difference that must be applied to bring about an increase in mass equal to the rest mass is a little more than half a megavolt. For a proton, the potential needed would be more than 1800 times as great, and unattainably high. However, with the advent of the pulsed, high-power magnetron during the war, it became possible to consider an electron accelerator which would operate on this basis. The method was established in principle by the Russian physicist V. E. Veksler – who was also one of the joint originators of the proton synchrotron – and the first microtron was built in Ottawa by P. A. Redhead, H. Le Caine, and Dr W. J. Henderson working for the Canadian National Research Council. This was a comparatively small machine giving electrons of 4.5 MeV energy. Soon after, a similar machine was built at University College London by Dr R. E. Jennings and two colleagues. Now, with Dr D. Aitken, Dr Jennings has built a microtron that gives energies of 29 MeV.

In a cyclotron, the particles start in the middle, are accelerated twice in each circuit as they pass from one half of the machine to

the other, and follow, near enough, a spiral path outwards. In a microtron, the electrons start near the outside, undergo successive accelerations in a single, rather closely defined, region of the machine, and the path that they follow is a series of expanding circles, which spread out, as it were, across the machine, and have a common tangent in the region of acceleration. To obtain an alternating high voltage from a magnetron it is necessary to use a cavity resonator of small dimensions, so that no other arrangement is possible. In the new University College machine the magnet is one of 80 in. diameter. This is large in relation to the energy reached, but the field required from it is both comparatively small and constant. As an instrument of research, the chief virtue of the microtron is that it yields electrons of closely the same energy. The greatest variation possible is less than 0.05 MeV, and this is independent of the final energy. In the new machine the variation is less than 1 part in 500.

Aitken, D., and Jennings, R. E. *Nature*, 1958 **181** 1726.
Jennings, R. E. *Electrical Review*, 1957 **161** 309.

CORRESPONDENCE

From Prince Louis de Broglie, F.Mem.R.S.,
Institut de France Académie de Sciences
Paris 18 April 1958

Gentlemen,

Professor Erwin Schrödinger has pointed out to me that *Science News* Number 46 contains an article by Mr J. R. Singer, 'The Twilight of Parity Conservation', which is in error as to origins of quantum mechanics.*

Mr. Singer states that Niels Bohr in his famous work of 1913 wrote something concerning a wave associated with the electron movement in the atom, and in this way could explain the quantization of the movement. This is not correct. It was I who, ten years later, in 1923-24, introduced this idea for the first time. Indeed, this is the reason I received the Nobel Prize in Physics in 1929.

I feel that this is an important point since it does not attribute a fundamental discovery correctly. I would appreciate publication of an erratum in *Science News* to correct the statement by Mr Singer.

I remain, gentlemen,
Yours faithfully,
LOUIS DE BROGLIE

Professor Singer comments :

Professor de Broglie is certainly correct. The recognition of the nature of the wave-particle dualism of electrons and, indeed, of all particles was first established by his observations in 1923-24. A statement of that principle is given by,

$$\lambda = h/p,$$

in which λ is the wavelength of the wave associated with the particle having momentum p , and h is the Planck constant.

* *Science News* No. 46 p. 9.

Professor Niels Bohr had previously discovered (1913) what he called the stationary states of atoms. He postulated that electrons did not radiate while they were in closed orbits. He did not however, as was implied in my phrase, explain these states as being due to a standing wave. Such an explanation came after the work done by Professor de Broglie in 1923-24.

Moreover, it is correct to say that a major portion of our present-day physical theory rests firmly upon foundations to which Professor Louis de Broglie has contributed much.

Yours, etc.,
JEROME R. SINGER,
Associate Professor.

University of California,
Berkeley, California
May 16, 1958

SOME BOOKS RECEIVED

THE CHEMICAL INDUSTRY DURING THE NINETEENTH CENTURY – A Study of the Economic Aspects of Applied Chemistry in Europe and North America by L. F. Haber (Oxford, at the Clarendon Press, 1958), pp. 292, 45s.

This book by Dr L. F. Haber (who is, by the way, the son of the German inventor who devised the well-known process for the fixation of atmospheric nitrogen) fills a gap that has existed for many decades both in the history of technology and in economic history. Chemical historians have been shy to venture into the economic field, while economic historians, on the other hand, have boggled at the complexity of chemical processes. Now in one treatise these two disciplines have been united and the influence on economic development of part of the chemical industry made plain.

The part discussed by Dr Haber in detail is the acid and alkali branch, and the synthetic dyestuffs industry. Few readers will find this book easy going because the author has been at great pains to accumulate an immense amount of factual material covering Britain, continental Europe, and North America, but a careful study of the various chapters cannot fail to be rewarding. Much of the information presented requires to be absorbed into the standard economic history texts which, as far as technology is concerned, have for the most part stuck to mechanical inventions and the development of communications. At the same time it will present to many chemists, whether they be engaged in the academic field or in industry, much new light on the historical development that has become a permanent part of the corpus of chemical knowledge.

Dr. Haber's book also contains chapters on schools of chemistry and the lot of the workers in the nineteenth-century chemical industry. It is fully documented and carries an extensive bibliography. The book production is of the standard we expect from the Oxford University Press, and as far as the reviewer noticed it is virtually free from printer's errors. It is certainly a must for every chemical library, and its comparatively modest price should make this possible.

SCIENCE AND ITS BACKGROUND (3rd edition) by H. D. Anthony (London, Macmillan and Co., 1957), pp. 352, 20s.

The reviewer had not before met the earlier editions of Dr Anthony's book, but this, the third, edition immediately gave the

impression that, for its size and price, it must be one of the best short histories of science now available. The point must also be made, however, that it is more than a mere history. Not only does it set out the history of science in surprising detail considering its size, but it elaborates the historical background of human affairs in which the science has evolved.

In an age of enforced specialization, any sixth-former, either on the Arts or the Science side, would draw great benefit from reading it. It is as up-to-date as any book of this kind can be, the text having been thoroughly revised and three new chapters added, one on the post-war utilization of science, a second on science for its own sake (the theme of Sir Edward Appleton's presidential address to the British Association), and finally a third on the International Geophysical Year. In the scientific field there are few books on which twenty shillings could be better spent.

REASON AND CHANCE IN SCIENTIFIC DISCOVERY by R. Taton (London, Hutchinson Scientific and Technical, 1957), pp. 171, 30s.

In this volume, with a wealth of illustrative material, Dr Taton analyses the relative roles that have been played throughout the history of science by active purpose and chance discovery. His examples range widely – from the discovery of Uranus to Fleming's work on penicillin. He divides his treatise into three parts. In the first he examines the different domains of discovery divided between mathematics, and theoretical and observational science. A large part of the mathematical section is taken up with a discussion of Henri Poincaré's *L'invention mathématique*. This makes a rather austere start, but should not entirely discourage the non-mathematician.

In the second part the author gets down to an analysis of various factors in discovery – the role of chance, the role of error, systematic discovery, and so on. There is much here to interest the general reader: telescopes and microscopes, radioactivity and spectrum analysis, the conquest of malaria and typhus – these alone illustrate the range of subjects treated.

The final section of the volume deals with what the author calls 'various aspects of discovery' – the singularity of the individual discovery, the problem of precursors, neglected and missed discoveries, coincident discovery – but these are enough to show that here we have a quite novel approach to the history of science. The

volume ends with a chapter on scientific discovery as the reflection of the civilization of an epoch, drawing our attention to the increasingly collective character of scientific research in the world today.

GENERAL SCHOOL BIOLOGY by K. G. Brocklehurst and Helen Ward (London, English Universities Press, 1958), pp. 341, 12s 6d.

This text-book of biology is a further addition to the Grammar School Series being produced under the editorship of R. Stone, Senior Science Master, Manchester Grammar School. It is, thus, a unit in the series planned in conjunction with three others as part of an integrated group of texts which take the student up to the end of the sixth form. It is designed to cover in two to three years the ordinary level syllabus of the General Certificate of Education – including recent revisions.

The volume is divided into three parts: (a) an introduction covering the characteristics of living organisms, particularly flowering plants and mammals, (b) an approach to the syllabus as a whole through functional morphology, and (c) a general section dealing with topics of general biological interest – food production, disease, genetics, and evolution. Each chapter is divided into sections so that they can be taken in almost any order to fit an existing syllabus.

One of the most striking features of this new volume is the illustrations. These have been prepared to be of maximum value to the student, and present the necessary scientific facts with great artistry on good quality paper. The eight half-tone plates, curiously enough, do not quite match up to the same standard. There is a useful glossary and an excellent index. Above all its low price makes it a most attractive buy.

MY LIFE WITH THE MICROBES by Selman A. Waksman (London, Robert Hale, 1958), pp. 320, 21s.

Scientists, by and large, are not addicted to the art of autobiography. Their life stories lie, in the main, in their scientific contributions to the learned society journals, from which all suggestion that the contributions come from beings who live and feel, as well as think, is rigorously excluded. It is refreshing, therefore, to come across the autobiography of the discoverer of streptomycin – told simply and almost completely lacking in self-consciousness.

Waksman was born in the Russian Ukraine in the government of

Kiev, seventy years ago, in a bleak town, he tells us, a mere dot in the boundless steppes. Sixty-odd years later he was awarded the Nobel Prize in Physiology and Medicine for a lifetime's work among the microbes. The intervening years of struggle, hardship, perseverance, setbacks and ultimate reward make up the content of this inspiring record.

THE CRIME OF GALILEO by Giorgio de Santillana (London, Heinemann, 1958), pp. 339, 30s.

In presenting afresh, as the result of the examination of a large number of little-known documents, the story of the seventeenth century *cause célèbre* between Galileo and the Church of Rome, Professor Santillana, who is professor of the History of Science at the Massachusetts Institute of Technology, has rendered a signal service to historical scholarship. The fate of the venerable Galileo at the hands of the Inquisition is vaguely known to every science student, but Professor Santillana's researches lead to conclusions markedly different from the accepted version.

The drama of the situations through which Galileo passed are here vividly reconstructed and one cannot but reflect on the recent American parallels to which the author himself draws attention.

DANGER IN THE AIR by Oliver Stewart (London, Routledge and Kegan Paul, 1958), pp. 194, 28s.

The human tragedy attendant on disaster in the air is only too well known, but the attitude that 'it isn't good for aviation' to talk about such accidents has perhaps obscured the fact that, by the most painstaking application of scientific methods of investigation, good, much good indeed, has been wrested from the most pitiable remains. There is, in fact, no doubt that several crashes have altered the course of aviation history.

The author is editor of *Aeronautics* – earlier in his career he was engaged in many test programmes at Orfordness – and he argues that the increasing safety of air travel, both with respect to machines and methods of operating them, stems in part from the detailed study of air accidents. To support his thesis he has selected a score of major disasters and has analysed them with the help of the official inquiries that have followed – proceedings that usually receive scant treatment in the popular press. From these analyses he extracts a number of situations that have been the cause of some of the best-known

crashes, and then goes on to explain how these findings have modified design and operating procedure.

Mr Stewart's examples range from the ill-fated R 101 to that most crushing of blows, the loss of the Comets. Each chapter is devoted to the discussion of one accident selected to represent a 'type' situation. No one could say that they make cheerful reading, but it is difficult to deny its fascination because in every instance it represents scientific detection of the highest order. Added to this, the author is no mere reporter. He frequently has his own point of view and does not hesitate to put it forward.

THE PLANET EARTH edited by D. R. Bates (London, Pergamon Press, 1957), pp. 312, 35s.

The International Geophysical Year is now well under way. Artificial satellites have been put in orbit and have radioed back to Earth measurements made for the first time outside the Earth's atmospheric mantle. A great and thrilling traverse of the Antarctic Continent has been made, punctuated by stops to collect scientific data. Information is being accumulated at a hundred and one geophysical stations which in the course of the years will be integrated into an increasingly complete picture of the structure and behaviour of our planet. This new knowledge will be of the utmost value, but in waiting for it we must not overlook the fact that down the generations we have already amassed a vast store of geophysical information. It is this existing storehouse that is presented as *The Planet Earth* under the editorship of Professor D. R. Bates of Belfast.

Professor Bates has assembled a team of some fifteen experts whose interests cover every aspect of geophysics, and they present in as many chapters the background of the International Geophysical Year. He tells us that his book was compiled in response to the widespread interest aroused by the organization of the I.G.Y., its main purpose being to provide the general reader with sufficient knowledge 'to enable him to understand, appreciate, and follow the work and findings of the International Geophysical Year'. At the same time, for scientists, it will serve as a useful review of fields other than their own speciality.

The volume is illustrated by a number of useful diagrams: each chapter is supplemented by a selected bibliography, but unfortunately there is no general index - surely a regrettable omission in a volume of this standing.

ABOUT OUR CONTRIBUTORS

J. R. ATKINSON was educated at Dulwich, Leeds Grammar School, and St. John's College, Cambridge. After he graduated he worked on radar research for the Air Ministry until 1945. Since then he has been a member of the staff of the University of Glasgow. He is a Senior Lecturer in the Department of Natural Philosophy under Professor P. I. Dee. His research activities have been mainly concerned with the use of expansion, diffusion, and bubble chambers for experiments with the 350 million volt electron synchrotron at the University of Glasgow.

W. B. BONNOR is Reader in Mathematics at Queen Elizabeth College, University of London. He started his scientific career as a chemist, but later took a degree in mathematics at Birkbeck College, and then spent some years on the staff of the University of Liverpool. His research subjects are relativity, cosmology, and astrophysics, and he is also interested in the philosophy of science.

R. H. MACMILLAN is Professor of Engineering at University College, Swansea, in the University of Wales.

N. W. PIRIE is Head of the Biochemistry Department at Rothamsted Experimental Station. His work has primarily to do with the properties of plant viruses and other proteins that can be extracted from fresh leaves. This work ramifies in various directions. It has led to much discussion of the essential differences between living organisms and other biochemical systems and so to discussion about the origins of life, and it has produced information about leaf proteins in bulk. Since 1940 he has been advocating the use of leaf proteins as human food and has slowly designed and developed machinery for their production in bulk from special crops and agricultural wastes.

M. H. THORNDIKE was educated at University College School, London, and at Corpus Christi College, Cambridge, where in 1956 he obtained an honours degree in Natural Sciences. He is now employed in the sales organization of Imperial Chemical Industries Ltd. dealing with organic chemicals. He has been an enthusiastic oarsman and is a keen amateur actor. He was recently married and now lives in Sussex.

GEORGE M. WYBURN has been Regius Professor of Anatomy in the University of Glasgow since 1948. His main work has been on embryology, reproductive physiology, problems of tissue grafting, particularly in grafts of bone, cartilage, and cornea. A more recent interest is in electron microscopic surveys of normal structure.

CONTENTS OF RECENT ISSUES

46

THE TWILIGHT OF PARITY CONSERVATION: *J. R. Singer*
NEW APPROACHES TO THE STUDY OF BACTERIA: *D. M. Adams*
MINERAL DRESSING: *E. J. Pryor*
THE ORBIT OF A SATELLITE: *W. C. Vaughan*
NUCLEAR COLLISIONS-PART 2: *P. E. Hodgson*
AVIATION MEDICINE: *G. W. G. Sharp*
RESINS IN EMULSION: *H. Warson*
RESEARCH REPORT: *A. W. Haslett*

47

THE GIBBERELLINS: NEW PLANT GROWTH SUBSTANCES:
A. M. Mayer
ELECTROLUMINESCENCE: *H. K. Henisch*
PSYCHOPHARMACOLOGY: *D. S. Trouton*
THE INTERIOR OF THE EARTH: *W. H. Marshall*
INFORMATION THEORY, PROBABILITY MODELS, AND
PSYCHOLOGY: *W. Sluckin*
THE OESTROGENS AND THEIR METABOLISM: *P. H. Jellinck*
DISINTEGRATION CRATERS: *F. N. Johnson*
RESEARCH REPORT FROM FRANCE: *A. W. Haslett*

48

Rocket and Satellite Research Number

PROBING THE UPPER AIR AND INTERPLANETARY SPACE:
H. S. W. Massey
ROCKET MOTORS AND PROPULSION: *W. N. Neat*
GUIDANCE, CONTROL, AND INSTRUMENTATION: *W. H. Stephens*
and A. W. Lines
HIGH PERFORMANCE ROCKETS: *K. W. Gatland*
SATELLITES FOR RESEARCH: *R. L. F. Boyd*
THE ROCKET-BORNE LABORATORY: *R. L. F. Boyd*
SPACE MEDICINE: *P. Howard*
THE PRESENT POSITION AND FUTURE PROSPECTS:
H. S. W. Massey

