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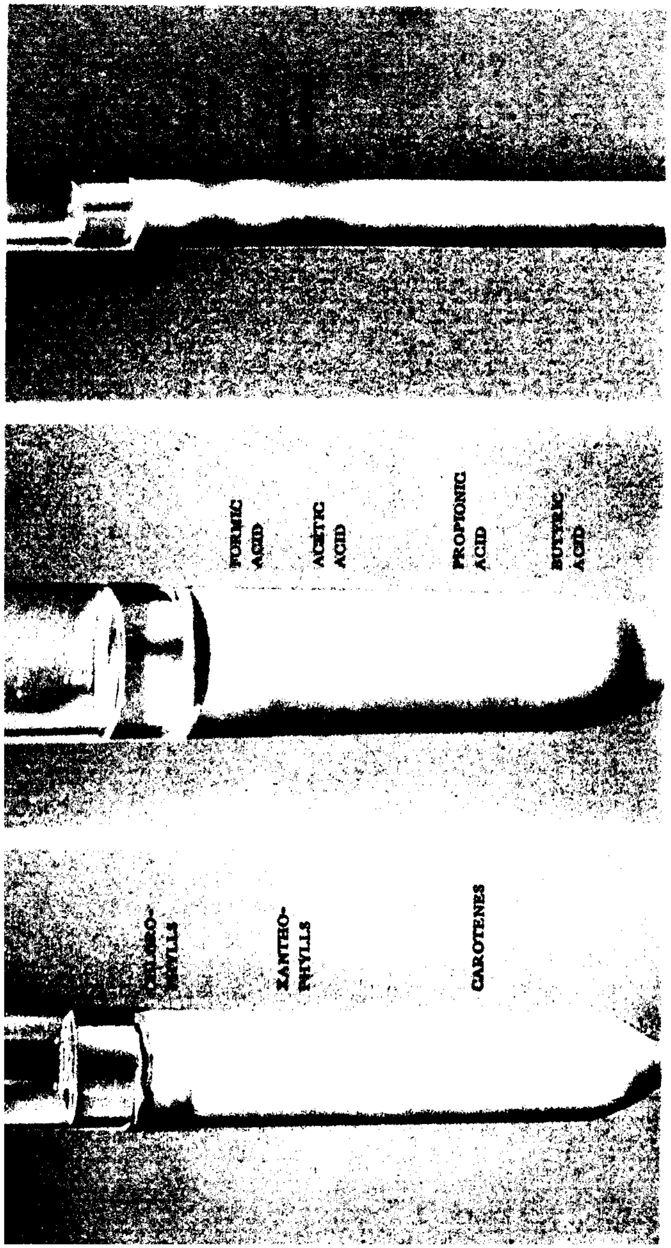

1. Adsorption Chromatogram of plant pigments

2. Partition Chromatogram of Fatty Acids

3. Partition Chromatogram of Acetyl Aminoacids

(See the article on 'Chromatography' by Dr. E. Lester Smith)

Plate 1

SCIENCE NEWS

EDITED BY J. L. CRAMMER

13

PENGUIN BOOKS

HARMONDSWORTH · MIDDLESEX

First published in October 1949

Photogravure plates printed by
Eric Bemrose Ltd, Liverpool

Made and printed in Great Britain
for Penguin Books Limited by C. Nicholls & Co. Ltd,
Manchester

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Editorial

THERE are now so many professional scientists at work, so many different scientific journals in the world, such an endless flood of papers reporting new observations and new ideas, that Science is in danger of fragmentation. No single individual research worker can hope to keep track of all that is going on in even his own special branch of Science. He relies on abstracts and review articles to bring the important work to his notice, and becomes more and more specialised in his reading in order to bring it within the bounds of human capacity.

This is a very dangerous situation for Science. An enormous responsibility is thrown on the abstracters and reviewers: they must miss nothing. Several recent conferences have debated ways in which to improve exchange of scientific information, notably that organised by the Royal Society last year, and by UNESCO this summer; and while improvements in abstracting may result, this is only half the problem and the danger of over-specialization remains.

The psychology of discovery, of fundamental creative research, is still very much an unknown territory, but it seems quite likely from the biographies of the great scientists that one factor at work is the ability of an individual mind to call on a very wide range of scientific information and muse on it at leisure. Now the way that Science is going, fewer and fewer individuals are acquiring this wide knowledge, and there is a possibility in the next fifty years or so that scientific progress will simply come to an end beneath a great mass of disjointed facts and papers, when the over-specialists are dying of lack of mental light and air.

Research by teams of specialists in different subjects working together is proposed as one way of avoiding this unhappy end. The trouble with it is that one man knowing everything from A to K, and another from L to Z by his side, is no good when it comes to musing at leisure: A to Z has got to be in the one brain.

This is where *Science News* comes in. When we started, we had no idea that research workers would read us in such number, or would even sometimes come to rely on us for information in their own subjects, as our correspondence shows they do. There is evidently a great need for popularising science amongst scientists and scope for a number of magazines of different levels of difficulty and comprehensiveness. Some of the scientific societies are beginning to realise this and cater for the need. The Chemical Society, for instance, now produces a Quarterly Review which offers chemists surveys of different specialities within the great territories of Chemistry; while in the United States *Physics To-day* does something of the same kind for physicists. But more of these periodicals are needed, especially those bringing several different sciences within the covers of a single issue and written in a correspondingly simpler style.

This may be the cure for the disease: not more abstracts, but simpler and wider and more critical reviews. If they can thus counteract the evils of specialisation the despised scientific journalists will prove to be our saviours after all.

One innovation in the present issue deserves comment: the colour plates. Our finances are not such that we can afford this as a regular feature, but from time to time, especially with subjects where colour conveys much more than monochrome, we hope to be able to introduce it again. *Science News* 15 will probably have such illustrations, and in addition will contain the frequently requested and long awaited special index to issues 1 to 15 inclusive.

Chromatography

E. LESTER SMITH

CHROMATOGRAPHY is being used to an increasing extent in chemical research, and more particularly in the field of biochemistry. As you can guess from the first part of the word, it has something to do with colour; the "graph" part of the word may, however, be just a bit misleading. You do in fact get coloured pictures, as you might imagine, but the point is that you persuade Nature to draw them for you.

Chromatography is a cunning method for separating chemical substances from one another, which is frequently though not invariably applied to mixtures of coloured substances. The biochemist is often confronted with exceedingly complex mixtures of natural origin – extracts of liver or yeast, for example, or extracts of plant materials – from which he wishes to isolate one or more pure substances. He may wish to do this in order to have sizeable amounts of the substance in question, perhaps for research on its constitution, or he may be interested merely in determining the amount present. In either event, chromatography may well be the tool most suited to his purpose.

The quickest way to get an idea what chromatography can accomplish is perhaps to do an experiment yourself in your own kitchen. You can take a sheet of blotting paper and about an inch from one side place a series of drops of coloured inks, or any other water-soluble colouring matters you may have available. You can also make a mixture of two or more of these inks and put a spot of the mixture on the blotting paper. All you have to do then is to stand the blotting paper upright in a dish of water about a quarter of an inch deep, with the row of spots at the bottom. The water is slowly drawn up the blotting paper by capillary attraction and, as its level in the paper reaches and passes through the row of spots, it tends to wash out the colouring matters and carry them up towards the top of the sheet.

In about half an hour, when the water level has nearly reached the top of the paper, the experiment is complete. You will probably find that the red ink, at least, has given rise not to a single spot or streak of colour, but to two or more, indicating that the original ink contains more than one dye. Similarly, your spot of mixed inks will probably separate more or less completely into its original components. In such an experiment it was found that a red ink separated into two or possibly three red spots. A green ink travelled quickly up the paper but revealed a small amount of yellow pigment which travelled less quickly. A yellow ink moved only a short distance from the point of application. A mixture of all three showed clear evidence of separation into yellow, red, the second red component of the red ink and green.

This simple example of chromatography is very easy to perform and to describe, but it is not quite so easy to explain why these astonishingly perfect separations occur. The simplicity of the operation is in fact a bit deceptive. We can give a rough explanation of this example by saying that some of the dyes present in the inks are 'faster' or more perfect dyes than others. The yellow dye in the above example is the 'fastest' of those chosen; it attaches itself rather firmly to the fibres of the paper and is not readily washed out. The green ink, on the contrary, is the least 'fast', and is readily leached out from its original spot and carried up the paper nearly as rapidly as the 'advancing front' of water. The two red dyes are intermediate in 'fastness' and so they are slowly leached out and carried part-way up the sheet of paper.

The utility of chromatography is already clear from this example. This technique and various modifications of it, which will be described later, are in fact used for the analysis of dyes and mixtures of dyes.

Water Softeners

Before attempting a more precise explanation of how chromatography works, a familiar example of its everyday use may be given. Many households nowadays possess a rather large chromatograph column in the shape of a water-softening unit. This may contain natural or synthetic zeolite (a complex aluminium silicate) or a special type of synthetic resin, in granular form. Tap water, run through this bed of 'base-exchange' material, emerges softened; freed, that is, from calcium and magnesium salts. After a period, the hard water 'breaks through', and the material has to be regenerated with strong brine, followed by thorough washing.

This is rather a special kind of chromatography and some of the textbooks would not accept it as an example, but I regard it, on the contrary, as an excellent illustration of the principle of chromatography. What happens in the water softener? The zeolite or the special resin is essentially an acidic substance; the whole surface of the porous solid is covered with acid groups, which can combine with any available base, lime, magnesia, or soda. The material is supplied as the sodium salt. If we took some of it and shook it up with hard water a *partial* exchange of bases would take place; some of the soda would pass into the water in the form of bicarbonate or sulphate, while an equivalent amount of the lime and magnesia (originally present as these salts) would become anchored on to the acidic groups of the material. But under these conditions the exchange is not complete and an equilibrium is quickly set up; the proportions exchanged depend on the amounts of the various substances present in accordance with the 'Law of Mass Action'.

This is where the chromatographic principle comes in. We do not just shake up the softener with the water. We run the water through a rather deep bed of the material. Thus we rely upon the *cumulative* effect of layer after layer of it. The first inch, let us say, may remove only 20 per cent of the hardness. But the next inch will take another 20 per cent out of the 80 per cent that was left in the water, i.e. 16 per cent, leaving 64 per cent. The next inch reduces this to 51 per cent, the next to 41 per cent, the next ones to 33 per cent, 26 per cent, 21 per cent, 17 per cent, 14 per cent, 11 per cent, 9 per cent, 7 per cent. Thus after 12 inches the water is almost fully softened, while the deeper beds often used are still more efficient.

The point to be emphasized is this: the softener works efficiently, *not* because of any special affinity of the material for lime and magnesia, but because of this chromatographic method of operation whereby these substances are gradually strained out as it were, by repeated equilibration with a succession of particles of fresh exchange material. After a while, of course, the top inch becomes saturated with lime and magnesia, having given up all its soda, so it can play no further part. Then the next layer becomes similarly exhausted, and so on until eventually only the few lowest inches contain active material and these are not enough to retain all the hardness. Then the householder realises that his little private miracle is not completely automatic.

However, he need not throw away the exhausted material. Just because it does not have any peculiar preference for lime and magnesia over soda, he can now reverse the process. By putting in strong brine (sodium chloride) he regenerates the sodium salt of the exchange material, and runs the displaced lime and magnesia to waste as chlorides. This reversal is still in accordance with the Law of Mass Action. It happens because we use an *excess* of the sodium salt, and because we again employ the chromatographic principle by running the brine slowly through the column, thus forcing the reversal to completion in successive layers.

This familiar example of chromatography is unrepresentative in three respects: the *chemical* exchange reaction is unusual, most chromatographic separations depending instead on the *physical* phenomena of adsorption or partition, as will be explained in a moment; secondly the customary 'development' with pure solvent is omitted; thirdly there is no separation of components into zones.

Protein Hydrolysate

However, we can use exactly the same column for other purposes, which will illustrate the last two features. It must first be treated with dilute acid, to convert the exchange material into the acidic form. Then, instead of hard water, we can run through a protein hydrolysate (i.e. the mixture of substances present after boiling a protein with acid for some hours) and, after a suitable amount has been added, we can 'develop' the column by running through distilled water. The result is to sort out the aminoacids present in the protein digest into groups. The acidic aminoacids, glutamic and aspartic acids, are unaffected and pass straight through with the water. The 'neutral' aminoacids – those carrying one amino and one carboxyl group – are somewhat retarded in their passage because of their mildly basic property. The true basic aminoacids, arginine, lysine, and histidine, are more strongly retarded because their two amino groups render them predominantly basic in character: they tend therefore to remain in the upper part of the column, which of course itself is acidic.

However, when the last of the hydrolysate has been added these upper layers will obviously contain a mixture of all the acids, though enriched in the basic ones. This state of affairs is resolved by washing with plain water. The tendency is to wash all the zones further down the column, but the less retarded ones travel the faster, so that after a while nothing is left in the upper part of the column except the most retarded basic aminoacids. These can be recovered by elution (washing-out) with dilute acid or with other solvents. Further, my colleague Dr J. E. Page has found it possible to separate the individual basic aminoacids on columns of this type, by the use of eluting agents of graded strength. This technique simplifies the isolation, in their natural optically active form, of these aminoacids, which are needed for nutritional research and as constituents of media for microbiological assays.

Plant Pigments

Chromatography was invented in 1906 by the Russian botanist Tswett for the separation of plant pigments. An almost exact repetition of Tswett's original experiment has been photographed in colour and appears in Plate 1 (a) in the frontispiece. A glass tube drawn out at the bottom is fitted with a filter disc or just a plug of cotton wool, and is filled with a suspension of a suitable adsorbent in an organic solvent. Tswett used columns of chalk or sugar, but in this experiment we have used aluminium oxide which is now one of the most widely used adsorbents for chromatography. The solvent was petrol and the material to be separated was a plant extract which originally took the form of a brown oil.

After the adsorbent had settled down in the tube to make a firm column, and when most of the solvent had percolated through, a strong solution of this plant extract was poured on to the top of the column and allowed to soak in. Clean petrol was then added in order to develop the chromatogram. In the course of half an hour or so the material sorted itself out into at least six different pigments, which can be seen in the colour photograph. They appear in narrow rings down the column, green due to chlorophylls near the top, then a yellow and two orange-brown rings due to xanthophylls, and lower down red and orange ones due to carotenes.

This example is typical of adsorption chromatography as it is carried out in the laboratory. We are dealing in this case with pigments that are not soluble in water. Another difference from our experiment on blotting paper is that these glass columns can separate useful amounts of material, whereas only a milligram or so can be used on a sheet of paper. The mechanism of the separation, however, is quite similar. Some of the pigments are adsorbed very lightly or

not at all by the alumina and so they travel down the column along with the solvent. Others are fiercely adsorbed and so are held back right at the top of the column, while other pigments are intermediate in their behaviour and their travel down the column is the more retarded the more strongly they are adsorbed.

The diagrams (Plate 3) illustrate an ideally simple case. Suppose we have three pigments, a yellow one (represented by open circles) not adsorbed at all, a blue one (represented by dotted circles) adsorbed so that it travels half as fast as the solvent, and a red one (represented by black circles) more strongly adsorbed so that it travels at one quarter the solvent rate. The first diagram shows the start of the experiment when a solution of these mixed pigments has been poured on to the top of the adsorbent column. In the second diagram this solution has just finished soaking into the column. The solvent and yellow pigment will have reached the point indicated, but of course will be present in the whole region above this. The blue pigment will similarly extend from the top down to half this distance. The red pigment will be concentrated into only the upper quarter of the coloured region. We now cease applying the solution, and develop with pure solvent only. The third diagram shows the situation when the solvent front has advanced a little. All three pigment zones have moved on at their own proper rates, retaining their original lengths; they are just beginning to separate. The other diagrams illustrate conditions at successive time intervals and show how all three pigments are eventually separated completely as coloured bands divided by white bands of unstained adsorbent.

As may be imagined such ideal behaviour is seldom realized in practice. From causes which, though understood, are not preventable, the zones usually lengthen as development proceeds. Frequently they have a sharp front but a diffuse tail. In other cases, however, a following zone will encroach on a tail and push it ahead, thus creating a narrow sharp band like those seen near the top of the column in Plate 1 (*a*).

Applications of Chromatography

The choice of adsorbents and solvents was at first entirely empirical. Gradually, however, an understanding of the principles underlying chromatography has been acquired. It is possible to grade both adsorbents and solvents roughly in series from strong to weak. This enables one to narrow down the choice for any particular problem. The behaviour of chromatographic columns has been worked out mathematically, and in theory it would be possible to carry out a series of measurements on likely combinations of solvents and adsorbents to determine which would be the best for a particular separation. In practice, however, it is much quicker to set up a row of chromatograms and determine by direct trial and error which combination works best. For other reasons, too, chromatography will probably always remain something of an art. It is definitely a technique where experience counts. There are all sorts of little manipulative tricks that make for better results.

This adsorption chromatography is at its best in separating minute amounts of particular substances from complex mixtures, and this kind of problem turns up most frequently in biochemistry. Thus it has been used in the isolation of one after another of the vitamins and also in the study of all kinds of natural pigments – from leaves and petals of plants, sea-weeds, butterflies' wings and so on.

We may take as an example the purification of vitamin A. It happens that vitamin A is colourless, so this example will also illustrate some ways in which chromatography has been adapted for the separation of colourless substances. The richest sources of vitamin A are liver oils of certain fishes, in particular the halibut. Considerable preliminary concentration can be effected by saponifying the oil, that is by turning the glycerides of fatty acids which constitute the bulk of the oil into soaps, which are sodium salts of the fatty acids. The vitamin A, along with a number of other colourless and coloured substances, is contained in the so-called unsaponifiable fraction, which can be extracted from the

soap with organic solvents. In this way it is possible to get a preparation containing as much as 10 per cent of vitamin A.

Such preparations can conveniently be further purified by chromatography on alumina or slaked lime, using petrol as the solvent. The columns develop a series of coloured zones separated by nearly colourless ones. There are several ways in which the colourless vitamin A zone can be located.

The column of adsorbent can be pushed out of the tube as a cohering cylinder and cut with a knife into sections. The coloured bands serve as some guide to this dissection. Each portion of the column can then be extracted with a suitable organic solvent, for example, a mixture of ether and alcohol, and each in turn can be tested for vitamin A. This can be done most readily by means of a blue colour reaction which vitamin A gives with antimony trichloride dissolved in chloroform. Once the vitamin A has been located in this fashion its position in relation to the coloured bands due to impurities can serve to fix its position in subsequent chromatograms.

A very much quicker and neater way of achieving this end is the so-called streak method. The column of adsorbent is pushed carefully out of the tube so as not to break it, and a small brush dipped in the antimony trichloride reagent is gently streaked down the length of the column. This reagent gives a deep blue stain where it meets the vitamin A zone. This enables the zone to be cut away very exactly from the impurities above and below it in the column. The narrow streak stained by the reagent is, of course, trimmed off before extracting the vitamin A.

This streak method for making a colourless substance reveal its presence by turning it into a coloured one can be applied in other cases. Another trick to achieve the same end is the examination of the chromatogram in 'black light'. By this we mean invisible ultraviolet light, usually derived from a mercury vapour lamp, from which almost all the visible light has been removed by a filter of Wood's glass; this is a very deep purple glass which is transparent to ultraviolet light. A number of substances fluoresce vividly in this 'black light' – you may have seen the phenomenon exploited in advertisements or on the stage. We shall come to an example of this later when we consider Plate 2 (*a*) and (*b*). Meanwhile, Plate 2 (*c*) illustrates a sort of negative use of fluorescence in chromatography. In this case we have a column of silica which is not itself fluorescent. It is mixed, however, with a few per cent of one of the fluorescent powders used for coating the fluorescent daylight lamps. This particular one glows a vivid yellow in the 'black light'. The column has been used for the separation of two substances, nitrobenzene and azoxybenzene. Now these substances do not themselves fluoresce, but they do absorb ultraviolet light and so prevent it from reaching the fluorescent powder. Thus the zones containing these substances show up as *dark* layers against the golden yellow luminescence of the rest of the column. This ingenious technique was described only a year or two ago and it promises to have wide applications.

Partition Chromatography

So far we have been talking about adsorption chromatography, and this was the only kind known until 1941. In that year, however, an entirely new principle was introduced into chromatography by Martin and Synge. Superficially their chromatograms look just like the others – there is a column of powder in a glass tube with a liquid percolating through it, and the end result is as before, a series of coloured bands. However, the principle involved is entirely different. The powder in the tube has nothing to do this time except to serve as an inert support for innumerable invisible globules of water and it is these sub-microscopic water droplets that make the column work.

The powder used has to be something which will soak up water like a sponge without becoming obviously damp. Such powders are starch, powdered paper, and precipitated silica. When a suitable mixture of substances in a

solvent like chloroform (which does not mix with water) is run through the chromatogram column, some of the dissolved substances are withdrawn from the solvent by the water droplets. This phenomenon is called distribution or partition, and so the technique is usually known as partition chromatography. Some substances will go mostly into the water, and others mostly into the solvent; in other words, the substances have different 'partition coefficients'.

In partition chromatography, then, the separations which occur are due to the differences in partition coefficients shown by the different substances in the original mixture. This is analogous, of course, to the differences in adsorption affinity, which bring about the separations in the earlier type of chromatogram. It is one of those techniques that seems beautifully simple and obvious once it has been invented – but which nevertheless takes a genius to invent it in the first place. The particular ingenuity involved is, of course, that of making water stand still, by soaking it up in an absorbent powder.

This new technique has not merely extended the range of chromatography. A study of recent research papers will show that partition chromatography in its various modifications is now much more widely used than the original adsorption chromatography.

Plate 1 (*b*) illustrates a typical partition chromatogram, while at the same time it introduces a new trick to assist in the chromatography of colourless substances. Precipitated silica is mixed with about half its own weight of water, or even more, an amount which it soaks up while still remaining an apparently dry powder. Mixed with the water, however, is a small amount of the indicator dye bromcresol green. This dyed damp silica is then suspended in chloroform and poured into the glass tube. When it has settled down and the excess solvent has drained through, a mixture of acids dissolved in a little chloroform is carefully poured in, to be followed in a few minutes by clean chloroform. The passage of the acids down the column is retarded because the water droplets extract part of the acids from the solvent, so that there is a continuous shuttling back and forth of molecules of the acid between the stationary water droplets and the solvent running through the column. The extent to which an acid is retarded depends on its 'partition coefficient'; the more soluble it is in water, the more firmly is it held back. The result is that as the column is developed the various acids we have used sort themselves out into horizontal bands. They reveal their presence by turning the blue indicator yellow, so that one gets a succession of yellow bands down a blue column.

The acids we have used are the simple fatty acids, formic, acetic, propionic and butyric, and they separate in that order from top to bottom of the column. This is the order to be expected, for it is also the order of increasing chain length in these fatty acids. The chain of carbon atoms tends towards solubility in organic solvents and insolubility in water, whereas the acidic or carboxyl group has the opposite tendency. Thus formic acid, which has no chain at all but one hydrogen atom, is extremely soluble in water and so sticks right at the top of the column; as the chain lengthens from one to three carbon atoms it increasingly dominates the molecule, raising the 'partition coefficient', and causing these acids to travel progressively further down the column.

It happens that I was the first to experiment with this particular application of partition chromatography; the technique has since been used by Elsden for analysis of the lower fatty acids occurring in the contents of the paunch of the cow. Modifications have been used for determination of the acids occurring in fruits – citric, malic, tartaric and other acids.

All this, however, developed readily from the work of Martin and Synge, the original inventors of partition chromatography. Plate 1 (*c*) illustrates one of their early experiments. Again we have a column of silica moistened with water containing an indicator dye – methyl orange this time. Again the solvent is chloroform, but the acids being

separated are the amino-acids glycine and alanine, or rather their acetyl compounds; that is to say, their basic amino groups have been masked by combination with acetic acid, so that they behave like strong acids and turn the indicator from yellow to red as they travel slowly down the chromatogram. These amino-acids are of interest because they are the 'bricks' out of which the proteins are built. Previous analytical methods were very laborious, but partition chromatography enables some of the amino-acids to be determined in a few hours' work, and using only a few milligrams of protein.

The efficiency of these separations is something quite remarkable; some of the compounds separable are extremely alike in constitution, and their 'partition coefficients' differ by only about 10 per cent. Martin and Synge have shown mathematically that the separation is due to the very small depth of column within which equilibrium can occur. Thus in a single inch the acid may be shuttled back and forth, to establish and re-establish equilibrium between the flowing solvent and the stationary water droplets, no less than one thousand times.

In *Science News* 9 I described the use of partition chromatography for purification of liver extracts, as a step in the isolation of the anti-pernicious anaemia factor or vitamin B_{12}. Plate 2 (*a*) illustrates an early stage in this work. A rather crude liver extract has been chromatographed on damp silica using butyl alcohol as the solvent. The photograph shows a dark brown band at the top and two yellow ones lower down. Plate 2 (*b*) is a colour photograph of the same column taken in 'black light'. This shows the two yellow zones fluorescing with the greenish-yellow shade characteristic of riboflavin (vitamin B_2) and its compounds. It also shows a blue fluorescing band just below the brown one. This is due to some unknown colourless substance which is not evident at all on examination by ordinary light. With a more highly purified liver extract, below the top brown band there would be a pink band due to the red anti-pernicious anaemia factor.

Paper Strip Chromatography

Finally there remains to describe a modification of partition chromatography which has found enormous application during the five years since it was first introduced by Consden, Gordon and Martin; it promises to become the most valuable of all chromatographic techniques. In this method the glass tube containing a damp porous solid is replaced by a strip or sheet of filter paper. This takes up sufficient moisture from the air. The mixture to be separated is put near one end of the paper as a tiny drop of solution which is allowed to dry off. Development is then effected with an organic solvent, either by dipping this end of the strip into the solvent and allowing it to be drawn up slowly by capillary attraction, or else by bending over the top of the strip and immersing this in a reservoir of solvent so that it travels slowly downwards past the spot. The only complication is that the strip and reservoir must usually be enclosed in an airtight vessel along with a trough of wet solvent, so that the air inside remains saturated with both liquids.

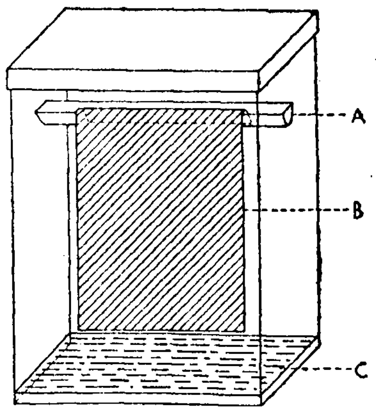

Fig. 1. - Paper chromatography apparatus. (A) Trough for solvent; (B) Sheet of filter-paper with test spot (not shown) in one top corner; (C) Wet solvent layer in the bottom of the air-tight box.

This paper strip chromatography was first used for separation of aminoacids (not acetylated). A number of different solvents were tried, but two of the most useful ones are phenol and collidine. After development with the solvent for some hours, or even one or two days, the paper strips are dried and sprayed with a weak solution of ninhydrin, then heated in an oven. This treatment causes a blue colour to appear where each aminoacid spot is located.

It would be too much to expect that all the 22 aminoacids should be capable of separation so simply. Some have very similar partition coefficients to others, so their spots overlap. However, they often differ in another solvent. Thus an unknown mixture of aminoacids could often be analysed by running two strips with different solvents.

However, Consden and his colleagues were not content with this: they invented a much more ingenious and elegant technique that extracts the utmost advantage from the use of two solvents. This is two-dimensional chromatography on paper. It starts exactly as described above except that a square sheet with the spot near one corner replaces the strip, and a long trough must be used for the solvent. Then after drying, the square is turned at right angles, and another edge is dipped into a trough of a different solvent, e.g., collidine. So one eventually gets a pattern of ninhydrin-developed spots scattered all over the paper.* With much patience, it was possible to identify all the spots and to show that this procedure *is* capable of separating all the known aminoacids. Indeed, its originators demonstrated the separation of all the aminoacids previously known to be present in wool (incidentally proving that there were no others that had been missed) using for the experiment the hydrolysate from only 0.2 mgm. of wool. Moreover, this brilliant technique has been used also for simple peptides and other related metabolites.

The interest of these methods for the determination of aminoacids in proteins goes beyond a mere analysis

* Plate 6 in *Science News 4* is a photograph of such an experiment.

Living matter is built up very largely from proteins of many kinds. These vary enormously in their properties, yet they are all built up from some or all of the same 22 aminoacids. It would help greatly towards our understanding of the mysteries of life-processes if we could unravel the structural patterns of these proteins. The determination of constituent aminoacids is, of course, only the first step, but the patient application of these chromatographic techniques to partial hydrolysis products promises an insight into the order of linkage of the aminoacids, and so to an understanding of why proteins differ so widely from one another. The first completed achievement in this direction is the work on the antibiotic, gramicidin S. This was shown to be a cyclic peptide containing only five aminoacids, but, what is more important, the precise *order* in which they occur in the molecule was determined.

Inorganic Chemistry

Paper chromatography has since been adapted for the separation of many other classes of compounds, such as the natural pigments of flowers, sugars, the various varieties of penicillin and streptomycin, purines and pyrimidines, and so on. It is not possible to describe all these in detail, but something should be said about the application of chromatography to inorganic chemistry.

Sporadic attempts have been made to use adsorption chromatography for inorganic separations, but with only limited success. Recently, however, much progress has been made along two different lines.

The first is the use of synthetic resins with base exchange properties (as used for water softening). This has been used with great success for the separation of the group of elements called the rare earths, which are exceedingly laborious to separate by other means because their chemical properties are so similar. This method has been used to separate the radioactive fission products made from uranium in the nuclear pile.

The other development has been the use of paper chromatography, with a range of special solvent mixtures, to separate various metals. This method was first developed at the National Physical Laboratory at Teddington for particular small groups of metals, but recent papers show that it will probably be possible eventually to separate and detect practically all the known elements by this means.

READING LIST

Introduction to Chromatography by T. I. Williams (Blackie and Son) is a readable and up-to-date elementary textbook.

Principles and Practice of Chromatography by Zechmeister and Cholnoky, translated by A. L. Bacharach and F. A. Robinson (Chapman and Hall) gives a thorough survey of the field of chromatography up till 1941.

Specialized aspects of chromatography have been dealt with in the following papers:

'Isolation of Vitamin A': Castle *et al.*, *Biochem. Jnl.*, 1934, **28**, 1702; Holmes *et al.*, *J. Amer. Chem. Soc.*, 1935, **57**, 1990.

'Partition Chromatography and Theory of Chromatography': Martin and Synge, *Biochem. Jnl.*, 1941, **35**, 1358.

'Chromatography on Paper': Consden, Gordon and Martin, *Biochem. Jnl.*, 1944, **38**, 224.

'Inorganic Paper Chromatography and Detection of Cations by Fluorescence': Pollard, McOmie and Elbeih, *Nature*, 1949, **163**, 292.

The Problem of Cancer

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THIS very brief review is intended to give the non-medical and non-biological layman a picture of the cancer problem as we see it to-day. There are many excellent works on this subject, of which the best is undoubtedly the book by Oberling, *The Riddle of Cancer*. This work, good though it is, is perhaps a little too detailed and requires too great a knowledge of biology for the average reader. The present review might be regarded as an introduction for those who would like afterwards to read further.

We must start with a definition of cancer. To the layman this conjures up some mysterious influence which eventually brings about the death of the patient. In most people's minds the cause of death is regarded as some vague malignant influence on the life of the victim. It must be pointed out that the mechanism of cancer growth and its method of killing its victims are understood perfectly.

The body consists of three types of tissue, ectoderm, mesoderm and endoderm. The ectoderm is the skin and external covering of the body, the mesoderm includes connective tissues, muscles, tendons and so forth, and the endoderm represents the lining of the digestive tract and the ancillary systems connected with it. Normally these tissues grow in an orderly manner and produce a perfectly functioning body. If the malignant process is initiated in any part of the body associated with these three types of tissue, the cells begin to multiply in an irregular manner. Thus if an ectoderm cancer is produced, the cells multiply and produce a swelling on the surface of the skin. The cells then break through the skin and invade the mesoderm, and pieces of this growth are broken off and are transported by either the

blood or the lymph stream and stick in other parts of the body. Here they continue to grow in the same irregular manner and the result is another cancer. The superficial tumour is known as the primary growth, whereas the pieces that are broken off and become deposited elsewhere are known as secondary growths.

Cancer has always been associated with the word 'tumour', which literally means a swelling. From time immemorial tumours have been classified into innocent and malignant, and it is really only with the latter type that we are concerned. An innocent tumour is one which grows locally and expands, but does not disseminate. This lack of the power to disseminate is due not to the fact that the tumour is encapsulated, but is due to the fact that the cells have only a limited power of reproduction at the local site. On the other hand the malignant tumour grows locally usually much more quickly than an innocent tumour and in addition has the power to disseminate.

It is possible to have tumours of the mesoderm, these being usually known as sarcomata; similarly one has tumours of the endoderm, such as carcinomas of the stomach, intestines and so forth.

Unfortunately cancer justifiably has the reputation of being a lethal disease, unless it is adequately treated in the early stages, and it is essential for anyone who wishes to have an intelligent understanding of the cancer problem to realise that the disease may be lethal. The layman always tends to regard matters of disease as being associated with some mysterious supernatural power and believes that if the disease is capable of causing death it does so in some obscure and inexplicable manner. Nothing can be further from the truth in the case of cancer. If the disease cannot be adequately treated by one or other of the methods which will be reviewed later, it produces the fatal outcome by purely mechanical means, such as pressure of the primary growth on some essential structure (e.g., the windpipe), extension of the secondary or disseminating growths, causing destruction of a vital organ such as the brain, or finally by the development of septicaemia. In view of the efficiency of antibiotics to-day, this last danger has largely been eliminated.

The above description is intended to demonstrate to the general reader that, once having started, the cancer kills by quite straightforward means, such as pressure, erosion and sepsis. Our problem, therefore, boils itself down to: what is the cause of the onset of cancer, what is the mechanism of its continuance, and is it possible to arrest the malignant process?

Methods of Producing Cancer

There are four known ways by which cancer may be produced in the body. These are:

1. By the application or administration of external agents.
2. By transplantation of tumours from one animal to another.
3. By injection of certain cell-free filtrates made from ground-up living tumour tissue.
4. By some factor within the body itself.

1. The fact that cancer can be produced by some external agent under certain conditions was suspected as long ago as the eighteenth century. The surgeon Percival Pott made the observation that carcinoma of the scrotum very frequently occurs in chimney sweeps and he attributed this to the continual contact with soot. It was known that workers in certain other industries are also very susceptible to cancer, but it was not until 1915 that a cancer was actually produced experimentally by the application of an external agent. In that year the Japanese workers Yamagiwa and Ichikawa succeeded in producing cancer in rabbits by painting the ears for long periods with tar. In 1922 Passey produced an experimental cancer in laboratory animals by the actual application of soot, thus bearing out the original

observation of Percival Pott. Kennaway and his collaborators in the early 1920's began their long series of researches which led eventually to the isolation and characterization of the pure compounds responsible for this type of cancer.

Kennaway's first step was to produce synthetic tars by passing acetylene and hydrogen through a heated tube. He showed that it was possible to produce a synthetic tar containing only carbon and hydrogen and that the crude mixture was carcinogenic. He and his collaborators then started fractionating gas works' tar. The next observation was that all the fractions with carcinogenic activity appeared to have the same type of fluorescence. The thing to do therefore was to examine as many compounds as possible with this same fluorescence spectrum. Some of the compounds tested were synthesized for the first time by members of Kennaway's team, others had already been synthesized by others. As the work went on, it began to appear that the active compound or compounds would prove to be compounds composed of a number of benzene rings fused together, such as derivatives of anthracene, pyrene, etc. This class of compounds is called polycyclic aromatic hydrocarbons and the ones which produce cancer are known as the carcinogenic hydrocarbons. The first two compounds of this type found to be carcinogenic were 1 : 2 : 5 : 6-dibenzanthracene and 1 : 2-benzpyrene (Figs. 2 and 3).

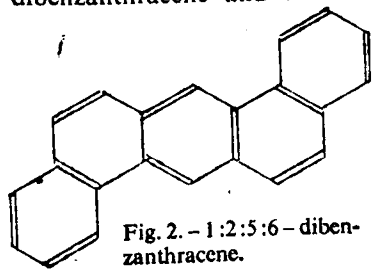


Fig. 2. – 1:2:5:6 – dibenzanthracene.

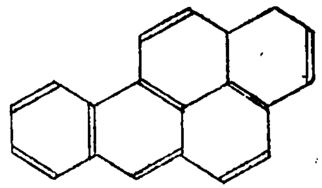


Fig. 3. – 1:2 – benzpyrene.

The first compound was synthezised by members of the team and the second was isolated from gas works' tar. Very many more compounds of the same type have been found to produce cancer when painted for long periods on the skin of mice. Intensive research has been devoted to an attempt to find out by what mechanism they produce their effect, but so far no solution of the problem has been found.

In addition to the polycyclic hydrocarbons, a number of other chemical compounds occurring as intermediaries in certain industries have proved to be carcinogenic. These so far have not been so intensively studied as the hydrocarbons.

Attention was directed to certain azo dyes and it was found by Yoshida in Japan that feeding of some of these to rats would produce tumours of the liver after a few months. The same effect was produced when the dyes were injected. These compounds act rather differently from the hydrocarbons as they produce tumours removed from the site of application, away in the liver, in which they can be detected and undergo biochemical breakdown.

Observations on workers in the dye industry showed that a significantly higher number of them than of the general population develop cancer of the bladder, though the disease often does not appear until many years after contact with dyes is ended. Researches have shown that the compounds responsible are β-naphthylamine and benzidine, two intermediary products associated with the manufacture of aniline.

In the same way it has been found that workers engaged in the so-called carbonyl process in certain metal industries are liable to develop cancer of the respiratory passages.

Another well-recognized form of 'industrial cancer' is that known as 'mule spinners' cancer'. This is due to continuous contact with the oil used to lubricate the machines. This oil has been shown by Berenblum to contain benzpyrene, which is the actual carcinogenic agent.

There is clear evidence that cancer can be produced not only by X-radiation but also by ultra-violet radiation or by excessive exposure to sunlight.

It must be clearly pointed out that there is no mere

chronic irritation which will produce malignant disease. Some years ago surgeons regarded certain forms of non-specific irritation as being the cause of cancer. Thus, the irritation of the tongue or cheek by jagged teeth, the chronic abrasion caused on the lips by the stem of a clay pipe, and similar irritations, were regarded as capable of producing a lesion which eventually turned into cancer. Whilst this is accepted by many clinicians, it is obviously a matter that cannot be subjected to experimental investigation in the human subject, but the results of laboratory research on animals suggest it is incorrect. It would appear that the chemical agent attacks the cell in some specific manner so that it becomes potentially malignant, though the malignant process may develop only years after exposure.

2. Another line of research which has been intensively followed is the transplantation of tumours from one animal to another. This was first done successfully by Jensen in 1903. At first it was hoped that a solution of the cancer problem might be reached by a study of these transplanted tumours, that curative methods could be tried out on them and that it might be possible to increase the resistance of the animals. These researches have been disappointing in that practically no new vital fact has emerged from the truly enormous amount of work performed on this subject.

3. One of the most interesting observations in the whole of cancer research was made by Peyton Rous in 1910. He found that it was possible to transmit certain fowl tumours by injection of a cell-free filtrate of the tumour. This observation has given rise to a wealth of speculation. There are two possibilities: the first that the filtrate contains some carcinogenic compound, and the second that it contains a filter-passing virus. This extremely important point has not yet been elucidated. It is quite obvious that if it could once be proved beyond doubt that any form of cancer could be transmitted like an infectious disease,

an entirely new direction would be given to the problem, although it would still be very far from solution, since the virus would first have to be identified, and since we have as yet no form of chemotherapy against viruses. So far it must be made quite clear that no mammalian tumour has ever been transferred by a cell-free filtrate. The only experimental evidence that a virus can play a part in the development of a mammalian tumour was provided by the work of Shope. He showed that the benign growths in certain types of rabbit can be transmitted by administration of a cell-free filtrate. However, these tumours are of a warty character and require further treatment before they can be converted into malignant growths. In some breeds of rabbit, however, they regularly become malignant.

4. It is obvious that in the majority of persons who develop cancer its origin cannot be traced to any of the carcinogenic substances mentioned, and therefore a great deal of thought has been devoted to the idea that some factor within the body itself may be responsible. Some very interesting facts have come to light in this connection. It should be explained here that the strains of mice used in all the experiments we have been discussing are obtained by selective breeding, and it has been possible to produce a variety of strains, some of which are very susceptible to cancer, whereas others are less so or very resistant. It was found by Bittner that if new-born mice of a susceptible strain are suckled by a mother of a resistant strain, their susceptibility to mammary cancer in later life decreases surprisingly. Other authors have found similarly that resistant mice are made more susceptible by the milk of a susceptible mother. This raises the possibility that a cancer 'inciting' agent may be present in the milk.

Before turning to this question of internal secretions in relation to malignant disease, it is necessary to define the terms to be used. By the expression 'internal secretion' or 'endocrine' is meant the substances secreted by a gland

into the blood. These substances exert their actions on certain tissues to which they are conveyed by the circulation. From the point of view of cancer we are concerned particularly with two groups of hormones derived from the reproductive glands, which are known respectively as androgens and oestrogens. By androgen is meant the male hormone – the secretion of the testis. This substance circulates in the blood and is responsible for the development of secondary sexual characteristics in the male. The oestrogenic substances are produced by the ovary and are responsible for the development of the female secondary sexual characteristics. In addition to the naturally-occurring oestrogens (Fig. 4) there are a large number of synthetic analogues which, though bearing no chemical resemblance to the natural hormones, exert all the same influences. One of the best known of these is stilboestrol (Fig. 5) which, in addition to being highly active, is also effective when given by mouth. This was developed by the writer and Sir Robert Robinson.

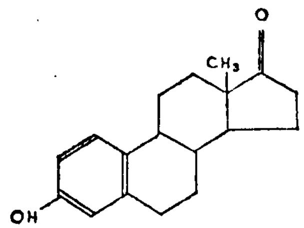


Fig. 4. Oestrone

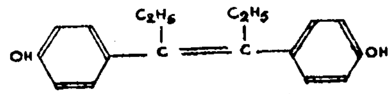


Fig. 5. Stilboestrol

Oestrogenic substances when administered produce a characteristic change in the cells of the genital canal which can be seen clearly if a smear is taken, spread on a slide and examined under the microscope. Great similarity was observed in the cell-changes caused by the onset of oestrus (or rutting), or the administration of oestrogens, and the proliferation caused by the painting of carcinogenic hydrocarbons on the skin, and this gave rise to the idea that possibly oestrogens might be able to cause cancer under certain conditions. The experiments of Lacassagne have shown this to be so. He found that the injection of large doses of oestrogen, either natural or synthetic, would increase the incidence of mammary cancer in a strain of mice already susceptible. It should be pointed out that the doses used were very much larger than any which would be given in clinical practice, and also that they exerted an effect only in animals already susceptible to cancer.

Mechanism of Cancer Production

Once having established the cancer, what is it that makes it go on being a malignant cell? We do not know. Various theories have been advanced.

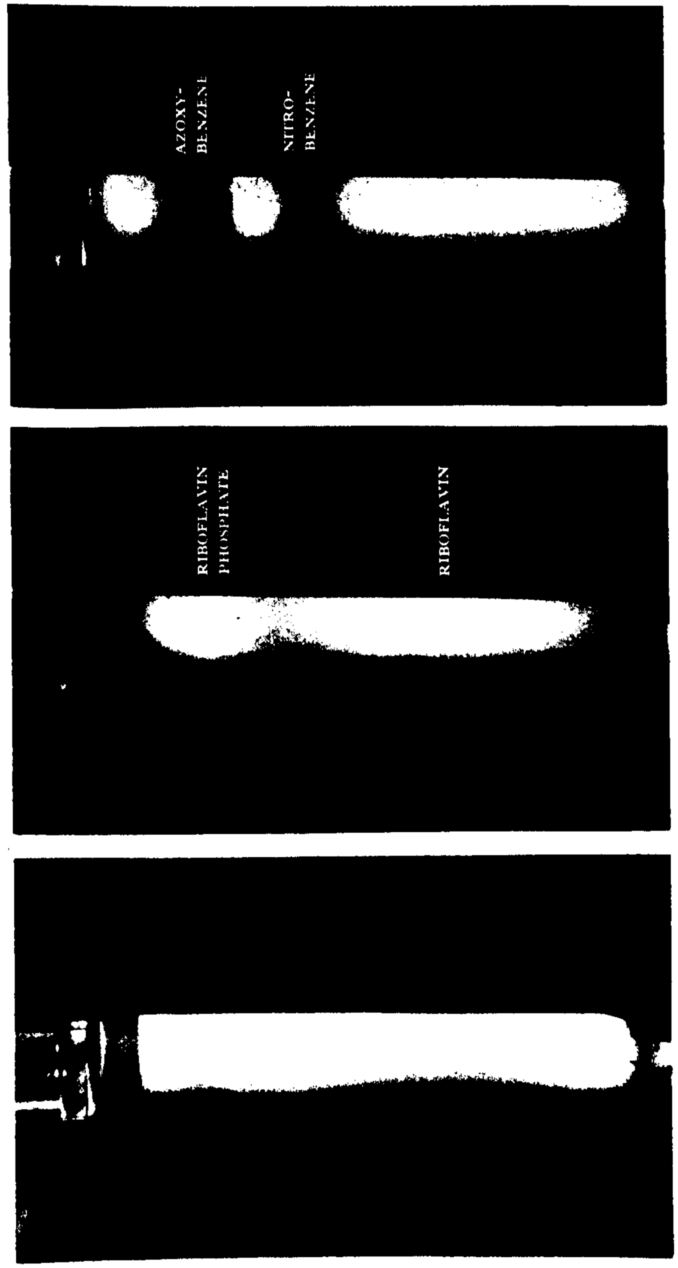
The most likely explanation is that some alteration in the metabolism of the cells takes place. Warburg was able to study the metabolism of malignant tissue by manometric methods. He advanced the theory that malignant cells have developed the ability to ferment carbohydrate under aerobic conditions, that is, they can obtain the necessary growth-energy from other sources than their respiration and this makes them independent of rich oxygen supply by the blood or tissue fluids: and that this power of aerobic glycolysis is responsible for their malignancy. However, it has since been found that other normal tissues, such as the retina of the eye and the intestinal mucosa, also have a very high power of aerobic glycolysis, yet are obviously not malignant.

It is clear that, unless we can solve this problem, any explanation of the mechanism of cancer must be mere guess-work.

There are certain tumours which depend on certain conditions of internal secretion balance. The most classical example of this is carcinoma of the prostate gland which can develop only in an androgenic atmosphere. It is possible to cut down the supply of androgens, either by castration or by the administration of oestrogens, and so partially inhibit the growth of a prostatic carcinoma. This, however, is an indirect effect on the background of the tumour.

Treatment

It must be admitted that, as we have no knowledge of the real fundamental nature of the cancer process, it stands to



4. Partition Chromatogram of Liver Extract

5. Chromatogram No. 4 under 'black light'

6. Adsorption Chromatogram under 'black light'

(See the article on 'Chromatography' by Dr. E. Lester Smith)

Plate 2

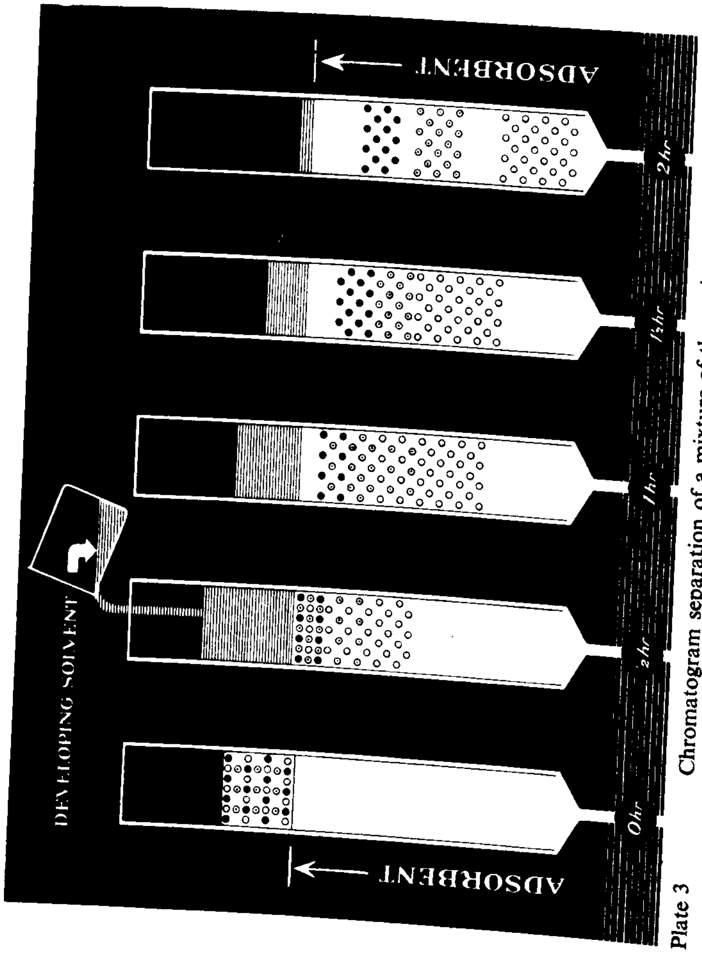


Plate 3 Chromatogram separation of a mixture of three pigments

(Plates 1-3 reprinted from the GLAXO VOLUME NO. 1)

reason that we cannot have any proper grasp of the methods of treatment. Whilst there are examples of the palliation and and even the cure of diseases being achieved before the actual cause was known, one must admit that these have been due to therapeutic good luck or centuries of trial and error. Examples can be quoted such as the use of quinine in malaria, the use of mercury in syphilis, and the use of digitalis in dropsy.

The only method of treatment open to the clinician is to eliminate the growth. This can be done by surgical removal, or the growth can be destroyed by radiation, or by the administration of some substance capable of destroying the tumour and not the host, in other words chemotherapy.

Turning to surgery in the first instance, for complete success one must have entire removal of the growth before it has started to disseminate throughout the body. The earlier the patient is operated on, the better the chances of recovery. Great work has been performed by the various anti-cancer organizations in educating the public as to the nature of the malignant process and encouraging them to visit doctors and clinics where the disease can be detected in its earliest forms. Improvements in surgical technique have resulted in the development of operations of astonishing ingenuity and it is an incontestable fact that many lives are saved by the brilliance of the surgeon. It can, however, be seen that surgery can never be a fundamental answer to the problem of cancer.

Radiotherapy can be administered in the form either of radium or of X-radiation. Radium is suitable for administration in the form of needles when the growth is superficial, such as on the lip or tongue and other accessible parts of the body. Experiments have shown that the cancer cell is more vulnerable to the radiation emanating from radium than is the normal cell and that, by skilful application in the right dosage, destruction of the growth can take place without the scarring which occurs after extensive surgical removal of superficial growths. Again, it must be obvious that the treatment with radium is useless if dissemination of the growth has occurred.

Finally the radiation can be applied in the form of X-rays produced from an X-ray tube. It is of course not possible in this brief article to explain the nature of X-rays, but these rays have the property of penetrating tissues and various types of radiation can be produced by altering the voltage applied to the tubes. To-day up to two million volts are employed to generate X-rays for therapeutic purposes. This subject is a science in itself, and is certainly one of the greatest consumers of time and money in the whole of the cancer problem. It is not possible at the present time to give a true assessment of the position of X-radiation in the treatment of malignant disease. Some experienced observers maintain that this is just a modified form of surgery and that it can do no more than surgical removal. Others, on the other hand, maintain that the high-voltage X-rays have a specific effect on tumours and that if even greater voltages can be applied some fundamental new observations may be made on the treatment of cancer. The general consensus of opinion is that, once dissemination has started, the victim can have palliation, but seldom cure.

As far as chemotherapy is concerned, there have been some developments recently, but it is too early to say whether there is any prospect of success.

We have already mentioned the treatment of carcinoma of the prostate gland with oestrogens. This treatment is due primarily to the work of Huggins. It is now well-established, and it is safe to say that in the majority of cases relief is obtained in a short time. The treatment is in no sense a cure, since, even in the cases which respond and do not later relapse, it is necessary to continue the administration of oestrogens. There is no question here of damaging the malignant cells, but simply of starving them of the androgens on which they depend for their growth. If oestrogen administration is stopped then the testis resumes its function and begins to secrete androgens again and the

tumour starts to grow. As we have indicated, in certain cases the effect of oestrogen administration appears to wear off and despite heavy dosage the tumour and secondary deposits start to grow again. Whilst there is no certain explanation of this phenomenon, it is fairly safe to assume that it is due to the production of androgens by organs other than the testis. It is well known, for example, that the supra-renal cortex can produce androgens, and it may be that this occurs in those cases which escape from the oestrogen control.

The principles of chemotherapy can be said to have originated in the classic researches of Ehrlich who, in popular language, conceived the idea of the 'silver bullet'. After Pasteur and his followers had established conclusively that the majority of diseases were due to the invasion of the victim by bacteria, Ehrlich was the first to conceive the idea of producing a chemical substance which would 'shoot' the bacteria but leave the tissues of the host unaffected. He was led to this conception by his observations on the staining reactions of bacteria. The early bacteriologists had shown that certain dyes had specific affinities for micro-organisms and Ehrlich conceived the idea of attaching to this specificity a toxic chemical substance, the idea being that, when administered to the body, the dye would fasten on to the invading organisms and the toxic chemical would be brought into intimate contact with the organisms and poison them. The first great success in this field was the discovery of salvarsan, which still remains the standard method of treatment of syphilis. This substance, relatively non-toxic to the host, becomes attached to the spirochaetes, the cause of syphilis, and kills them. Since the days of Ehrlich we have seen very nearly 40 years of progress in this field. The sulphonamides and the anti-malarial drugs are brilliant examples of success in this branch of investigation.

It is only natural that attempts should have been made to apply the same general principles to the treatment of cancer. It is obvious from what has already been said that the would-be chemotherapist is on very uncertain grounds, since he does not know the nature of the process he is attempting to reverse. The only knowledge he has got is that the cancer cell grows in an unrestrained and disorganised manner as compared to the normal cell. Apart from that, they appear to be exactly similar. It is a common biological experience that rapidly-growing cells are more sensitive to toxic agents than cells of normal established tissues, and the only hope of the chemotherapist is to find some substance which will be more toxic to these rapidly proliferating cells than it will be to the normal cells. This has led to the introduction of a number of chemical substances known as cytotoxic agents. Three groups have emerged and are the subject of active experimentation.

The first group of substances to be tried in the treatment of cancer were the so-called nitrogen mustards. These compounds were evolved as a result of researches on the actions of mustard gas conducted during the war of 1939 to 1945. In the course of this work it was discovered that mustard gas and compounds allied to it can cause mutations of the genes in the Drosophila fly, i.e., can change the working of inheritance in the fly without killing it or otherwise harming it. This indicated that the gas had some very specific action on cells, and an attempt was made to evolve compounds which might exert a poisoning action on human malignant cells without the blistering and other poisonous effects of mustard gas. By introducing certain alterations into the molecule, it was possible to produce the so-called β-chloro-ethyl amines or nitrogen mustards (Fig. 6). These have been used to treat certain types of cancer. They have been found to bring about improvement in a fair proportion of cases treated, but this improvement as a rule is only temporary. Although nothing like so poisonous as mustard gas, they are still dangerous drugs and have to be used with great care.

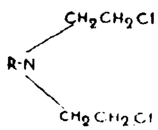


Fig. 6. – Nitrogen mustards.

Another substance which has been chosen for trial is urethane ($NH_2CO.OC_2H_5$). This substance was first used as an anaesthetic for laboratory animals and during the course of some experiments it appeared to exert some specific effect on experimental tumours in these animals. Trials were therefore made on a number of cases of cancer in human beings. The story is very much the same as that of the nitrogen mustards: temporary improvement only.

The story of the researches leading to the third group of substances, the so-called anti-folic-acid compounds, begins rather differently. It really starts with the attempts to isolate and identify the various members of the group of vitamins known as the Vitamin B complex, and the attempts to isolate and identify the active principle present in liver which cures pernicious anaemia. Papers began to appear in the literature in about 1940 in which workers in various laboratories described a substance or substances found to be essential for the growth of certain bacteria. In 1945 Du Vigneaud and his colleagues worked out the chemical constitution of the substance now called folic acid (Fig. 7).

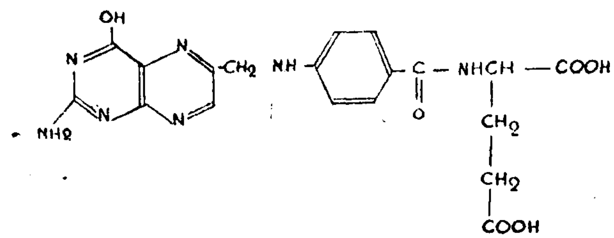


Fig. 7. – Folic acid.

This is the compound essential for the growth of certain bacteria and apparently also for the proper development of blood cells, since it can be used to treat certain types of anaemia. A large number of synthetic variants of this complex molecule have been made. Some of these have actions similar to those of folic acid itself. Others, however, have been found to be antagonistic to folic acid. Now, as folic acid apparently plays some essential part in the development of cells, it is logical to suppose that a substance antagonistic to folic acid would be able to retard such a development, and would be most antagonistic to the rapidly proliferating malignant cells. Several of these so-called anti-folic-acid substances have been the subject of special investigation for their possible anti-cancer effects, and two of them, aminopterin and a-methopterin (Fig. 8), have been used to treat patients. The only publications available

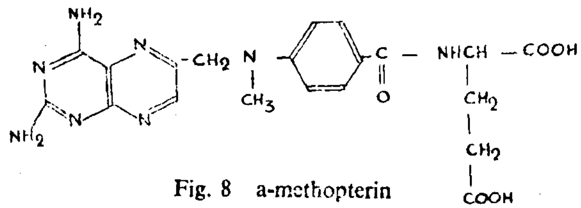


Fig. 8 a-methopterin

on the use of these substances are American, and they all stress the great caution that should be exercised both in the use of these compounds and in the interpretation of their action. They are very toxic indeed and any possible curative dose is so near the toxic dose that their administration is always fraught with considerable risk. Remissions in various types of malignant disease have been described, but it is again too early to say how permanent these changes will be. Experiments are also being conducted in Britain, but it will be some considerable time before an evaluation can be arrived at.

To conclude, it will probably appear to the lay reader that the situation borders on the hopeless and that, after fifty years of modern cancer research, it is unfortunate that so little progress has been made. It must be pointed out that advances in pathology and therapeutics cannot be forecast on a time basis, that is to say, in order to know twice as much as we know at the present time, it may not necessarily take another fifty years of intensive work. A discovery in some allied field may alter the whole nature of the problem. This should influence very considerably those responsible

ɔr the distribution of funds for cancer research. The onsiderable sums available are diverted into the various hannels, such as radiological investigations, surgical ıvestigations, and so forth. From the purely research point f view the question arises as to whether the funds are better pent by establishing research institutions or by supporting xisting sciences such as pathology, biochemistry, physio- ɔgy and so forth. There can be no doubt that both forms f research fill an important place, but it is essential for the ıyman to realize that the broader the basis upon which the esearch is conducted, the more likely is the successful outcome. 'o many non-technical people, a great deal of the work that ; done under the aegis of cancer research funds would ap- ear to have nothing to do with the subject, but it must be emembered that, if one is in an entirely unknown field, any orm of knowledge may turn out to be of vital importance.

It will be permissible perhaps to conclude with an nalogy. A hundred years ago one of the greatest menaces to fe was suppuration. Anaesthetics had recently been intro- luced and surgical technique was at a very high level, yet mportant parts of the body prone to go wrong were bsolutely forbidden ground for the surgeon. Thus, a per- orated gastric ulcer, or any abdominal catastrophe, was ntouchable by surgery, because no matter how dextrously he operation was performed, peritonitis supervened and he patient invariably died. The same applied to the chest nd of course to the head. Nor was this problem of pus ormation confined to these areas, but superficial operations vere almost invariably attended with prolonged suppura- ion, in fact pus was regarded as normal and under certain ircumstances was referred to as 'laudable'.

One can well imagine a group of philanthropic people anding together to form an organization to investigate this atal malady. Having collected the money, they would be aced with how to proceed to spend it. One way would be to orm institutions to study suppuration and these would orrespond to the purely cancer research institutes. Here one can imagine the workers collecting purulent discharges, analysing, investigating them microscopically and so forth. We know to-day that they could have gone on doing this until the present time without getting any nearer to the solution. Before the mystery of suppuration could be solved, Pasteur had to found the science of bacteriology. This came about primarily through his study of fermentation processes and his deep interest in crystallography. Having established the microbial origin of disease, we then had to have Lister with his development of antiseptic surgery, and from that era we proceed to the modern one of aseptic surgery.

We can see, therefore, that our hypothetical benefactors of the suppuration campaign would have done very good service to their cause by distributing their money to the basic sciences, even those as far removed from the practical problem as crystallography.

Another example that can be quoted is the difficulty of rearing cattle in certain parts of Australia. Here again, examination of the cattle from every point of view failed to demonstrate the nature of the trouble. It was eventually solved by a spectrographic examination of the mineral content of the pastureland soil. This was shown to be deficient in cobalt and the spraying of the ground with minute quantities of this element has made it possible to rear herds of cattle on lands which were hitherto valueless.

We should take this lesson to heart and realise that everyone who is working in the biological sciences is a potential cancer research worker and may actually be paving the way to the knowledge that will discover a cure of this disease.

Note. – It is not proposed to give a detailed list of references. The following general works will give the reader an introduction to the literature, should he require it:

The Riddle of Cancer, C. Oberling. Translated by W. H. Woglom. Yale University Press, New Haven, 1944.

The Biochemistry of Cancer, J. P. Greenstein. Academic Press, New York, 1947

The Sources of Solar Radiation

JACOB KASWAN

THE problem of the origin of the sun's constant energy emission, and whether it will in the future ever exhaust its prodigious stores of heat and light and then cool down and expire, has excited an interest in thinking men since ancient times. Nor is this surprising since no life could exist on earth without the sun, and all evolution is completely dependent on its continued shining. The oldest and most obvious answer is that the sun is a gigantic fire, getting its energy by combustion, just like a furnace or a burning pile of wood. However, computations show that even if the sun consisted throughout of best coal, the heat and light generated by its combustion would amount to only 1/500,000 or 1 millionth part of the energy actually emitted. Moreover, its entire radiant life with coal as its fuel could not exceed 5,000-6,000 years. It is therefore abundantly clear that the sun derives its power neither by combustion, nor by any other similar chemical reaction, since any rearrangement of atoms into new molecules can involve only small energy changes.

In the last century Helmholtz and Lord Kelvin suggested that the slow and gradual contraction of the solar sphere under the influence of gravitation might account for the energy output. Though doubtless this process may play some part as a source of energy, particularly, as we believe to-day, in the early and the final stages of the sun's evolution, taken alone it is utterly inadequate to account for sunshine throughout the geological past of 2 milliard* years, which scientists now regard as the age of the earth. During at least half of this immense time-span the radiation of the sun,

*1 milliard = 1000 million

apart from minor fluctuations, was much the same as it is to-day, as the record of the fossils seems to indicate, so that its surface temperature cannot have decreased appreciably since then. Yet calculations show that gravitational contraction could supply only 1/1,000 part of the energy actually expended by the sun, if it had to contract from a globe of almost infinite size down to its present radius; and furthermore, that this process could not have lasted longer than 45-50 million years. At this rate of contraction, corresponding to an annual decrease of the sun's radius by about 35 metres, it would halve its present radius in about 10 million years, and shrink to a ball the size of the earth about 19½ million years hence. As these figures are obviously not in agreement with our present geological and astrophysical evidence, contraction as the sole or main source of the sun's power appears to be highly improbable.

Another hypothesis held that the sun replaces its energy as it goes along, chiefly by the fall of meteors upon its surface and the accretion of interstellar matter in the form of dust particles, and atoms of certain elements like sodium, calcium and hydrogen, known to be present in space. As it has roughly to maintain a balance between income and expenditure thereby, this accretion would have to be of about the same order as its loss of matter by radiation, which amounts to 4.2 million tons per second. But no proof exists that anything like this amount of matter falls continuously into the sun. On the contrary, what we know of the extremely tenuous density of interstellar matter, which is in the average 10^{-24} gm per cubic centimetre, makes such a view very unlikely. Moreover, recent studies indicate that small dust particles and gaseous matter would be pushed away from the sun by radiation-pressure, rather than be pulled in by its gravitational attraction.

As the three theories so far discussed are all unsatisfactory, we must look for some other, more efficient source of solar radiation. It was not until the turn of the century and the discovery of radio-activity that the fundamental importance of atomic processes for this problem was recognized, and the prospect of solving it noticeably improved. Historically speaking, three different views have successively prevailed in the past 50 years, all regarding the liberation of atomic energy in the deep interior of the sun as responsible for its shining, and for its long life-span.

The first and most obvious assumption was that the sun contained a great quantity of radio-active elements. This theory, however, soon met with serious difficulties. Even entirely composed of uranium, which with 4½ milliard years has a sufficiently long half-life period to equal its supposed task, the sun would generate only one third of the energy actually emitted. As it is on earth the most frequent of all radioactive elements (though all of them are very rare and hard to come by), it is somewhat surprising that its spectral lines have so far not been detected in the solar spectrum. But this does not necessarily mean that radioactive elements are entirely absent from the sun. They may be found in considerable quantities in the interior, below the photosphere whence no light reaches us, as they are heavy elements, or else, under the extreme physical conditions obtaining in the sun, their lines may be modified or masked, so that they are not as yet identified, as was the case with the mysterious nebulium lines, later recognised to be due to oxygen. Yet even if a greater abundance of radioactive elements at the time of the formation of the sun is admitted, they would now, just as on the earth, have become so scarce by their spontaneous decay and conversion into lead that the sun's brightness should be much less than it actually is. Moreover, the assumption of a sun heavily stocked with radioactive matter would lead to quite another mass-luminosity law, contradicting the observational evidence on which the generally accepted one from Eddington is based, so it is manifest that radioactive elements play no, or only a small incidental, rôle in the sun's energy generation. For it can be shown that their combined actual amount in the sun is less than 1/10,000 part of its total mass, so that they can supply only a similarly small fraction of the energy in fact expended.

Turning now to the second view, which enjoyed a wide popularity between the two world wars, owing mainly to the famous work of Eddington and Jeans, it is suggested that the sun shines by constantly annihilating matter of every kind, and transforming it into energy. There is no doubt that this is the most fundamental and powerful energy-generating process imaginable, and that it would amply provide the stupendous quantities spent by the sun over billions of years. But so far there is only a small likelihood of this process actually happening in the sun, or for that matter anywhere else in the universe, except perhaps when a Nova or Super-Nova flares up. In these huge stellar explosions the origin of cosmic radiation is now sought, because its high penetrating power and great intensity might well be brought about by just such a large-scale annihilation of matter.

To find out how much energy this complete atomic disintegration process could supply, we recall that 1 gram of any matter, according to Einstein's well-known formula $E = M.c^2$, would yield 9.10^{20} erg when all its 10^{23}-10^{24} atoms are entirely annihilated. As the total mass of the sun amounts to 2×10^{33} gm., this means that it can expend 1.8×10^{54} erg before it has radiated away all its mass, or is reduced to a small dark globe of planetary dimensions. Of this store, however, the sun has already used up in the last 2 milliard years 2.4×10^{50} erg, by annihilating 2.65×10^{29} gm., that is 1/7500 part of its total mass. For to keep shining on at the present rate, the sun has to turn 4.2 million tons of matter into energy every second, corresponding to an annual loss of 134 billion tons. Yet so massive is the sun that even at this tremendous rate it would lose only 1/1,000 part of its mass in 15 milliard years, so that its brightness cannot have appreciably diminished during the 2 milliard years or so usually regarded as the age of the earth. The sun's immense total life-span would

therefore cover, according to this so-called 'long-time scale', about 15 billion years, and evolutionary courses of a similar duration must then be assigned also to most of the fixed stars.

If this were true, then the stars might well be regarded in human terms as eternal. However, the adoption of this long-time scale led to serious difficulties in astro-physics. For such ages for the sun and stars seem not compatible with our modern ideas about such problems as the expansion of the universe, the rotation of the galaxies, the structure of matter and the radiation balance of the stars. It has, therefore, been nearly abandoned to-day in favour of the 'short-time scale' – which works well by postulating only some 10-12 milliards of years for stellar evolution; and at the same time the theory that the sun generates its energy by the wholesale annihilation of matter has been entirely given up.

After having rejected so far both radioactivity and complete annihilation of matter as sources of solar radiation, on the grounds that the former produces less and the latter more energy than is actually the case, there exists still a third possibility – atomic disintegration, or building up – where elements are changed into one another while some small fraction of their mass is converted into energy. As it appears that the sun does in fact shine by employing such a process, we shall first briefly consider its general atomic physical background.

Thirty years ago Rutherford smashed the nitrogen nucleus with alpha particles, thereby getting protons and oxygen atoms, and since then scientists have increasingly engaged with the help of highly ingenious apparatus like the electrostatic generator, cyclotron, and betatron, in this kind of atomic disintegration, which has virtually realized the old dream of the alchemists and is therefore appropriately called the transmutation of the elements. By bombardment with protons, deuterons, neutrons or alpha particles, all nuclear building material themselves, atomic nuclei can be fragmented, split, or built up to form new nuclei, and thus elements can be transformed into one another merely by the intrusion or ejection of nuclear particles. The radioactive elements provide an example of such transmutations taking place spontaneously in nature, and many other elements have been successfully induced to exhibit a similar phenomenon, termed artificial radioactivity.

The atomic energy liberated in all these processes is small, but in 1939 Hahn and Meitner found that at the fission of the uranium nucleus into about two equal parts, which were later identified as krypton and barium nuclei, a quite considerable amount of energy was released suddenly. It was the following up of this clue during the war by Allied scientists which ultimately led to the invention of the atomic bomb in 1945, and thus to the first large-scale utilization of atomic power by man, though characteristically for destructive purposes only.

In comparison with complete annihilation of matter, the transmutation of elements is a less fundamental process and yields on the average only 1/100-1/10,000 part of the energy liberated by the former, because only a small fraction of the mass of the atoms involved is converted directly into energy, while the remainder of each atom is transformed into another element. Calculations showed, however, that just such a rate of conversion would fit exceedingly well with the actual energy generation of the sun. The problem was to find the specific nuclear reaction, the energy production of which would just tally with the observed energy output and luminosity at the estimated central temperature of 20 million degrees C. and a pressure of 10 milliard atmospheres.

It is to the great credit of Dr Bethe, an American astrophysicist, that he solved this problem satisfactorily in 1938, and thus revealed to us the real source of solar radiation. Essentially the reaction consists in the transmutation of hydrogen into helium in the solar interior (hydrogen-helium synthesis), not in a single process, but through a whole series of six linked phases forming a closed circle, or

a so-called cyclic and repetitive chain-reaction. If we liken the sun to a blast furnace, then we can say roughly that hydrogen represents the fuel and helium the ashes of the 'atomic combustion' taking place therein. Its net effect is, that four protons, each of an atomic weight of 1.00813, combine to build up a helium nucleus or alpha particle of 4.00386 atomic weight. But, as protons cannot meet directly on account of their equal positive charges which repel one another (among other reasons), the whole cyclic reaction of six phases has to unroll before combination is achieved.

It will be noted that the weight of the helium nucleus is 0.02866 or 1/141 part less than that of the four protons put together. This apparent loss of mass represents just the fraction which is turned into energy in this process. Though it may seem a small one at first glance it is in fact quite sufficient to account for the sun's steady radiation since the earth's formation about 2 milliard years ago, and to keep it shining for a further span of 10 milliard years or so. For, as was already emphasized, even small amounts of matter supply stupendous quantities of energy if wholly annihilated in accordance with Einstein's formula, and as on the sun not just a few atoms are destroyed, but the quite considerable mass of 4.2 million tons of hydrogen every second, this means that when 592.2 million tons of hydrogen are converted into 588 million tons of helium, the 7.1×10^{30} protons annihilated thereby yield an energy amount of 3.8×10^{23} kilowatts (380 trilliards) electricity per second.

As the total hydrogen content of the sun is estimated to amount to one-third of its mass it could continue shining at the above rate of conversion (5.92×10^{14} gm hydrogen per sec.) for a further 33-35 milliard years. The same life expectation is arrived at when its lifespan of 15 billion years, computed according to the long-time scale, is divided by the quotients of 141 (actual fraction of matter annihilated in the hydrogen-helium synthesis) and 3 (proportion of hydrogen to total mass). However, this life expectation must again be shortened by two-thirds to about 10-11 milliard years, which is now considered as the most probable old age attainable by the sun before it cools down and expires. For it can be shown that the increasing opacity of the solar interior through mounting accumulation of the denser and less transparent helium 'ashes' necessitates a corresponding rise of the central temperature and so of the rate of energy generation. This will of course result in the hydrogen available for conversion being used up much faster than would be otherwise the case.

One consequence of this will be that the sun will gradually wax hotter and brighter in the future, for its surface radiation will increase in accordance with its rising internal energy production. It is clear that the ensuing slow rise of terrestrial temperatures will have the most far-reaching repercussions on man and the whole world and will seriously affect the whole course of evolution, not only on this planet but wherever else within the solar system life of some kind or another has evolved. According to Professor Gamow's investigations the sun's radiation will have increased a hundredfold by the time its store of hydrogen is nearly depleted, about 10 milliard years hence. After it has thus reached a brilliant climax of feverish activity in its long drawn-out career, it will, when its hydrogen is completely gone, collapse rather rapidly to the White-Dwarf state, to linger on the small amount of energy supplied henceforth by gravitational contraction until finally darkness overtakes it for ever, in a further few hundred million years.

The collapse of the sun's body signifies not only a very marked decrease of its luminosity, accompanied by a shrinking of its radius to planetary dimensions, but means also quite literally that nearly all its matter will be in the so-called collapsed, or nuclear, or crushed state, with an average super-density more than 50,000 times that of water, which is a common feature of all White Dwarf stars. But no human eyes nor those of any other organisms will be present on our earth to watch the last stages of the dying sun. Neither need we fear that our race will be doomed

to freeze to death through the sun's cooling down, as was generally believed in the last century. For long before, through a slowly hotter and more luminous sun, all life will have gradually vanished from the earth, after its adaptative faculties have at last failed to cope with the ever-rising surface temperature. We may expect that in these long aeons of time still open to evolution, the human mind will attain its very summit of achievement and grandeur, and mankind may be able to emigrate to another star-system before the sun, a hundred times more radiant, shines down on a lifeless and scorched world, where all the oceans have boiled in the increasing heat and long since have evaporated.

Having briefly discussed how, according to Bethe's theory, the further life-course of the sun will run and what its most probable end will be in the remote future, we have now to describe more closely the special energy-generating mechanism operating in the solar interior, as suggested by that theory. It was already pointed out above that the hydrogen-helium synthesis is performed in a cyclical nuclear reaction consisting of six linked phases. In the transmutation participate, besides protons, electrons, positrons and alpha particles, the nuclei of oxygen, carbon, and nitrogen, with the latter two elements playing the rôle of chemical catalysts. Assuming that 33 per cent of the sun's mass consists of hydrogen, while carbon and nitrogen amount to 1 per cent each, figures which are well supported by spectroscopic evidence, Bethe was able to show that only one particular nuclear reaction cycle would liberate the quantity of energy exactly agreeing with the measured energy output of our sun. Its six phases may be summarized as follows:

(1) $C^{12} + H^{1} \longrightarrow N^{13}$ + Gamma rays radiated.
(2) $N^{13} \longrightarrow C^{13}$ + Positive electrons (positrons) emitted.
(3) $C^{13} + H^{1} \longrightarrow N^{14}$ + Gamma rays radiated.
(4) $N^{14} + H^{1} \longrightarrow O^{15}$ + Gamma rays radiated.

(5) $O^{15} \longrightarrow N^{15}$ + *Positive electrons emitted.*
(6) $N^{15} + H^{1} \longrightarrow C^{12} + He^{4}$ (Helium nucleus or alpha particle).

We see that, as was stressed above, the alpha particle is not formed directly but built up by the successive entry of four protons into the reaction. The emission of beta (+) particles (electrons of the positive type or positrons) and of the highly intense gamma radiation at the formation and subsequent disintegration of the unstable nitrogen, carbon and oxygen isotopes is of course due mainly to their radioactivity, while the total amount of energy actually released in the reaction is a function of and dependent on the enormous pressure and temperature in the solar centre. The cyclic character of the chain is exhibited by the reappearance of carbon and nitrogen at the end of the reaction, so that these elements are always automatically re-created in the sun's interior without ever being used up in the process, which is just the distinguishing feature of all chemical catalysts.

It should be noted that the duration of the complete cycle is about 5-6 million years, at the end of which period the C and N atoms re-emerge, as complete and unaltered as when they started, and ready to enter all over again into a new reaction. This is particularly true of the carbon nucleus, which at the end of each cycle is reconstituted in its original form as C^{12}. This fact is not only of the most profound significance for all life on earth, but represents also one of the most startling examples of the marvellous wisdom and purposeful beauty inherent in the design of the universe. Like the legendary phoenix, rising alive from its ashes after it has burned to death, all the carbon atoms, apparently transmuted into other elements reappear afresh as if by magic at the close of each cycle, to be utilized again and again as long as the hydrogen lasts. It should be well understood that, though an individual cycle may require 5–6 million years to unroll completely, the reaction is in fact going on continuously and ceaselessly in the solar interior, so that energy is produced in a steady flow all the time.

There is after all some sense in the ancient theory discussed at the beginning of this article that the sun's heat originates from burning coal. Only to-day we know that carbon, instead of being just a fuel as was at first erroneously assumed, plays a much more important part. By acting as a catalyst, together with nitrogen, it supplies the fundamental impulse which keeps the hydrogen-helium synthesis going, and so is after all truly responsible for the sun's shining. Yet its comparison with the symbol of the phoenix has a further, still more profound meaning. We know that all life on earth is carbon life, in the sense that the carbon atom plays the key rôle in the chemical composition of all organisms, and now we see that the very existence of all this terrestrial carbon life is entirely dependent on the proper functioning of the solar carbon atoms in the sun's energy-generating mechanism.

We have now to examine how the energy produced in the central regions of the sun can be transported to the surface for subsequent discharge into surrounding space. There are two different processes imaginable: the one operating normally, the other only in emergency cases as a kind of safety valve when too much energy is produced, which may dangerously upset the radiation equilibrium of the sun.

To understand the normal one, we assume that the central core of the sun consists of matter in the crushed or nuclear state, i.e., is composed of coalesced protons, helium nuclei, neutrons, positrons and electrons forming a nearly continuous substance of nuclear gas, where under the enormous pressure of the overlying layers the ordinary inter-atomic distances and interstices have been almost completely squeezed out. Such matter must be extremely dense and heavy, and one cubic centimetre of it would weigh several tons. As it is so highly compressed, it has naturally a tendency to expand again, not unlike a spring, can do but so only when it moves upward to regions of lesser pressure. Some small parts will therefore constantly detach themselves from the core, forming so-called nuclear clouds, and, when floating up to the surface, carry away with them the excess energy generated. This would result in a temporary cooling of the central regions, while the relatively colder matter sinking down from higher levels to replace the nuclear clouds which have gone would in turn be heated and compressed until they started on the same journey.

There seems to be a definite link with the sunspot cycle of 11 years, in that it coincides with a very distinct peak or maximum of these nuclear cloud migrations, though of course they will be welling up more or less regularly and continuously throughout this time interval. When approaching the cooler surface layers, the bare nuclei would acquire electrons, thus greatly expanding and so becoming normal atoms again. This will bring about a tremendous expansion pressure of the cloud, similar to a spring suddenly relieved of a compressing weight, causing it to burst through the photosphere like a gigantic geyser or volcano, thereby producing sunspots, prominences or solar flares, all or any of them according to circumstances. Sunspots may, therefore, be similar to safety-valves through which the superheated steam of a high pressure boiler can be let off, the prominent though not the only outlets for the discharge and harmless dissipation of the highly-charged nuclear matter and energy generated in the solar interior.

A second way for the sun to get rid of its internal surplus energy would be to cool off all over simply by the expansion of its whole volume. This is a kind of safety-valve device which would operate quite automatically. Suppose that too much energy is produced, which cannot flow out fast enough, then the central matter becomes overheated and its temperature rises. Simultaneously the internal nuclear gas pressure will then start to mount, and by its powerful impact force the outer layers to give way and to expand. This will at once reduce the excessive internal temperature,

and steady flow of energy will again ensue. The whole process is in fact a very ingenious regulative mechanism. For, when the generation of nuclear energy in the interior drops lower and lower, expansion of the sun's body will not continue indefinitely, because, from a certain limit on, gravitational contraction will come into play again, cause an immediate increase of the central temperature and so bring back energy production to its original rate.

A regular pulsation of the solar sphere could thus be started, but as actual conditions in it never get far out of balance this up and down surging is probably too small to be detected by our instruments, or it may take the form of minor adjustments through any of the numerous phenomena happening on its turbulent surface. But it is thought that the marked pulsation which some stars exhibit, notably the Variables of the delta-Cephei type, is due to some such process. Usually the radiation equilibrium and the material stability of a star is ensured by the neat counterbalancing of a set of opposing forces in its interior, viz., gravity and weight of the overlying matter on the one hand striving to compress its body, while on the other hand the internal temperature and the pressure of gas and radiation seek to accomplish its expansion. Where this remarkable equilibrium is seriously disturbed, distinct pulsations, as in the Cepheids, or even fearful explosions of the whole star, as in the case of the Novae, may be the result. Fortunately our sun belongs to neither type, and, as its steady shining since immemorial times amply proves, we need have little fear that it will begin suddenly to pulsate, or even to destroy itself and us in some huge and frightful cosmic catastrophe.

In concluding our survey of the possible sources of solar radiation we may say that the hydrogen-helium synthesis suggested by Bethe works quite satisfactorily in the case of the sun and the majority of the stars, whose luminosities fit into the main sequence of the Russell-Hertzsprung diagram. Similar processes of nuclear transmutation take place in the other classes of stars, as for example in the cool red giants and dwarfs, in the white and blue giants, and in the red and white super-giants, while the white dwarfs subsist as we already know on gravitational contraction. Such reactions are known, the deuterium, lithium, beryllium and boron reactions for instance, but none of these is cyclic and has, therefore, the remarkable self-regenerative phoenix-like character of the solar carbon cycle. Some of them produce more, others less energy than the carbon cycle of the sun, and which one in particular is at work depends on the age, the central temperature and the luminosity of the star concerned. The bigger energy-supplying reactions take place in stars with very high central temperatures, and vice versa.

During its entire course of evolution a star probably makes use in turn of all the nuclear reactions possible for its energy production. Our sun is probably not massive enough to utilize more than the hydrogen-helium reaction throughout its life. But other, bigger stars may during their long career employ several reactions, one after the other, in accordance with the slow rise and fall of their central temperature, until, when it has dropped to about one million degrees at the end of their radiant life, they too have to fall back on gravitational contraction for their energy supply.

However, in the case of these more massive stars, including the highly luminous red, white and blue giants and super-giants, considerable difficulties are encountered. For their stock of the relatively rare light elements to keep the nuclear reactions going would, even in the most abundantly supplied, be exhausted in a few hundred million years, as, unlike carbon and nitrogen, they are not regenerated, and these stars are surely older than that. On the other hand the carbon-nitrogen cycle, even if they convert hydrogen into helium at a much faster rate than the sun, could scarcely account for the prolific amounts of energy they radiate, as they are on the average 10,000-500,000 times brighter

than the sun. Moreover, if they really consume their hydrogen more rapidly than the sun, and even if it amounts to as much as 80 per cent of their total mass, their future life expectations would have to be shortened in the same proportion as their past age to a few hundred million years.

But from all that we know about their evolution, and of the constitution of the major stellar systems in which they are all so beautifully arranged, it is evident that the cosmos has been in a state very much like the present for more than two and more probably for 5 to 8 milliard years, and has a very good chance to last with most of its stars and galaxies for a further period at least twice as long as that. It would therefore seem that the very massive and luminous stars make use in their interior of some other more plentiful source of atomic power, as yet unknown to us, to keep up their stupendous radiation; while in all probability the sun and the majority of the ordinary stars get along fairly well on the carbon-nitrogen cycle, as suggested by Bethe's theory.

Ancient Peoples of the Andes

G. H. S. BUSHNELL

I. Introduction

WHEN the Spaniards reached America at the end of the 15th century they found a new world indeed, inhabited by peoples with a civilization which differed in many respects from their own. The highest expression of it which they met at first was the Aztec kingdom – with its capital where Mexico City now stands – which had absorbed a number of neighbouring states and made vassals of others, so that it was in a fair way to becoming an empire. It was not until several years later, about 1511, that, having reached Panama, they heard rumours of a land far away to the south where gold was as cheap as iron was with them. This land, the Empire of the Incas, had so little contact with Mexico that the material products of one seldom if ever reached the other, yet their civilizations shared many features which separated them from the Old World, and both may justly be described as characteristically American.

Shortly before the Spanish conquistador Pizarro landed at Tumbez in Peru in 1527 the Inca Empire reached its greatest extent, from the north of what is now Ecuador southwards to the Rio Maule in Central Chile; and it has been deduced from Spanish chronicles, written shortly after the conquest, that the Empire grew from small beginnings, round Cuzco in Peru, to its full extent in less than a century.

Before this mushroom growth began, the area was occupied by a large number of independent tribes, and, within the confines of modern Peru, by some considerable states. The archæological record shows that the cultures of these tribes and states were preceded by a complex

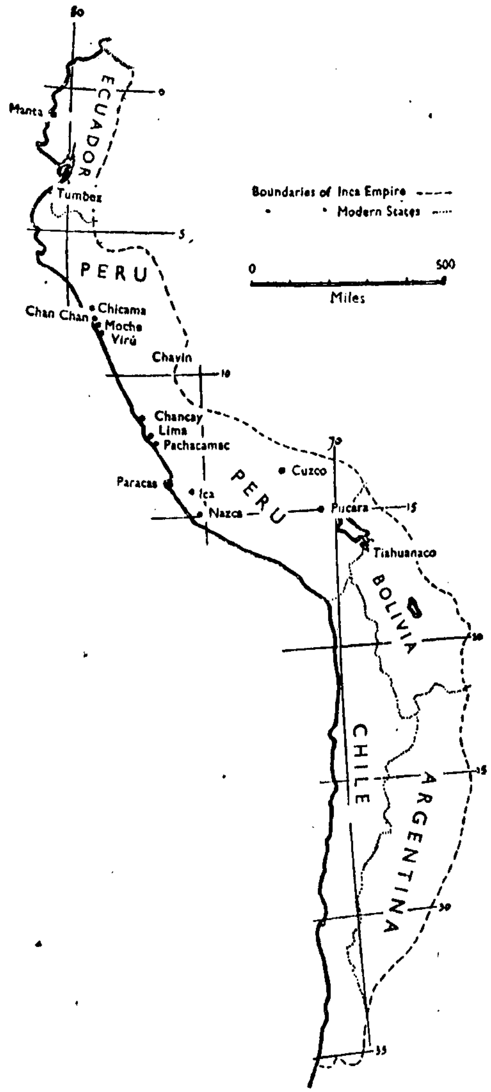


Fig. 9.

They supplemented their diet in the appropriate areas by hunting and fishing. Game was generally rounded up in great communal hunts (Fig. 11), imprisoned in netted enclosures and killed by means of clubs or spears thrown

Fig. 11. – Hunting scene from a Mochica pot. (From T. A. Joyce, *South American Archaeology*. Courtesy of the Medici Society Ltd.)

from spear-throwers. Slings were also largely used. Fish were caught by means of hooks or nets.

The Peruvians were skilled weavers and potters; using primitive looms and lacking the potter's wheel, they made fabrics of unsurpassed quality, and a great variety of fine pottery. The only beast of burden, the llama, and its relations the alpaca, the guanaco and the vicuña, are high-land dwellers which cannot live long in the coast, but the wool of these creatures is found in coastal textiles, proving that there was trade between the two areas from early times.

II. Early Man in America

No remains of Palaeolithic man have been found in America, and it is generally believed that men first came into the New World at a time when the last Pleistocene ice sheet had retreated enough to leave a way clear from north-east Asia across the Behring Straits and southwards east of the Rockies. The date of this first migration cannot be fixed, but geological evidence suggests that it was between 10,000 and 40,000 years ago. It is at any rate certain that the first men in America were hunters with no permanent dwellings, who lacked all the features which we associate with civilization. They did not know agriculture, pottery, weaving, or the working of metals. We have no reason to believe that they collected wild plants or berries systematically for food; and their stone implements were flaked, either by percussion or by pressure, but not ground.

The remains on which these remarks are based have been found in the United States, but it is necessary to mention them as an introduction to what happened in the Andean region. It is most probable that the first wandering bands of men to reach South America were at a similar stage of development, and workshop sites, with pressure-flaked stone implements, which have recently been found on the surface in the neighbourhood of Trujillo in the north part of the Peruvian coast may possibly belong to this stage. If they do, we have been lucky to find them, since South America must have been populated very sparsely, if at all, at that time.

In the United States the Folsom Culture, in which pressure flaking first occurs, is believed to be 10,000 to 15,000 years old, approximating to the lower of the two limits already mentioned, and this trait may be expected to have reached Peru considerably later. Some confirmation of this is afforded by the excavations carried out by Mr Junius Bird in Patagonia, where the earliest levels contain pressure-flaked points. By methods admittedly fallible, based on rates of rise of land and of accumulation of cave deposits, he estimates their antiquity at 5,000 years. It may therefore be surmised that the earliest man reached Peru some time between 5,000 and 10,000 years ago.

III. Dating

The approximate nature of these dates raises the whole question of dating in American archaeology. In parts of the United States, study of the rings produced by seasonal growth in trees has enabled archaeological remains to be dated exactly, when they contain beams to which the method can be applied. In this way a time scale going back to about A.D. 200 has been established.

In Central America the Maya Calender is very useful, but there remains some uncertainty about its correlation with our own calendar. The most recent calculations, which are probably correct, indicate that the earliest surviving date on a Maya inscription is A.D. 328.

Neither method is applicable in South America, where Maya inscriptions do not exist and suitable wood for tree-ring studies has not been found in archaeological deposits. We know that the Spaniards landed in Peru in 1527. Using the genealogies of the Inca kings preserved by the early post-conquest chroniclers, we can go back with reasonable certainty to the early part of the 15th century, and with some probability to the 12th. All other dates are more or less intelligent guesses based on the probable rate of development of the various cultures, and in the earlier stages on the physiographical factors already mentioned, which can at best give only very approximate results. It is fair to add that the independent guesses of several archaeologists have led to very similar results, so the dates are probably of the right order of magnitude.

IV. The First Farmers in Peru

The next stage of which anything is known in Peru, indeed anywhere in South America, is found in the neighbourhood of the Viru and Chicama Valleys on the north part of the coast. Here Mr Bird has recently found midden deposits up to 12 metres thick, containing material left by a people who may be called the Early Farmers, a very great step forward from the primitive, wandering hunters. Owing to the dryness of the climate all kinds of perishable objects have been preserved, so we have a rather full picture of their material remains. Much of their livelihood was derived from fishing, the capture of sea-lions, porpoises and birds, and the collection of shell-fish, but they also cultivated cotton, squash, peppers and several varieties of bean, besides collecting certain wild plants and fruits. It is probable that agriculture was made possible by irrigation, but at this early stage it is unlikely to have been very extensive.

They twined baskets, and made fishing nets with which they used gourd floats and perforated stone sinkers. They made cotton textiles by twining and to a less extent by weaving, the earliest record of a craft in which their successors excelled.

In the later stages, at any rate, they lived in subterranean houses lined with cobble stones or mud bricks. There were no hearths, and cooking was done, probably in baskets, by means of pot-boilers. Apart from some toy slings, no weapons have been found. No trace has been found either of that most indestructible material, pottery, so there is no doubt that it was unknown. Another most important absentee was maize, which affords evidence, contrary to common belief, that a complex early culture could grow up in America without it.

The stone implements prompt another interesting observation; these are of the crudest possible description, and, if their ancestors had ever known pressure flaking, these people had forgotten it. If the perishable substances they used had disappeared, as they have from many Stone Age cultures, their stone implements alone would have given us a totally false idea of their economy.

In one of these middens plain pottery appears in the upper part. It may have been invented on the spot, but it is more likely to have been introduced from elsewhere. The continued use of pot-boilers shows that its potentialities for cooking over a fire were not at first realized, though hearths appear soon afterwards. Other new features are pottery figurines, and bone tablets and tubes for taking some form of snuff, a practice associated with shamanism among some modern South American tribes.

V. *Early Peruvian Civilisations*

In the same area there is a continuous succession of deposits upwards into what is called the Cupisnique or Coastal Chavin culture, in which maize appears for the first time. It yields a pottery style of which the most characteristic feature is a type of jar with a heavy stirrup spout and the body modelled or bearing boldly-incised decorations. (Plate 11a).

Chavin, which gives its name to this culture, is a site up in the Andes, just over the eastern slope, which has produced numerous stone carvings in low relief representing grotesque animals, of which by far the commonest is a feline creature with conspicuous fangs, often combined with parts of

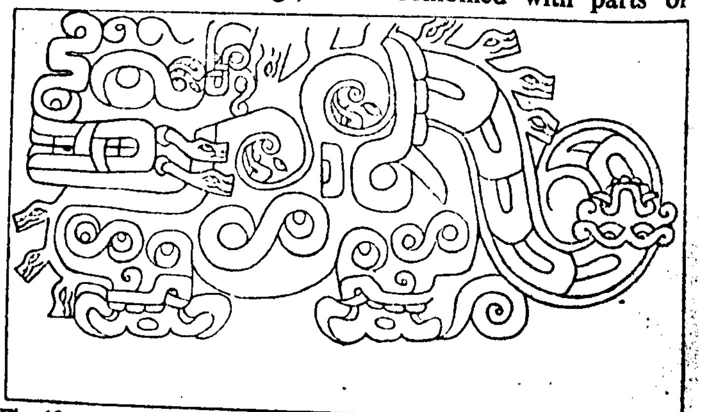


Fig. 12. – Stone carving, Chavin. (From *Handbook of South American Indians* Vol. 2, Bureau of American Ethnology, Bulletin 143, 1946.)

Plate 4. Twin newts produced by dividing a single very young embryo. (*Reproduced by courtesy of Yale University Press, from Spemann's 'Embryonic Development and Induction'*).

Plate 5. Direct growth of nerve fibres linking two fragments of embryonic nervous system in tissue culture (*from Paul Weiss, Jl. of Exp. Zool. 68; 411*).

Plate 6.

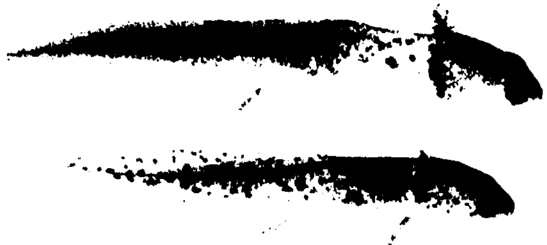


Plate 7.

Plate 8.

Plate 6. Siamese twin embryos of newt, produced by grafting an organiser. (*From the 'Biologisches Zentralblatt', Vol. 53, 1933, published by Verlag Georg Thieme, Liepzig*).

Plate 7. Two newt tadpoles of different species with different pigment patterns (upper, finely speckled; lower, large blotches). A short length of the pigment cell rudiment, just behind the fore-limbs, was exchanged when they were young embryos. (*From Victor C. Twitty and Dietrich Bodenstein, Jl. of Exp. Zool. 81*; 369).

Plate 8. Newt tadpole from which, when an embryo, all but a short length of the pigment cell rudiment was removed. The animal is nevertheless well pigmented. (*From Victor C. Twitty, Jl. of Exp. Zool. 95*; 281).

Plate 9. Terraces near Pisac, Urubamba Valley.

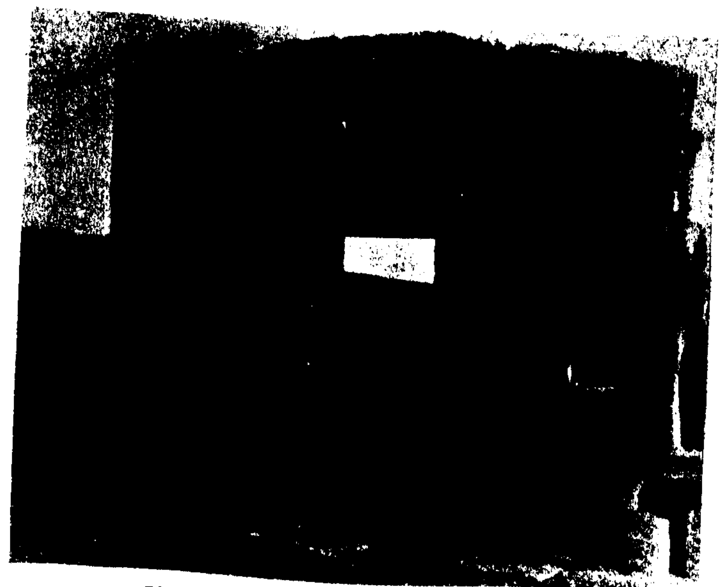
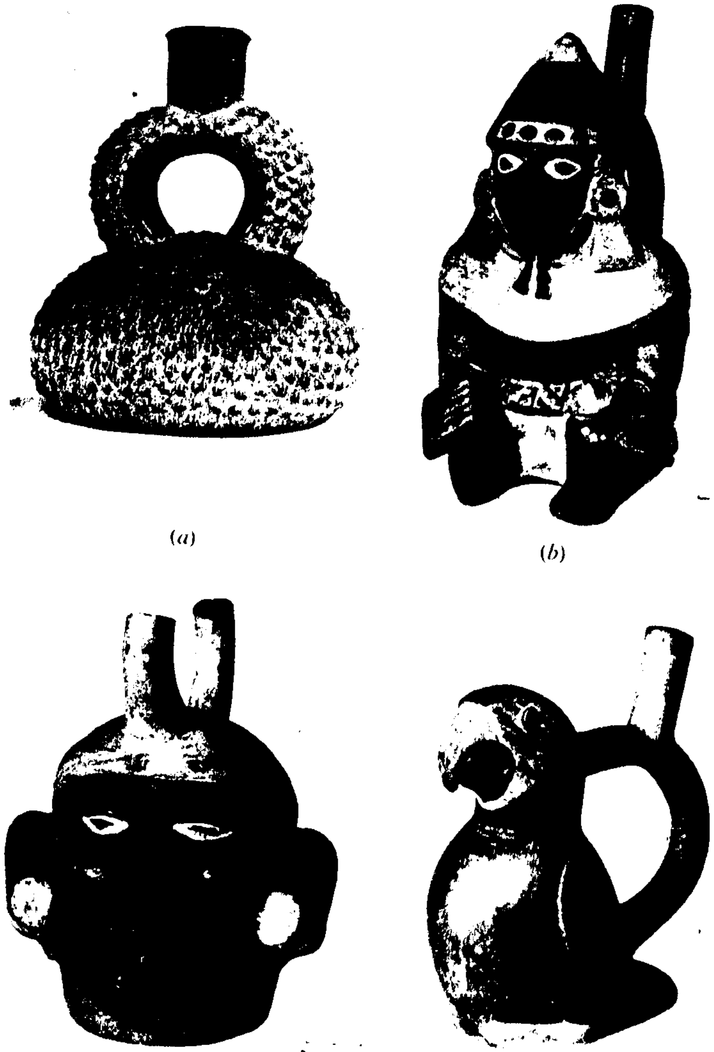


Plate 10. Monolithic Gateway, Tiahuanaco.
(***Reproduced by courtesy of P. F. Holmes, Esq.***).

Plate 11.



(*a*) (*b*) (*c*) (*d*)

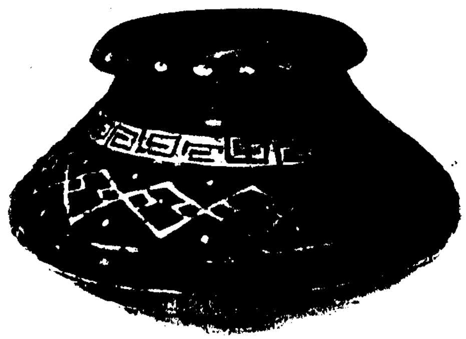
(*a*) Stirrup-spouted jar, Cupisnique, (*b*) Mochica jar representing a warrior, (*c*) Mochica portrait jar, (*d*) Whistling-jar representing a macaw.

Plate 12.

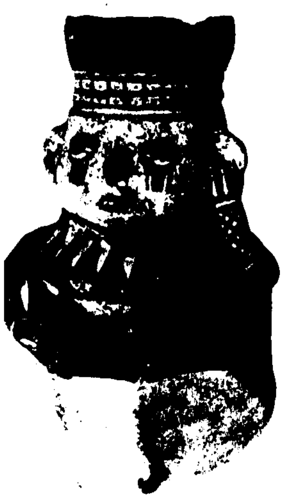
(*a*) (*b*) (*c*) (*d*)

(*a*) Polychrome double-spouted jar with bridge handle, Nazca, (*b*) Polychrome bowl, Nazca, (*c*) Pottery vessel, Coast Tiahuanaco, (*d*) Pottery beaker, Tiahuanaco.

Plate 13.



(a)



(b)

(c)

(a) Bowl, Ica, (b) Figure vase, Chancay, (c) Blackware vessel in form of a raft with two fishermen, Chimu.

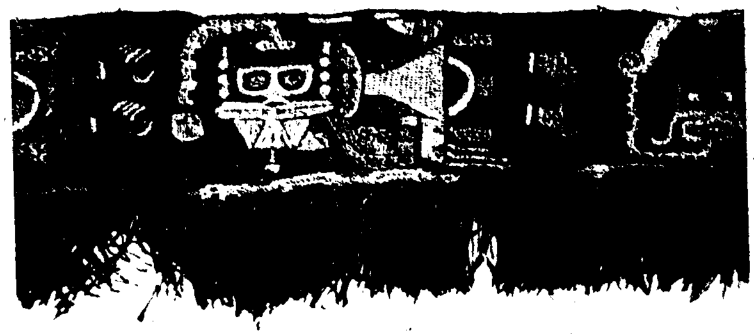


Plate 14. Fragment of textile from Paracas Necropolis.

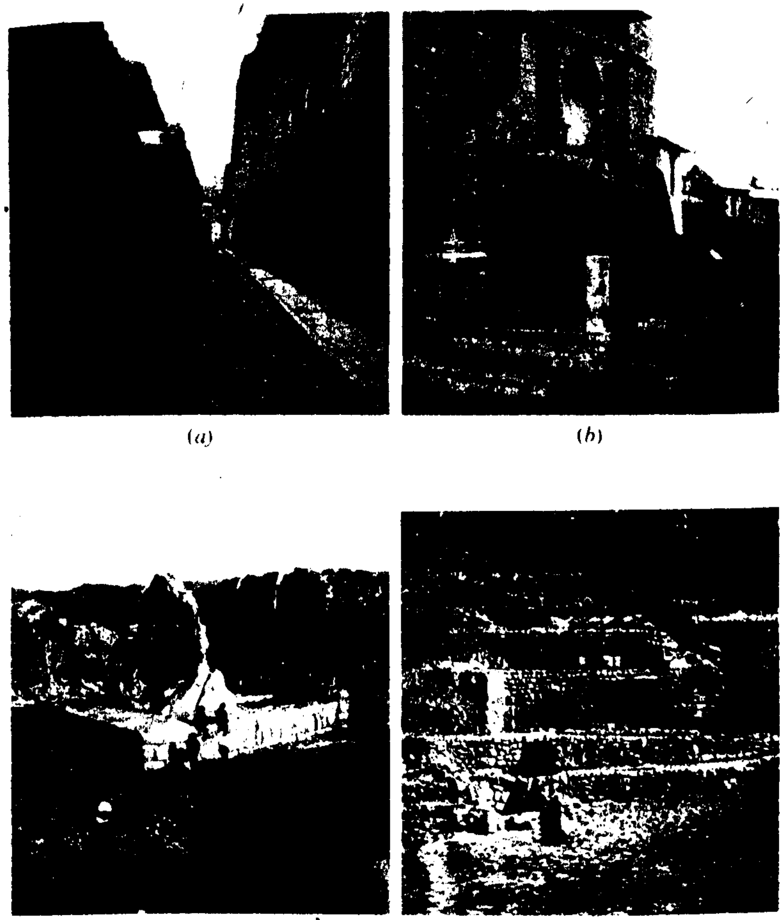
(Plates 11b to 14 reproduced by courtesy of the Cambridge University Museum of Archaeology and Ethnology). (Scale in inches).

(a)

(b)

Plate 15. (a) The fortress of Saccsaihuaman, overlooking Cuzco, (b) Jatun Rumiyocc, an Inca building in Cuzco.

Plate 16.



(a) (b) (c) (d)

Plate 16. (*a*) House of Virgins of the Sun, and palace of Huayna Capac, Cuzco, (*b*) "Sun Temple", part of Dominican convent, Cuzco, (*c*) Kenkko, a rock standing at the focus of an amphitheatre, probably a *huaca*, (*d*) Tampu Macchai, near Cuzco, perhaps a water shrine.

snakes or condors (Fig. 12). There is a massive platform-like building there, made of regular dry-built courses of stone with grotesque heads, mainly feline, tenoned into the walls. This contains a labyrinth of passages and chambers arranged in three storeys, and was almost certainly religious.

The same feline motive appears on the Cupisnique pottery of the coast, and a plainer type of pottery, similar to that found at Chavin itself, occurs in middens of the same age at Ancon and Supe on the central coast. The frequency with which the feline is represented, its appearance on a great carved monolith in the temple at Chavin and the importance of the temple itself, leads to the belief that it was the principal object of worship, and that religion was an all-important consideration in the lives of the people. It has been suggested that they lived in a number of communities, theocratic in nature, in peaceful touch with one another, since, apart from a few stone mace heads, there is no evidence of weapons or of war.

Most estimates of the age of the Cupisnique culture place its beginning at about 1 A.D. and certainly not earlier than 500 B.C., but Mr Bird, the discoverer of the preceramic cultures, thinks that it may date from about 1800 B.C. (about 3,750 years ago). This estimate is based on the rate of deposition of sediments in the Virú valley, by no means an infallible guide, but if the method can be checked in similar sections the results may be acceptable. The same deposits lead Mr Bird to date the beginning of agriculture in this region at about 5,000 years ago.

The essential unity of the Chavin-Cupisnique Period is followed by a number of local developments, of which only three can be briefly mentioned. On the north coast, Cupisnique graves have been found to be disturbed by later ones belonging to a culture known as the Salinar, and these in their turn are disturbed by still later graves. The Salinar culture is not well known, but its pottery shares certain characteristics both with the earlier Cupisnique and with the later Mochica culture, and it is in a sense transitional.

In the Central Coast, sites in the Chancay valley have yielded red pottery painted with simple designs in white; this occurs at the base of an early stratigraphical sequence which is almost certainly post-Chavin, so it is inferred to be contemporary with the Salinar. Further south, on the Pisco Peninsula, is Paracas, where the earlier of two cultures, known as Cavernas from its deep grave-chambers excavated in the rock, is believed to be of the same age. The pottery bears motifs derived from the Chavin; its mode of decoration is peculiar, the designs being painted in bright yellow, green, red, and black, and outlined by incised lines. The only metal worked at this stage was gold, and this is probably its earliest appearance in South America. Dates of between 1 and 500 A.D. have been assigned to this epoch.

VI. *The Heyday of the Regional Cultures*

Much more is known about the subsequent stage in which the regional cultures attained their fullest development. In a group of valleys in the north coast is found the Mochica culture. Its graves have yielded many thousands of beautifully modelled and painted vessels (Pl. 11b, c, d), stirrup-spout jars and double whistling-jars being the most common forms, in red and white, sometimes with the addition of a little black. They provide us with realistic representations of most aspects of life, showing gods, men and women with their clothing and ornaments, animals, fruits and vegetables, boats, houses, weapons, hunting scenes, battle scenes, prisoners and corpses. Some of the jars are in the form of heads which are clearly portraits, and on some diseases and mutilations are graphically portrayed.

Temples of mud brick (adobe) were built on great pyramidal mounds, and the dead were buried lying on their backs with a rich array of goods, particularly pottery. Houses and forts, like the temples, mostly had adobe walls,

the houses being roofed with matting, straw or reeds supported on beams. Elaborate irrigation systems already existed at this time, and silver, copper and lead were worked as well as gold. Wool from the Andes, as well as the local cotton, was used in the textiles, and llamas from the same region are represented on the pottery.

On the south coast at about the same time flourished the Nazca Culture, which is known chiefly by its pottery (Pl. 12a and b), in which modelling and painting are less realistic than in the Mochica culture but far more colours are used, though the frequent use of a dark red background sets a sombre tone, particularly in the earlier examples. At Paracas, the Cavernas culture has been replaced by the Necropolis, famous for its mummy bundles, wrapped in large quantities of textiles (Pl. 14), some of which are richly embroidered with gods or demons resembling those shown on Nazca pots.

At this stage it is possible to say something about developments in the Andes, since it is likely that the Tiahuanaco culture of the Titicaca region, with its famous monolithic gateway (Pl. 10), stone statues and other remains, was flourishing. There is a well-marked polychrome pottery style, some of the best vessels being hollow-sided beakers (Pl. 12d) and bowls painted with step and other geometrical designs, or somewhat conventional pumas or condors. Gold, silver and copper were worked, copper cramps being used to hold the stones together in some of the buildings. Perishables are not preserved, so we know little of the daily life of the people, but the bleakness of the climate so limits the mode of life that it cannot have differed much from that of the modern Indians, who cultivate a few plants, notably the potato, another tuber called oca, and quinoa, a grain.

The area covered by this culture in its normal development is small, and a short distance north of Lake Titicaca a distinct though related culture, also marked by stone working, has recently been found at Pucará. Its pottery bears conventionalized animals and geometrical designs in yellow and black, outlined with incised lines on a red ground.

In the northern Andes, near the home of the Chavin culture, this period is believed to be represented by the Recuay pottery style; this ware is painted with conventionalized cats and other designs in black and red, and is sometimes elaborately but not very realistically modelled in the form of human beings, animals and groups. The black paint is generally applied by a negative technique, which leaves the object represented in the colour of the ware

Fig. 13. – Negatively painted feline, Recuay style. (From T. A. Joyce, *South American Archaeology*. Courtesy of the Medici Society Ltd.)

against a black background (Fig. 13). This pottery mostly comes from stone-lined subterranean rooms. It has been proved by excavation to precede the spread of Tiahuanaco influence to the area, and is inferred by indirect means, including style, to be later than the Chavin culture.

The depiction of spear-throwers, clubs, shields and fighting scenes on pottery and textile, and the finding of weapons in the graves, show that war had come into the picture at this stage. The original motive at any rate was probably the desire to acquire extra cultivable land to feed increasing populations. It is surmised that the date of this period is approximately 800 to 1000 A.D., and some support has been lent to this by a recent attempt to date Mochica objects by the depth at which they were found buried in the guano on the islands off the coast, assuming that it accumulated at a constant rate.

VII. *The Tiahuanaco horizon*

After this, the local art styles of the coast get submerged in a great wave of Tiahuanaco influence, and we find gods or warriors, pumas and condors, clearly derived from those shown on highland pottery and stone carving, all represented on the pottery (Pl. 12c and d) and textiles of what is called the Coast Tiahuanaco or Epigonal style. The influence is most marked in the south and central coast, particularly at the important site of Pachacamac, but it also extends to the north coast and even from there to the northern highlands. The way in which this took place is not known, but many archaeologists believe that it is due to military conquest or to the threat of it, and it is difficult to explain in any other way. The chronological position of the style has been established chiefly by grave stratification at Pachacamac and elsewhere.

VIII. *The City-building States*

After a time the Tiahuanaco characteristics in coastal artifacts degenerate and local styles emerge again. In the Nazca and Ica valleys in the south a pottery style with painted designs clearly influenced by those woven on textiles appears (Pl. 13a) and can be traced through various stages. In the centre the main feature is a well marked black-on-white style of pottery found in the Chancay valley (Pl. 13b). In the north coastal valleys there are a number of local styles, including one painted in black, white and red with geometrical designs, but all finally give place to the black Chimu pottery (Pl. 13c), well known for the variety of its moulded forms, which have many affinities with their Mochica predecessors in the same region. This is the product of a people who dominated an area which extended beyond the Mochica both northwards and southwards, a new feature of whose civilization was the building of great cities of mud brick and puddled clay. The best example is at Chan-Chan, near Trujillo. It consists of about ten large units, each completely surrounded by a high wall and containing streets, houses, irrigated gardens, pyramids, cemeteries and a reservoir. It is probable that each was occupied by some such division of society as a clan. The Chimu region constituted a great and powerful state under a supreme chief, and the magnitude of its irrigation schemes suggests that its control of the sources of water went far back into the mountains. Similar but lesser states are believed to have existed round Chancay and Ica.

IX. *The Incas*

The stage was now set for the rise and expansion of the Inca* Empire. The place of origin of the Incas is unknown, but excavation has shown that they were preceded at Cuzco by a different and lowlier culture, and the suggestion that they migrated there from elsewhere is supported by their legends about themselves, which have been preserved by the early Spanish chroniclers. The genealogies of their rulers suggest that they reached Cuzco in the 12th century, and their subsequent history is obscure until they were attacked by powerful neighbours, the Chanca, early in the 15th century. Having barely escaped defeat, they prevailed over these people under the Inca Pachacuti who was crowned in 1438, and found themselves the strongest tribe in the neighbourhood. From then on their expansion was rapid. and one of the earliest regions to be subjugated was that around Lake Titicaca, where it appears that the Tiahuanaco culture had degenerated and disappeared before they arrived.

Then, under Pachacuti and Topa Inca his son, they spread northwards, first along the Andes to Quito and thence down to the central part of the coast of Ecuador, and subsequently over the northern and central regions of the Peruvian coast. This involved the conquest of the Chimu kingdom, which was effected without serious fighting, chiefly because the Inca attacked on the north flank, the place where he was least expected. He was then

*The name may be applied to the tribe or to the ruler.

able to persuade the Chimu king to give in, partly by convincing him that resistance was futile and partly by allowing him to continue in office, subject to his own overriding authority, a principle which was widely followed in Inca dealings with conquered peoples. Many of the Inca conquests were carried out in this way, but here and there, for instance in the case of the Cañari tribe of southern Ecuador, fierce fighting was necessary.

Pachacuti having resigned his kingdom about 1470, Topa Inca continued his conquests, pushing his empire to its limit in southern Peru, Chile and north-west Argentina. Dying about 1490, Topa Inca was succeeded by his son Huayna Capac, who extended his dominions eastwards in northern Peru and north of Quito to the modern limits of Ecuador. When he died in 1527 Pizarro's first expedition had already touched at Tumbez and the end was in sight. The story of the dispute between his sons Huascar and Atahuallpa and of the Spanish conquest is well known from

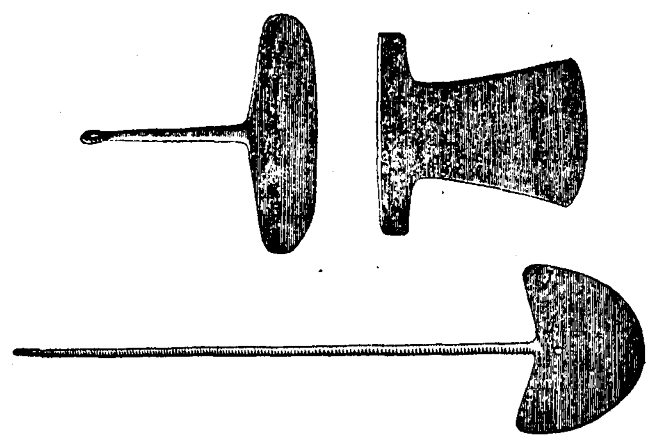


Fig. 14. – Inca bronze axe, knife and pin. (Drawn, to different scales, from Bingham, *Machu Picchu, A Citadel of the Incas*, by courtesy of the Yale University Press.)

the pages of Prescott, whose century-old description has in most respects stood the test of time.

The facts about the expansion of the Empire are known largely from stories recorded independently from the Indians by a number of Spanish and half-caste writers

Fig. 15. – Inca pottery: (a) polychrome aryballus, (b) unpainted covered vessel, (c, d) painted platters with bird-head handles. (Drawn from Bingham, *Machu Picchu, A Citadel of the Incas*, by courtesy of the Yale University Press.)

shortly after the Conquest, but their truth is attested by archaeological remains. From one end of the Empire to the other we find ruins in Inca style, built of stone or adobe,

Fig. 16. – Messenger. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris, 1936.)

bronze knives, axes and pins (Fig. 14), and above all pottery of characteristic forms (Fig. 15), particularly the aryballus (Fig. 15a), which may also be reproduced in the local material, such as the Chimu blackware. The reasons for the Inca expansion and for its success will be considered later.

Most of the Andean tribes were organized in *ayllus*, which appear originally to have been enlarged family groups, living in a village or group of scattered dwellings and owning their lands in common. The Incas made use of this unit, but tended to convert it into an administrative group of convenient size rather than a kin group, cultivating lands which were assigned partly to the support of the ruler, partly to that of religion, and partly to the families composing the group. They were obliged to cultivate the state and 'church' lands (Fig. 10), and this or some specialised labour, such as military service, mining, metal-working or carrying messages (Fig. 16), constituted the only form of taxation.

A number of ayllus made up a province, within which the ayllus were grouped into two or sometimes three sections, two of which corresponded with the 'upper' (Hanan) and 'lower' (Hurin) moieties into which Cuzco was divided. The provinces in their turn were grouped into the four quarters of the Empire, Collasuyo to the south-east of Cuzco, Kontisuyo to the south-west, Chinchaysuyo to the north-west and Antisuyo to the north-east.

The organization of this vast empire within a short time, and its maintenance, required two things; communications and administrators. Communications were ensured by the construction of roads wide enough for foot or llama traffic, paved or cut out of the rock in the mountains, and marked by posts or mud walls in the coastal desert. The numerous streams and chasms were spanned by bridges, the longer and more difficult crossings by suspension bridges, and their upkeep constituted part of the local labour tax. At intervals along these roads runners were stationed to carry messages by relay (Fig. 16), and shelters (tambos) were built for official travellers (travelling by others was forbidden). Storehouses were also built at convenient points for the produce of the public lands, which was used to supply the army and to feed the population in times of shortage.

Administrators were derived first from the Incas by blood, members of the royal family and of the original small Inca tribe, then from the Incas by privilege, members of other tribes speaking the same language (Quechua) near Cuzco, and finally from the Curaca class, rulers of subjugated tribes or commoners selected for their ability. The Curacas, who were hereditary, ranged from chiefs of 100 'taxpayers' (heads of families) to chiefs of 10,000, and they appointed lesser, non-hereditary officials, foremen of fifties and tens. The maintenance of order was assisted by the removal of unruly sections of the population to more settled areas, and their substitution by mitimaes, or colonists from Cuzco or other loyal districts. The sons of vassal rulers were taken to Cuzco to be educated, and thus became hostages for the good behaviour of their parents.

Organization did not stop at the group of ten, and individuals were classified and numbered in twelve age groups, ranging from the infant in arms to the 'old man sleeping'. Census and tribute figures were recorded by means of the Quipu, a system of knotted strings (Fig. 17), and there was a special class, the Quipucamayocc, who were expert in manipulating and reading them. There was no writing.

Together with the organization of the Empire went the spread of the Quechua language and the propagation of the state religion, demonstrated by the remains of great religious buildings in the Inca style at Pachacamac, a notable pre-Inca centre, and other places on the coast, all of which tended to knit the many tribes into a nation.

Rulers who have recently obtained considerable power have a way of marking their success by great building programmes, and the Incas were no exception, for Pachacuti, the first of the great expansionists, rebuilt Cuzco in the middle of the 15th century, erecting the buildings of which so much can still be seen to-day, intermingled with later work. Most of the well-known Inca buildings in the same area date from this period. There are various types of Inca masonry, but it appears that they are related to differences in function rather than to differences in age. An instance is the so-called cyclopean type which was formerly ascribed by some writers to a pre-Inca people; the classical example is the great fortress of Saccsaihuaman (Pl. 15a) on the hill above Cuzco, which has produced nothing but late Inca pottery on excavation, and which also illustrates the fact that Inca towns were not themselves fortified, but were supplied with a pucarà, or fort, in which the inhabitants could take refuge.

Other examples of Inca masonry are shown in the plates. Plate 15b shows on the right the building known as Jatun Rumiyocc, with a more regular type of cyclopean masonry than at Saccsaihuaman; it is built of syenite, a rock as hard as granite, in spite of which the stones are perfectly fitted together without mortar. Plate 16a shows the house of the Virgins of the Sun (right) and the palace of Huayna Capac, both of regular masonry of the finest type. Both these examples are of interest because they show the original width of the Inca streets.

Although the Incas knew and perhaps invented bronze, most of their stone work was done with stone hammers and finished with sand and water. The typical Inca house was a rectangular building of stone or adobe, with a loft in the gabled roof, but rare instances have one or even two upper storeys. The square-headed doorway tapers upwards, there are a number of niches of the same form inside the house for storage or ornament, and there may be stone pegs on which things can be hung. A very common arrangement is for three or four of these units to be placed so as to enclose a kind of court, perhaps occupied by an ayllu.

Inca religion has been popularly represented as sun

Fig 17. – Quipu. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris, 1936.)

worship, but recent investigation has shown that the sun, though prominent, was not so all-important as had been believed. It is probable that the great Creator, generally known by one of his many titles, Wiracocha, had a more important place in the cult than was formerly supposed, though he was rather too remote to mean much to the common people. The so-called sun temple at Cuzco (Pl. 16b), parts of which are still to be seen in the Dominican convent, was dedicated to Wiracocha, and contained his golden image in human form, besides the images of the sun and other heavenly bodies, including the thunder. The sun had a particularly close relationship with the ruling family, and his importance to a people living in the bleak highlands cannot be exaggerated; but the coast people ascribed more importance to the moon and the sea.

After the heavenly bodies came all kinds of things regarded as Huacas, or holy things, in varying degrees. Mountains, trees, rocks (Pl. 16c), animals, the mummies of the dead and other things were worshipped. It is possible that Tampu Macchai, a well-preserved system of terraces and basins near Cuzco, was a water shrine (Pl. 16d). In all these cases the object of veneration was not the huaca itself but a spirit which dwelt in it. Lesser beings in the hierarchy were personal amulets or charms, such as crystals, peculiarly shaped stones or small carved objects. Examples are the small stone llamas and images of maize cobs which were, and probably still are, buried in the fields to ensure fertility. The most important huacas of conquered peoples were brought to Cuzco as a kind of hostage, and they were visited there from time to time by prominent members of the tribe concerned.

In each month there were festivals, most of them associated with the agricultural year, marked by elaborate religious ceremonies. Among the expressions of religion were sacrifice (Fig. 18), prayer, divination, dancing, ceremonial drinking (Figs. 19, 20), and purification, which included confession of overt sins. Human sacrifice did not

Fig. 18. – A sacrifice. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris, 1936.)

ynca

Fig. 19. – Dancing. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris, 1936.)

Fig. 20. – Ceremonial drinking. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris, 1936.)

play nearly such a prominent part as it did in Mexico, but it did take place on special occasions. For example, Dr Uhle found an Inca cemetery at Pachacamac full of richly adorned burials of young women who had been strangled. It is probable that these were some of the 'chosen women', sometimes called the Virgins of the Sun (Fig. 21) who were picked as a kind of tribute from among the most beautiful girls all over the Empire. They were occupied in the service of religion and in weaving clothes for the emperor, and some were given in marriage to successful warriors. They lived in convents at each important centre, and that at Cuzco survives in part in a modern convent (Pl. 16a).

With this amount of background it is possible to consider briefly the reasons for the successful expansion of the Incas. They were not distinguished from their neighbours in weapons or type of equipment, but the maintenance of something like a standing army, superior discipline, good roads and an organized food supply enabled them to concentrate an overwhelming force wherever they chose to plan an attack. This initial advantage, combined with threats and persuasion, often meant that they were able to incorporate large areas in the Empire without actual fighting.

The reasons why they wanted to expand are less easy to put in a few words. The beginning followed closely on a desperate fight for survival and it is probable that the first conquests were made in a desire for security. Success brought wealth and power to the ruler, and this provided an ever-increasing incentive to further conquests; his prestige and his reputation in the eyes of posterity also depended on his success as a conqueror. The various types of Inca and Curaca, already outlined, formed a privileged class; most of them were polygamous, so they increased rapidly and their dependence on official positions bringing wealth and influence was a spur to the conquest of fresh areas. Without this outlet they would have become discontented and a danger to the state. Military success tends

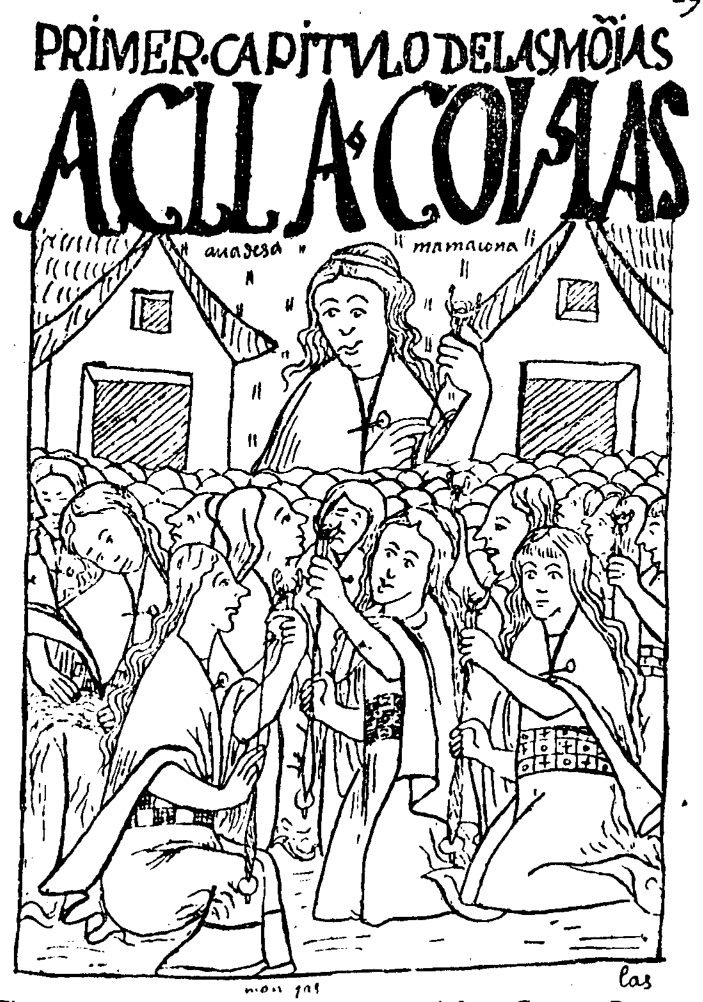


Fig. 21. – Virgins of the Sun. (Reproduced from Guaman Poma *Nueva Coronica y Buen Gobierno*, a late 16th century MS with contemporary drawings. Published in facsimile by the University of Paris 1936.)

to glorify war and to make it a desirable end in itself, and what we know of the education of the youth of the nobility suggests that it was designed to arouse an aggressive spirit.

We cannot tell what would next have happened to this rapidly growing state if it had been left to itself. Certain of the nobles received grants of land and might perhaps have formed the nucleus of a more stable society, but it seems more probable that the militaristic factors would have resulted in further conquests until the organism became too unwieldy and had to split. Such forecasts are pure speculation, because the Spaniards were on the threshold. They struck straight at the heart in the person of the ruler, and the perfection of the organization is vividly shown by the rapidity of its collapse.

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Experimental Embryology To-day

MICHAEL ABERCROMBIE

WHAT I ought to put into this essay would have been perfectly plain ten or fifteen years ago. The study of embryos had in those days an exciting focus of attention: the *organizer* of vertebrates. Then, the solution of an important problem about the organizer's rôle in development, which I will describe in a moment, seemed almost within grasp. It looked as though a fundamental piece of the mechanism by which an egg cell divides into many cells and elongates and folds itself into a young animal was about to be elucidated. Writing now, I shall certainly have to say something about the famous organizer; but it cannot be the central theme as it inevitably would have been in the 'thirties. For though some of the finest experimentalists in embryology, such as Waddington and Needham in this country, were hard on its track, the solution of the problem escaped. The exhilaration of that concerted pursuit is over, and the reaction has been one of some disappointment.

Embryologists have at the moment no main objective which can focus the activities of a notable proportion of their effort. They give rather the impression of casting about for new hypotheses to pursue. There is a great deal of apparently sporadic thinking around and trying out. To present in this essay a single theme or a solid body of factual achievement would not at all reflect the mood of the moment. Much more representative would be to describe a few of the ideas that are current, and that is what I shall try to do. But at the outset it must be emphasized that these are mostly working hypotheses which are ready for serious testing; they are certainly not established truths.

For the sake of some degree of unity I shall consider only the vertebrate group of animals. (Vertebrates are the back-boned animals – fish, amphibia, reptiles, birds and mammals.) Very important work is done on a few other groups. But generalizations about mechanisms of development common to diverse animals are hardly feasible yet.

To get the modern trends in proper perspective, let us first consider what the vertebrate organizer is; so great has been the reaction from organiser work that one is almost inclined to say, what the organizer *was*. Actually it is a region of the early embryo with special and complicated properties. The great German embryologist Hans Spemann discovered them in about 1921. He experimented on newt embryos, but it was subsequently shown that most, probably all, vertebrates have organizers of similar properties; indeed to a certain extent their organizers are interchangeable.

At the stage of development when the organizer can first be shown to be active, the vertebrate embryo consists of a simple arrangement of numerous rather simply-shaped cells. (For a description of the structure of these early embryos see 'From Egg to Adult' in *Penguin New Biology No.* 5.) Like all cells those of the embryo are tiny blocks of protoplasm each containing a nucleus (which in turn contains the genes, the hereditary factors) and each surrounded by a surface membrane. But the simplicity of form and of arrangement of these embryonic cells contrasts markedly with the complexities of adult cells.

The organizer has an important role in converting this early simple arrangement of simple cells into the adult complexity. Indeed so important is its organizing rôle under experimental conditions, that a piece of an organizer (taken from an embryo which is discarded) grafted into the future flank or belly region of another young embryo can form there a second individual, in Siamese union with the first. A striking instance, obtained in a newt, is shown in Plate 6,

where the original embryo has developed to the top, head pointing leftwards; and the new embryo, constructed out of the material of the grafted organizer together with material incorporated from the belly of the other embryo, has developed upside down, its tail behind the first embryo's head.

Activity of the sort just illustrated is the result of a complex of properties in the organizer. It was one particular property which was the cause of the great excitement about organiser research: its power of causing the development of the nervous system. At the stage of development of Fig. 22, the organizer region has a situation at least partly at the surface of the embryo. The next step in development is that it slips inside the embryo (Fig. 23). As it does so it comes to underlie the layer of cells which has been left outside. It comes to

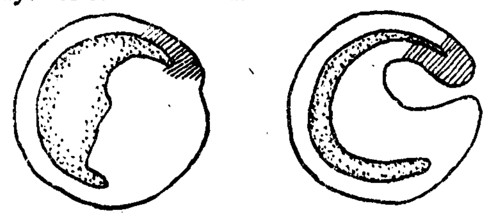

Fig. 22 Fig. 23

Fig. 22. – Early amphibian (e.g. newt) embryo, cut in half and seen from the cut surface. Future head will be to left, and belly downwards. Organiser material hatched.

Fig. 23. – Later embryo, halved, and in same position. The organiser has started to slip beneath the surface. It begins to underlie part of the superficial layer, which will become the nervous system, along the future back (which is uppermost in diagram).

be situated immediately inside a broad strip of this layer along the middle of what will be the embryo's back; and this strip of the superficial layer becomes the nervous system. It first becomes visibly distinct when it thickens, owing to one of the earliest modifications of the very simple cell-shapes of the younger embryo (Fig. 24). Once the thickened strip is established, it proceeds inevitably to turn into nervous tissue.

The initial impulse which starts the nervous system de-

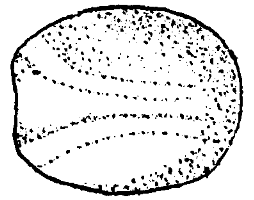

Fig. 24. – Later embryo still, entire, seen looking down on to its back. Future head to left. Nervous system just become visible, as a strip along the back, bordered at its sides by two distinct ridges.

veloping in this way is some influence which comes from the organiser cells lying immediately underneath. The organiser is said to *induce* nervous tissue, and this is perhaps its most characteristic property. If you prevent it from slipping underneath the surface, then the strip which should have become the nervous system fails to do so. It becomes skin instead (actually epidermis, the outer layer of the skin). If you arrange for the organizer to slip beneath the superficial layer in some abnormal situation (say in the future flank or belly) it will still induce a strip of nervous tissue, but from cells which ought to have become skin. The organizer region itself, normally and experimentally, turns into muscle, backbone and other tissues.

What passes between the organizer and the superficial layer whose future it determines? This is what embryologists thought they had a very good chance of finding out. They discovered that if they killed a piece of the organizer, and put it beneath some of the superficial layer, the latter was still directed to turn into nervous tissue. Extracts of organizers, and of other tissues, worked too. Surely the organizer must release some active chemical which refined analysis would soon identify? Unfortunately, if there is such a substance, it has still not been identified.

Throughout the organizer work there was a recognized snag in the argument. Always it was hoped that it would not prove serious; but in the end it brought the temporary defeat to which I referred earlier. The trouble was that the

superficial layer of cells had only to be damaged to turn itself into nervous tissue. Anything which damaged it enough to set the process going, but not too much so as to kill it altogether, would induce nervous tissue. Now tissues can be damaged in innumerable different ways. Hence, when pure substances were tested for their inducing power, an extraordinary variety, including such surprises as chalk, were found to be effective. There was no conclusive way of telling which, if any of them, was at work in normal development. What passes between the organizer and the superficial layer it directs was really no clearer after all the work than before it. Indeed some distinguished workers doubt still whether an actual substance passes at all, any more than a substance passes between a mould and the blancmange it shapes.

It would be quite wrong to conclude from this that the organizer research was a waste of time. The results established a great deal about those particular relations of *dependency*, which are fairly common in embryos, where the rudiment of an organ is controlled in its development by a neighbouring rudiment. The formation of the nervous system by the organiser is the outstanding instance of this. And, although the attempt to tie down the agent which stimulates the formation of nervous tissue was disappointingly in vain, even in that direction much valuable incidental information accumulated.

Along what new lines then are embryologists thinking and experimenting? Naturally enough, none is absolutely new. These ideas have been foreshadowed by individual workers or isolated researches. What is new is the momentum they are gaining.

The first idea that I want to discuss concerns *the stickiness of cells*. It appears that the stickiness of the surface membrane of each of the numerous cells which constitute an early embryo is very important in determining the architecture of the animal. This stickiness (except at the beginning of development) is not indiscriminate in the sense that *all* cells hold tightly together. Each cell has a stickiness of a most particular kind, so that it will stick firmly only to some types of cells, and will fail to stick to others.

This is the phenomenon of *specific adhesion.* Its importance was first demonstrated in a paper by Holtfreter (now of Rochester University, New York) in 1939, and the theory has since been elaborated, particularly by Paul Weiss of Chicago. Let us see some of the experimental evidence before we consider the far-reaching theoretical implications.

Holtfreter, using newt embryos, cut out fragments of early developmental stages and isolated them in salt solution, where they lived and continued their development. The fragments were so prepared that they contained certain combinations of tissues; and Holtfreter observed the mutual behaviour of these tissues, especially whether they adhered or separated, during their sojourn in the salt solution. Consider those tissues to which we have already referred in our discussion of the organizer: the superficial covering of the embryo, part of which later becomes nervous tissue and the rest mainly skin; and the organizer material, which develops into muscle, backbone and other internal tissues. When a fragment which will form both superficial layer and organizer is isolated at a very early stage (that of Fig. 22), while the organiser is still on the surface of the embryo, the two components stick closely together. But soon they tend to separate: not completely, but so as to become visibly distinct masses. Then once more they enter into closer union. And now the piece of the superficial layer, hitherto a single coherent mass, starts to become partly nervous tissue and partly skin; and these two tissues completely fail to stick together and divide into separate lumps, though each maintains an affinity with the organizer material, which has now begun to turn into muscle, etc.

That is but one example of the complex shifts in mutual affinity which Holtfreter found. The exciting thing is the neatness with which it is parallel to what happens in normal development. The organizer material tends to stick closely to the superficial layer, except during the phase when it is sliding inside the embryo and moving into place beneath the cells it is going to turn into nervous tissue. It is free to move relative to the superficial layer during that phase. The newly-formed nervous tissue separates off from the skin, beneath which it sinks, at a time precisely corresponding to the loss of affinity between them in Holtfreter's experiments. There can hardly be a doubt that Holtfreter has uncovered, in these changing affinities, an important part of the mechanism of these embryonic movements of tissue.

We have shown how Holtfreter's results apply to the earliest development of the nervous system. But his principles are of much wider importance than that. They are likely to apply to many phases of the development of all vertebrates. The separation of blocks of cells from each other, each block becoming a separate organ, occurs frequently in development: for instance the separation of the organizer material into muscle rudiments, embryonic skeletal rod (notochord) and other organs. These can clearly be brought into Holtfreter's scheme, as can also the eventual degree of mutual application of cells of the same type, whether they form compact masses (e.g. muscle), continuous sheets (e.g. epidermis) or are linked only by tenuous processes (e.g. bone cells).

Further, not much of animal development is just the crystallization of a complex pattern within an amorphous mass. There is on the contrary a constantly changing pattern. A frequent event is for a group of cells to separate from its neighbours, migrate away, and join up elsewhere in some new association of cells. The mass migrations, exemplified by the inward movement of the organizer material we have already mentioned, are succeeded by innumerable smaller-scale migrations, rearranging the minor details of the pattern. For instance, as the thickening which is the future nervous system sinks beneath the surface, certain of its cells separate from it, migrate away, and establish themselves beneath the skin all over the body, where they form the future sense-organs of touch, heat and cold. Other cells of similar origin become black pigment cells, responsible for the pattern of light and dark in the skin of many vertebrates.

Leaving aside the intermediate process of actual movement, it is clear that the starting and stopping of such cell migration can be readily explained (though the explanation has not yet been experimentally validated) by the principle of specific adhesion. These cells seem suddenly to lose their adherence to the rest of the nervous system. Off they wander. Eventually the going becomes sticky, either because of the new surroundings or because of changes within the migratory cells or both; the travellers bog down completely, and there they are, for the rest of their lives perhaps, in the position characteristic of the adult animal.

The separation or fusion of tissues, the starting and stopping of these migrations, receive an illumination from Holtfreter's work which is sure to lead to many fruitful experiments. Perhaps the processes which are most attractively illuminated (though the illumination may possibly be rose-coloured) are those which determine the enormous complexities of the fully-formed nervous system; which are ultimately responsible for the marvellous complexities of animal behaviour. The adult nervous system is often compared to a telephone system; and, however false the analogy in functioning, at least there are nervous conducting elements comparable to wires, the nerve-fibres. These exceedingly fine threads may be regarded as the results of migratory processes something like the ones we have already mentioned. But here the migration is not of a whole cell. It is, so to speak, a part of the cell which wanders off, drawing out a fine thread behind it; and into this fine thread the rest of the cell pumps a continual supply of protoplasm; so that the thread, the nerve fibre, extends and worms its way through the tissues. The nerve cells which form these nerve fibres arise in the strip of tissue along the back which

is the earliest vestige of the nervous system. And there, with minor shifts, they mostly stay, constituting the brain, spinal cord and associated ganglia, that is the central nervous system. Their nerve fibres extend through the tissues, until the whole body is enmeshed in a tangle of these fine threads, connecting all parts of the animal to the brain and spinal cord. Nerve fibres which pass on the impact of the outside world connect, for instance, with the sense-organs for touch we have referred to; nerve fibres which carry the calls to action connect, for instance, with the muscles which have been derived from the organizer. And by similarly extending within the brain and spinal cord, the nerve fibres connect the nerve cells to one another, providing the intricate pattern of pathways for nervous activity within the central nervous system.

To say that the nerve fibres form a tangle is inadequate, because it suggests disorder. Actually the arrangement of nerve fibres and nerve cells laid down by these movements is a definite one, repeated with fidelity in the development of every individual, and of a complexity quite unparalleled amongst the organs of the body. Not that every single nerve fibre is arranged in exactly the same way in every member of a species; but on a somewhat broader scale the same basic pattern of groups of fibres is rebuilt during each and every development. The determination of this intricate pattern poses fearful problems to the experimentalists. But now at least we can suggest, following Weiss, that part of the explanation of the way nerve fibres always make the right connections is that they stick to them when they meet them, and to nothing else, by an extraordinary perfection of the principle of specific adhesion.

Does this seem to be stretching the principle of specific adhesion too far? Can one really envisage specific properties peculiar, for instance, to each of the thousands of different groups of nerve fibres, and to the places where each of them normally ends? There seems little difficulty in providing innumerable pairs of specifically adhering surfaces, if we suppose the adherence is due to combination of proteins in the cell membranes. Antigen-antibody reactions provide the model. It is well known that certain substances (antigens) normally foreign to the blood stream, usually proteins or complex carbohydrates, produce a highly specific response when they are injected into a vertebrate. The body somehow elaborates a corresponding protein, called an antibody, for each antigen. An antibody combines with its own antigen and with no other (unless it happens to be chemically closely related to the first one). The restriction of the immunity acquired from one disease to future attacks of that disease and of that one only is an illustration of antigen-antibody specificity; because such immunity depends on antibodies developed in response to, and reacting exclusively with, parts of the invading germs which act as antigens.

Such matched pairs of combining proteins could surely provide the basis for matched pairs of cell-types which stick to one another in preference to others. One of the most famous examples of specific fusion – that of sperm and egg – has indeed been analysed by Tyler in terms of antigens and antibodies. The sperm of a given species of animal can usually fertilize the eggs of that species only, and of no other. This may be a close analogy to the specific adhesion of tissues in embryonic development.

When embryonic development is finished, we may regard the cells as stuck in their definitive places. They are further anchored down usually by the appearance of a ubiquitous tangle of fine tough protein fibres (collagen and reticulin) around the cells, by cement substances between the cells, and by other non-cellular concretions. In the adult, therefore, few kinds of cells move about. But many cells can be stimulated to move again, just as they did in the embryo. The most effective stimulus is wounding. Cell movement, for instance, recolonizes an injured area. Evidence is now beginning to be collected that mobilization as a result of injury, and the subsequent settling down again when the damage has been repaired, also involves these specific adhesions which are so important in the embryo.

We can account perhaps for the starting and stopping of cell movements by this new theory. What about the *directions* in which the movements go? On the whole they follow prescribed paths. The cells do not just wander at random until they happen to hit on their goal, or until they perish by the way. They are guided, at any rate approximately, towards their goal. To what directional cues are they responding? Here the outstanding worker has been Paul Weiss. The classical explanation has always been in terms of some chemical attraction emanating from the goal. But twenty years ago Weiss showed how in their movements nerve fibres and other cells really respond to the orientation of structure in the material through which they go. A jelly-like medium, such as a blood clot, can be made to take on an oriented structure by, for instance, stretching it. Its molecules then tend to lie mainly in the direction of stretching; and the movement of cells takes place preferentially in the same direction. In Plate 5 is a striking example of the way in which directed outgrowth of nerve fibres can link two fragments of nervous tissue maintained in a medium of clotted blood plasma. This sort of direction Weiss has shown to be due to stress in the clot between the two tissue fragments.

Weiss's work has had great influence on our ideas about the laying down of embryonic structure. A jelly-like matrix, capable probably of orientation, can be demonstrated in very early embryos, and much directed movement may be explained in this way – though what orientates the matrix in the first place is not so clear. Yet the mechanism in this simple form is not specific enough to explain everything, especially about the migration of nerve fibres, whose pathways are particularly definite, particularly complex, and particularly in need of explanation. Weiss has recently proposed a refinement of his theory of guidance by contact, which brings it close to the notion of specific adhesion. He supposes as before that the structure of the matrix directs the nerve fibres; but also that there are kinds of matrix subtly distinct, and that each kind of nerve fibre responds only to a specific kind of matrix. This idea, therefore, again involves matching of surfaces.

We must not, however, overdo the emphasis on the notion of surface interactions. An interesting case where other principles are perhaps involved in the distribution of pigment cells, studied in newts by Twitty and his school at the University of California. The pigment cells which form a conspicuous pattern in the skin of some newts are, as I have mentioned, curiously enough a product of the early nervous system. They are amongst the cells which, when the nervous system disappears beneath the surface of the embryo, lose their affinity with their previous neighbours and scatter away, most of them spacing themselves out immediately beneath the outer layer of the skin (epidermis). Twitty has shown that they migrate from their place of origin in the middle of the back practically straight down towards the belly, without much forward or backward deviation. This can be shown by transplanting recognizably distinct pigment cells, in the form of lengths of the nervous system while it still contains the future pigment cells, from one species to another. Plate 7 shows how, when pigment cells are exchanged in this way, the migration of each kind is vertical only, since the length of rudiment originally exchanged between these two animals of different species corresponded to the present longitudinal extent of the abnormal pigment pattern. There has been no lengthwise extension of either pattern.

But this vertical migration is not the result of some directive property of the skin through which the cells migrate. For, if all but a short remnant of the nervous tissue which gives rise to the pigment cells is eliminated early in development, the vacant regions of the flanks to which the missing pigment cells would normally have gone are soon colonized from the remnant by forward and backward movement of its pigment cells (Plate 8: the position of the deleted

lengths of the pigment cell rudiment can be detected by the corresponding absence of the fin along the back). Pigment cells are kept in their normal migratory course because they will not go where other pigment cells are already. How do they repel one another?

Twitty is working on the hypothesis that they keep their distance because they always move with that side foremost which is exposed to the lowest concentration of a chemical substance (nature unknown) they themselves are producing. If two cells approach, the concentration at their nearer surfaces will rise above that at their further surfaces, and they will move apart again. This tends to keep them evenly spaced; though later clumping occurs in some species, giving rise to the characteristically bold specific patterns of many newts. How Twitty's explanation will fare is a matter of great interest, because a rather evenly scattered distribution similar to that of pigment cells is common amongst, for instance, the cells of connective tissue and the skeleton, and similar mutual repulsions may exist between these cells.

So far we have tended to deal with cells much as if they were unchanging atoms, and development consisted simply in moving them to their appropriate places. We must now give some consideration to the changes within the cells. Fundamentally, differences between different kinds of cell, between nerve cell and muscle cell and blood cell, must be due to the organization within each kind of special proteins, and special enzyme systems for carrying on their own particular line of activity. Muscle cells for instance have special contractile bundles of protein fibres, and special enzyme systems which mobilize the energy for contraction. These specific constitutions appear only gradually during the early stages of development. Once a specific make-up is established in a cell (and incidentally no mixture of two different constitutions is ever formed) it not only persists; it *breeds* true. Each cell may continue multiplying and give rise to a numerous lineage of similar cells. It is not, therefore, simply a matter of forming the necessary specialized components, but of getting them going on a self-reproducing basis, so that two complete cells can form from every one.

The classical self-reproducing bodies are the genes, situated in the cell nucleus, which themselves multiply so that at cell-division both of the two new cells get a complete gene set. If it really is a complete set, that rules the genes out as responsible for the reproduction of the characters *peculiar* to different kinds of cell. And the evidence to date shows that every cell of the body contains all the different genes. One looks, therefore, to a rather new sort of self-reproducing body, plasmagenes in the cytoplasm, for the continuous production of the special enzymes and other proteins characteristic of each kind of cell. It must be admitted, however, that so far no evidence of the responsibility of plasmagenes for the major cell types has been obtained; and there has not yet been an adequate suggestion about how they could originate during the development of each type. But a relevant and most important instance of plasmagene activity is in process of elucidation by Medawar and Billingham of Birmingham University. In adult pied guinea-pigs the difference between pigment cells which blacken and those (in the white patches) which fail to do so seems to be due to a plasmagene in the former. These plasmagenes are detectable because they can infect a colourless pigment cell when a black cell makes contact with it.

I shall end by calling attention to perhaps the most challenging problem of vertebrate embryology: the phenomenon of *regulation*. If an early newt embryo is divided into two, along the plane corresponding to the future head to tail and back to belly directions, each half continues development as a single, perfect, though small later embryo and tadpole (Plate 4). This is no doubt the basis of human identical twinning. If an organizer is divided into two lateral halves, and each is suitably grafted, each forms a complete set of organs, and induces a symmetrical nervous system.

We can go from organ to organ in vertebrates and show in each that there is an early stage of development when removal of a piece, even up to a half, or addition of an extra piece from another embryo, does not prevent the ultimate development of a normally-formed organ. In each case there must be a system of interaction between the cells which decides the path of development each cell shall pursue, of so simple yet so subtle a kind that it keeps its essential property when maltreated in this way. What sort of a system can it be? We have at the moment only very tentative suggestions, and the problem urgently needs a point of attack.

That is a very brief survey of vertebrate experimental embryology today. I have selected only a few out of the many interesting current ideas; and I shall be lucky if I have included the one which will set going the next concerted forward drive of embryologists.

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Waddington, C. H., *Organisers and Genes* (Camb. Univ. Press, 1940).

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The Population Problems of India and Pakistan*

SRIPATI CHANDRASEKHAR

INDIA's population problem arises primarily out of an extremely high fertility accompanied by a high mortality which is only slowly declining. The resulting increase of people, which amounted to more than four million a year in an undivided India, would not constitute a problem if the Indian food supply was high enough to allow for the additional population, without reducing the standard of living. But India's standard of living is so low that any further addition to the number of poor families may well be disastrous; and as they are so numerous, it may be generalized that the total population will find further increase a great problem.

The net addition of four or more million a year, or fifty million in a decade, a grand total of 350-400 or even more millions in India, is not the only difficulty. What is worse is the well-known and depressing qualitative aspect of the Indian population problem. The quality of the people is related to the quantity and it cannot be improved without controlling this: hence the importance, if not the danger, of the number of India's teeming millions to her overall economic and social development, and her place in the modern world.

*This year for UNESCO is a year of publicity: making known the size of the world's population, and the state of its food supply. We are glad to be able to collaborate in UNESCO's programme by publishing this revealing article on India, whose millions recurrently face famine.

Growth of Population

The population of the combined Dominions of India and Pakistan to-day is nearly 450 million, or about a fifth of the total world population. The estimated population of the two Dominions for 1947 was 336,000,000 for India and 71,000,000 for Pakistan, but this is only an estimate, probably an under-estimate, as there are many unknown factors in Indian demography.

In the sixteenth century, according to some rough estimates, the population of the sub-continent was about one hundred million. In the middle of the nineteenth century the figure reached about 150 million. In 1881, when the first regular, although incomplete, census was taken, the population stood at 254 million. In 1931, fifty years later, the census revealed 353 million, representing an increase of 10.6 per cent over the 1921 figure. The last census of 1941 showed a total of 389 million, showing an increase of 15 per cent over the 1931 figure, or an increase of 50 million. The 1951 census may show a similar increase, if the present trends of mortality and fertility continue.

The *rate* of increase of the Indian population though high has not been abnormal. For instance, between 1872 and 1941 the population of undivided India grew by 54 per cent. The United Kingdom during the same period increased by 56 per cent. Japan during the same period increased by 136 per cent. So the rate of increase has not been very rapid. But the growth over the years has not been uniform, for the controlling factor has not been increasing fertility but fluctuating mortality. The population has responded to the presence or absence of wars, famines and epidemics. As these checks appeared or disappeared, the population grew accordingly.

Voluntary limitation of births has not played any significant rôle in determining the size of the Indian population. Till 1901 the population was almost stationary. The years between 1901 and 1921 witnessed an irregular and spasmodic growth. But in the two decades between 1921 and 1941 the country registered a growth of 10.6 and 15 per cent respectively. And, if the present public health conditions continue unaccompanied by any famine, the 1951 census may show a large addition.

But the problem in India is not the rate of increase but the *net addition* to the existing population every decade. Because of the large size of India's existing population, even a modest rate of increase of 10 or 15 per cent yields a net gain of some 50 millions (as during 1931 to 1941), in itself larger than the population of any European country except Germany or Russia, or of any Latin-American country. And it is this large net addition that constitutes the problem because it nullifies all efforts to improve the admittedly very low standard of living of the Indian people.

Fertility

Among all demographic factors, the rate of fertility is the most important, for international lack of balance in fertility constitutes the crux of the world population problem. Within a nation differences in fertility between different ethnic, cultural, economic and religious groups constitute a serious problem in the formulation of any democratic population policy.

If Indian vital statistics are accepted as fairly reliable, despite their well-known inadequacy due to under-registration, we find that the birth rate is between 45 and 50 per thousand. The figure for 1941 is 43, and this is comparable to high birth rates in Egypt (47 in 1940), Palestine (40 in 1935), Puerto Rico (40 in 1942), and Mexico (42 in 1940). A discussion of the corrections to be made in the estimated and recorded rates of fertility cannot be entered into for lack of space, but the table opposite gives India's birth and death rates per thousand since 1885. The significant fact about the Indian birth rate is not that it is one of the highest in the world but that it has shown no signs of decline during the last fifty years. It is obvious from the table that there is no definite downward trend and the little variation that is seen must

be taken to be a natural and normal fluctuation for such a high figure.

Birth and Death Rate of India per thousand since 1885

Year	Birth Rate		Death Rate		Natural Increase	
	Recorded	Estimated	Recorded	Estimated	Recorded	Estimated
1931-35 ..	35	46.7	24	31.2	11	15.5
1921-31 ..	35	46.7	26	33.8	9	12.9
1911-21 ..	37	49.3	34	44.2	3	5.1
1901-11 ..	38	50.7	34	44.2	4	6.5
1890-01 ..	34	—	31	—	—	—
1885-90 ..	36	—	26	—	—	—

As for rural-urban fertility differences, India conforms to the experiences of other countries. In Western and industrialized countries, the decline in fertility began in urban areas, and the rural areas tended to follow the downward trend after a time lag. This has been so because industrialization has been accompanied by the widespread adoption of the planned family habit. Though India may conform to this experience eventually, it has not been the case till now. The lower fertility in Indian urban areas must be explained in terms of adverse sex ratio in the cities, where the relative scarcity of females and the absence of wives constitute a remarkable feature.

Indian industrial workers have a rural background and they come to the cities in search of employment only when they are faced with agrarian distress. As such they come to the cities single, unaccompanied by their wives and children. When agricultural conditions improve, large numbers of these industrial workers return to their villages and to agriculture. Another reason for this rural-urban fertility differential may be the high infant mortality rate in the cities.

An examination of the fertility rates by occupational and income groups reveals, however, a slight decline in the high income groups. This group generally embraces the so-called higher castes who have a better education, better jobs, and consequently a higher standard of living. Here again the lower fertility cannot be explained in terms of birth control. Though adequate data on the question are lacking, the real factor is the social ban on widow remarriage, which withdraws many women from potential motherhood. As this ban on widow remarriage is not generally observed among the lower income groups (which roughly correspond to the so-called low castes) the fertility of this group is higher. Thus the little decline in fertility that is registered for certain groups of the Indian population has not become a marked trend and the differential is not large enough to affect adversely the future growth of population.

Mortality

India's population growth during the last century has been conditioned mainly by the high but fluctuating death rate. Famines, epidemics, the general insanitary environment and wars have contributed to the death rate, though the last factor has almost disappeared in the last half century. During 'normal' years the death rate has been consistently high because of the striking lack of public sanitation and hygiene, and widespread under-nutrition of the population. The death rate rose distressingly during bad years, when epidemics and famine broke out due to the scarcity of food. It can be said with some truth that famine and epidemics alone have controlled the growth of India's population during the last hundred years.

The Indian death rate is high – 30 per thousand. The recorded death rate for 1931 was 24 per thousand and 22 for 1940, but these are under-estimates because of incomplete returns. This means that more than 10 million people die every year in India! While the all-round death rate is appalling enough, the death rate in various age groups is equally unusual. The most disquieting factor of the Indian death rate is the high incidence of mortality among first year

infants, women in child-birth and women of the reproductive age group. The infant mortality rate is very high – nearly one-fourth of the babies born die during their first year! According to official estimates, about half the deaths among infants occur in the first month and, of these, nearly sixty per cent in the first week. Mortality remains high throughout early childhood. About forty-nine per cent of the total mortality in any given year is among those below ten years of age, while the corresponding figure for England is only twelve per cent.

As for maternal mortality, the figures are equally shocking. Sir John Megaw, when he was Director-General of Medical Services in India, made a random sample survey and arrived at the maternal mortality rate of 23.5 per thousand births. That is, at least 200,000 women die every year during child-birth, or 100 out of every thousand girl-wives are doomed to die in child-birth!

In brief, out of every hundred babies born, one-quarter die before they reach their first birthday. By the fifth birthday, forty per cent have disappeared, and when the twentieth birthday is at hand only fifty per cent are left.

But, despite the present mortality rates, the average annual addition to the population of both the Dominions was five million. During the last two decades there has been, however, a slight but steady fall in the general mortality rate. A further fall is bound to occur if the large-scale programmes for improving the health of the country are effectively put into operation. It has been calculated that even a slight improvement in the present health conditions can save three million infant lives. When this is done, India's population will increase by not five but eight million a year. And it is possible that the 83 million increase that took place between 1921 and 1941 could take place between 1941 and 1951. To repeat, a planned and purposeful control of mortality without a corresponding control of the birth rate, can have only disastrous consequences for India.

Morbidity

If the available information on birth and death rates is somewhat incomplete and unreliable, that on the incidence of diseases is even more so. Rural India and Pakistan which shelter nearly eighty per cent of the total population have no adequate hospitals, clinics or other general or specialized medical services. Thus there is no way of estimating the total morbidity of the population. Some information, however, is available for urban areas, and such figures must be multiplied five or six-fold to get a complete picture for all India.

For instance, according to official sources, in normal years malaria is directly responsible for at least one million deaths every year. This must really mean that at least three million people die of malaria every year. If three million people *die* of malaria, it also means that at least ten million people *suffer* from it. The cost of treating the affected people – granting that they get some kind of treatment, expert or quack – and maintaining them in low health, and the indirect cost of man-hours lost in the fields, factories and offices must be enormous. When people have actually recovered from an attack of malaria their already low efficiency, due to lack of proper nutrition, is impaired further, making them less resistant to that catalogue of diseases that haunt the Indian countryside.

Besides malaria, cholera, kala-azar, smallpox, beri-beri, dysentery, tuberculosis, hookworm disease, filariasis, guinea-worm and venereal diseases are ever-present and take their due toll. Then there are leprosy, blindness and partial blindness, mental disorders and mental deficiency, and a score of other infirmities. Nearly all these are curable or, what is more important, preventable, more or less, but in India the lack of comprehensive and organized medical services manned by an adequate number of competent and qualified doctors makes them very formidable. Curative medicine will solve only half the problem. As long as the people's vitality and resistance to disease is low, owing to poverty, malnutrition and ignorance, and as long as the shockingly insanitary and unhygienic conditions of the towns and villages persist, any medical approach to this problem can be only fragmentary.

Despite the inadequacy of the returns on the specific causes of death, a rough idea can be obtained from the following table for a representative pre-war year: 1939. The general death-rate of 22.2 for 1939 was distributed as shown in the table. It is highly probable that where deaths have been unattended by doctors, as considerable numbers are, the returns usually list 'fever' as the cause of death. This lack of precise information nullifies the efforts of the public health department because the authorities, who are anxious to control the death rate, do not really know its exact causes.

	Cholera	Small-pox	Fever	Dysentery and Diarrhoea	Respiratory Diseases	Injuries	All Other Causes
Deaths per 1,000 of population	0.4	0.2	13.0	0.1	0.9	1.8	5.8
Percentage of Total	1.8	0.9	58.1	0.5	4.1	8.1	26.5

Social Factors

The demographic situation of any region is largely the product of its peculiar social characteristics affecting in their turn births, deaths and migration. The population problem in India might be very different if the social institutions of early marriage, universality of marriage, the ban on widow remarriage, and the joint Hindu family, and other institutions and attitudes resulting in an adverse sex ratio did not exist. But, as these institutions with a socio-religious tradition and sanction behind them do exist, and condition the lives of an overwhelming majority of the people, the demographic problem has become what it is today.

Early marriage and universality of marriage are dominant features of the Indian social scene. Indian girls attain puberty between the ages of twelve and fifteen, and though often physically immature they are physiologically ready to bear children. And cases are not wanting where reproduction has begun at the age of fourteen or fifteen. The Report of the Age of Consent Committee and the Reports of the All-India Women's Conference have estimated that nearly 50 per cent of the girls married in India are below the age of fifteen. While child marriage as such has largely disappeared, a majority of girls between 15 and 20 are married. The girls in rural areas marry as soon as they reach puberty, begin bearing children early, and reduce the period of lactation, thereby shortening the intervals between childbirths and dying young.

The second factor is the universality of the married state. Everyone in India, sooner or later, gets married. It is a quasi-religious duty. As an individual's economic security is not a prerequisite to marriage, and as there is no individual choice, by and large, in obtaining a partner, there is no deterrent to marriage. For a representative census year like 1931, we find that 467 males and 492 females out of every thousand were married. That is, taking into consideration all widows, some widowers, ascetics and mendicants, almost everyone of marriageable age was actually married.

Whether factors favourable to the postponement of marriage, like prolonged education, waiting for lucrative employment, eagerness for personal and social advancement, free choice in securing life's partners, and other considerations that operate in a normal western society, will come to operate in India, it is difficult to say. But the sooner such considerations come to operate, the easier will be the approach to solve some of India's social problems.

A third striking characteristic of the Indian social situation is the scarcity of females. There has been a deficiency of women in the Indian population within the knowledge of her regular census history. In 1941 there were only 934 females for every 1,000 males. In 1931 and 1921 the ratio was 940: 1,000. The sex ratio in England and Wales in 1940, for

instance, was 1,000: 940 revealing a contrasting deficiency of males. The steady fall in the proportion of females to males has been going on in India since 1901, and the 1951 census is not expected to reveal any significant change.

Several explanations have been offered for this phenomenon of deficiency of females. Some explain it as the result of relative under-enumeration of women. This is possible, but during the last fifty years the efficiency of the Indian census organization has consistently improved, but the adverse sex ratio has increased rather than decreased. Some argue that excessive masculinity is an index of 'racial decadence'. But the sex ratio is more unfavourable in the north and northwest – parts of the present Pakistan region – where the so-called 'martial races' live. We have little knowledge of what constitutes 'racial decadence' and still less scientific evidence of the causes and symptoms of such decadence. If there is any truth in the idea, the virile people of the northwest must be the most decadent people. As this seems unlikely, racial decadence is no explanation of the odd sex ratio.

Some others, like the Census Commissioner for Bombay (1921) and the Census Commissioner for India (1931), have offered a biological explanation. According to the former, 'the Indian caste system with its exogamous *gotra* (sept) and endogamous caste is a perfect method of preserving what is called in genetics "pure line". The endogamy prevents external hybridization while the exogamy prevents the possibility of a fresh pure line arising within the old one by the isolation of any character not common to the whole line'. The latter, accepting this view, comments 'whether this (above) proposition be entirely acceptable or not, it may be conceded that if once a caste, whether as a result of inbreeding or some totally different factor, has acquired the natural condition of having an excess of females, this condition is likely to be perpetuated as long as inbreeding is maintained'. This explanation is at best plausible but we have very little knowledge about the presence of a genetic factor, if any, in the Hindu caste system.

The available statistics tell a different story. Actually, between the ages of 1 and 5, India has an excess of girls and only at the next age group is the sex ratio reversed in favour of males. A more rational explanation for the scarcity of females is that though the female infant is definitely better equipped by nature for survival than the male, the advantages she has at birth in India are probably neutralized in infancy by comparative neglect, and in adolescence by the strain of bearing children too early and too often. As Hindu parents put a greater premium on male children, they are apt to treat female children with relative neglect, especially when they are ill. This, coupled with early marriage and a high birth rate, results in greater and earlier deaths among women.

We have some comparable evidence in China that supports this view. Dr Ta Chen, discussing the sex ratio in the Kunming Lake region, observes 'It seems clear that in China relatively more female infants are born, but, as they grow up, the male babies gradually catch up with them in numbers, evidently indicating a proportionately higher mortality among female children. This may be due to the fact that in the Far East generally, and in China particularly, parents usually put higher value on male children for the perpetuation of the family line and for the observance of filial piety. Thus female children are unconsciously neglected, thereby leading to the higher death rate among them.'

The social ban on widow remarriage is yet another reactionary feature of Indian demography. The Indian demographic situation is closely interwoven with social problems, for one undesirable social institution leads to another, and so on, in an endless chain. This practice of 'socially sterilizing' the widows results in considerable disparity in age between husbands and wives. Since most widowers remarry, and since they cannot marry widows, they have to seek wives among girls much their juniors. This unequal combination leads to an increasing number of widows, for the old husband dies, leaving behind his young wife a widow. And, of course, she cannot remarry. The

disproportionate sex ratio and the resulting deficiency of women keeps up the custom of early marriage for girls.

Improvement of Agriculture

What is the way out? The problem of population has to be considered in relation to the food supply. Nearly 70 per cent of the population is dependent on agriculture for a livelihood. As the number of mouths to be fed every year increases, the area of productive land diminishes. That there is pressure on the land in India to-day cannot be denied.

Indian agriculture is characterized by primitive methods of farming, dependence on the vagaries of the monsoon, subdivision and fragmentation of land consequent on the Hindu and Moslem laws on inheritance (which enjoin the succession to immovable property by all male heirs, usually in equal proportion), leading to uneconomic holdings and to excessive dependence by the majority of the people on the land for livelihood.

Moreover, a quasi-medieval land-tax system has created a large number of parasitic middlemen who have come to possess undue rights on land, claiming a considerable share of the income arising from it without deserving it. The primitive technique of Indian farming is responsible not only for the low yield per head, even when compared to countries like Japan and China, but also for the gradual deterioration of land through soil erosion and deforestation.

This does not mean, however, that there is no immediate scope for improving Indian farms and their yields. According to 1939 official statistics, one-third of the cultivable land in both the Dominions lies idle – not fallow. The government statistics for undivided India (which exclude the Indian States) are as follows:

Agricultural area of the Provinces	*Millions of Acres*
Net area of professional survey ..	667.4
Area under forest	89.5
Area not available for cultivation ..	145.0
Cultivable waste other than fallow ..	153.6
Fallow land	51.0
Net area sown with crops	229.9

Thus, of a cultivable area of 432 million acres, only 53 per cent is sown with crops, 11.8 per cent is fallow, and no less than 35.8 per cent of land is cultivable but left waste. Then there is land 'not available for cultivation'. About this land the Royal Agricultural Commission (India 1926) said, 'It is difficult to believe that the whole of the vast area now classed as not available for cultivation, amounting as it does to 150 million acres or 22.5 per cent of the total area of British India (provinces) is either not available for cultivation or not suitable for cultivation'.

India has, therefore, not exhausted the supply of her cultivable land, and what is cultivated appears to be eroded and exhausted because of the primitive technique of farming. With modern methods of agricultural science, of erosion prevention and soil reclamation, the cultivated land can be made to double its present yield and much of the so-called uncultivable waste can come under profitable cultivation. Such an improvement would be welcome, but it would touch only a fringe of the problem.

While increased yield and more acreage of cultivation are possible with the aid of science, they cannot by themselves afford a better standard of living to the Indian population, or completely solve the population problem, unless and until a substantial number of people now dependent on land are transferred to some other productive employment such as industry.

Industrialization

Industrialization is often offered as a stock remedy for Indian population problems. A discussion of the possibilities of rapid and large-scale industrialization of India is beyond the scope of this article, but it must be pointed out that the basic prerequisites for industrialization, namely, raw materials, capital resources, skilled labour, a market and technological 'know-how' are available in India to a greater or lesser degree.

The industrialization that has taken place in India during

the last thirty years, however, has not helped to ease population pressure because it has been piecemeal and unplanned, and the percentage of population gainfully employed in modern industry has been less than one per cent of the total population. This haphazard industrialization has also led to the decay of cottage industries, causing further unemployment.

Only planned large-scale and rapid industrialization and the development of cottage industries – there need be no conflict between these two – can keep pace with the growing population and siphon off the surplus population from the overcrowded land to the factories.

India's industrialization is important in the solution of her population problems for two reasons. It will increase the productivity of labour and create an abundance of badly needed commodities and services and transform the present economy of scarcity into an economy of abundance. Secondly, and this is probably more important for India, industrialization will encourage the development of new urban patterns of living which lead to the control of the high birth rate. The 'why' of this process need not be discussed here, but this has been the experience in the United Kingdom, the United States and the West generally, and in Japan. There is no reason why India should not conform to this experience of other countries, where industrialization has been accompanied by declining fertility.

Migration

What about migration as a solution to the Indian population problem? The world has not reached the stage for the adoption of an international migration policy based on the needs and available resources of various countries and peoples. And once we grant, as we must, that every country must have the right to determine the composition of her population, India cannot object to the unwillingness of certain countries, however thinly populated they may appear to be, to receive large numbers of Indian immigrants. Nor does India want to create unhappy minority problems such as exist in the Union of South Africa.

The total number of Indians settled overseas as permanent immigrants is to-day about four and a half million, but the annual increase of India's population is about five millions. Even were emigration outlets available it is unreasonable to expect a major portion of this annual increase to leave their homeland. For India, such relief may not be a permanent solution. All the available evidence shows that, though the immediate effect of large-scale emigration is to reduce the population of the sending country, such effect is always shortlived because the vacuum thus created is soon filled up again.

As for the possibility of internal migration as a method of relieving the population pressure, there is not much scope here either, because there are no empty spaces within the geographical confines of India and Pakistan. There are, of course, certain provinces and regions where the crude density per square mile is relatively low, as in Assam in India, and in Baluchistan in Pakistan. During the last fifteen years, half a million immigrants went to Assam from other provinces, particularly Bengal. The provision of some admittedly inferior land for half a million people during a decade and a half, when the country's population increased by more than fifty million people, is only a drop of relief in an ocean of need.

For this and other reasons, internal migration offers no substantial relief from population pressure. And the partition of the country, which has already forced communal migrations upon both the Dominions, renders the prospects of further inter-provincial migration dim.

Birth Control

The last and the most important solution is that of Birth Control. It is too late in the day for India to discuss the pros and cons of birth control. The arguments for and

against contraceptives have been advanced *ad nauseam* and the scientific verdict has been in favour of it. Birth control appears to be an important solution. It has a vital role to play in India's population policy, along with the modernisation of agriculture and the industrialization of the Indian economy.

Apart from the general rural conservatism of the masses, who offer resistance to every reform, there is no organized resistance either by the Government or by the Church, as in some countries. Nor are the Indian religions opposed to planned parenthood. It will not be a hard task, therefore, to enlighten the public mind in India as to the benefits of birth control. Once the public health officials begin hammering its importance, it will spread even to the traditionally forgotten villages. Once Indian mothers are educated in the knowledge that there is a scientific device to meet their desperate, albeit latent demands, birth control can easily make headway.

There are, of course, certain special difficulties which should be taken into consideration before planning a network of birth control clinics. It should be recognized that a majority of the Indian people live under backward conditions. Matters like bathrooms, running water, privacy, cheapness, the reliability and availability of contraceptives, and the illiteracy of women, need attention. No matter what the obstacle, this reform must be brought about.

Fortunately, this question has not been completely ignored in India. The authoritative Health Survey and Development Committee appointed by the Government of India observes, in its Report (1946), 'All of us are agreed that when child-bearing is likely to result in injury to mother or infant, there is every justification for the practice of contraception. In such cases it should be the responsibility of Governments to provide instruction regarding contraception in maternity and child welfare centres, dispensaries, hospitals and any other public institutions which administer medical aid to women. We also consider that the supply of contraceptive requisites should be made free of cost by the State to necessitous women when the practice is advocated for reasons of health. There is also unanimity among us in respect of State action in two other directions, namely (1) control over the manufacture and sale of contraceptives, as in the case of food and drugs, and (2) assistance from public funds towards research for the production of a safe and effective contraceptive.'

But the most important need in India is to provide contraceptive advice on *economic* grounds. Even this authoritative committee could not shake off India's traditional obscurantism and include poverty and the low standard of living as a pressing reason for adopting contraception and limiting the size of the family.

The Indian National Congress, however, set up during the war a National Planning Commission under the Chairmanship of the present Prime Minister, Pandit Jawaharlal Nehru. One of the Committee's resolutions recommends, 'In the interest of social economy, family happiness and national planning, family planning and a limitation of children are essential, and the State should adopt a policy to encourage these. It is desirable to lay stress as well as to spread knowledge on cheap and safe methods of birth control. Birth control clinics should be established and other necessary measures taken in this behalf and to prevent the use or advertisement of harmful methods.' The resolution is significant enough, but goes on to add, 'A eugenic programme should include the sterilization of persons suffering from transmissible diseases of a serious nature such as insanity or epilepsy.'

This resolution was adopted by the National Planning Commission when India was not free and when it had no governmental authority. Now that the Chairman of the Committee is the Prime Minister of India, it is to be hoped that the resolution will not remain a pious sentiment on paper but will be translated into action. India's population

problem is distressing enough as it is to-day, and any delay will only accentuate the difficulty.

Human Conservation

In brief, despite the unprecedented scientific advances in the world during the last thirty or forty years, there is an enormous loss of human life in India. With all the available resources of scientific knowledge, skill and facilities for protecting people's health, and curing or alleviating the many ills and disabilities to which people are exposed, India continues to waste thousands of human lives.

Living conditions to-day have become complex and difficult compared with conditions a century ago. The majority live in overcrowded villages without any sanitary or medical facilities, and those who live in towns and cities find themselves in crowded conditions where earning a living, rearing children and running a home have become a formidable problem. Despite the fact that our belief in the intrinsic value of human life is a central part of our culture, we have offered resistance to certain reforms that encourage healthy and purposeful living.

This resistance comes from certain traditional ideas and beliefs that still linger from the past, when we were largely helpless against the diseases and dangers of life, and more or less ignorant of human needs and possibilities. To-day much human waste is tolerated because of a fundamentally defeatist belief in man's helplessness against superhuman and mysterious forces which are supposed to control his life and make everything inevitable. Perhaps not a little of the tragic waste of human life is due to a conviction that human ills and misery are well-merited punishments for our misdeeds and guilt. Many a marvel of medical advance has been more or less opposed as interfering with a divine purpose which has ordained human suffering.

While belief in 'fate' as a controlling factor is slowly tending to disappear, it has not disappeared completely. These fatalistic beliefs persist in every society, but much more so in India, long after they have been rendered obsolete by a scientific knowledge which is yet powerless to displace them. The sooner we can truly get rid of them the better and easier will be our approach to the human problems of life, longevity, and death.

(This article is part of the Unesco *Food and People* series, and will be republished later in a separate volume with other articles on population problems.)

Science Front

Chloromycetin

SINCE Florey put penicillin on the map, there has been a feverish search through all the known moulds for similarly effective antibiotics. More than that, pretty well every plant in the botanical kingdom has been minced and extracted to see if its juices are anti-bacterial, while the quest for new species of moulds has forged ahead. Streptomycin, a substance made by a mould which grows in the soil, has already proved successful in some forms of tuberculosis, and gained world-wide fame in consequence. It has encouraged further search among the teeming millions of microscopic individuals representing thousands of different plant and animal species, many of them as yet unknown to science, which live and die in soil all over the world.

In 1947 Dr Burkholder of Yale had a stroke of luck. He discovered a new species of mould, a relative of the one which makes streptomycin, in some soil from Caracas (Venezuela), in South America, and found that this mould, which he called *Streptomyces venezuelæ*, produces an unusually promising antibiotic. It not merely killed a number of different kinds of bacteria growing in test-tube cultures, but protected mice infected with the germs of typhoid and of Relapsing fever. More important, it seemed to be valuable in a number of virus diseases too, when tried on embryo chicks infected with various viruses while growing inside the egg.

To understand the significance of its action against viruses, we must say a word about infectious diseases in general. There are two great groups of them. In one, the infectious agents, in the group called bacteria, grow and multiply and make their poisons in the fluids of the body.

They may live in the mucus of the nose and throat or the juices of the intestine, or in the circulating blood stream or the lymph, but they never penetrate within the cells of the various organs; they exist only outside the cells and do damage from outside by the chemicals they produce. Diseases such as scarlet fever, pneumonia, diphtheria and typhoid are thus caused.

But in the other group the infectious agents, the viruses and the rickettsiæ live inside cells interfering with their normal life. The common cold, measles, infantile paralysis, are such illnesses; while the rickettsiæ are larger intracellular organisms causing various forms of typhus. These germs inside cells are much more difficult to fight. Any drug which interferes with their existence may kill their host cell too, and safely tucked away in the host's cytoplasm a virus is out of reach of the body's usual defences, the antibody and the phagocyte of the blood stream. So we find that hitherto chemotherapy has had its big successes against bacteria which are free in the body. Sulpha drugs, penicillin, streptomycin, all go for the extra-cellular germ and are powerless against viruses, and consequently the first news that chloromycetin would attack certain viruses in the chick embryo was exciting and hopeful.

Chemists of Parke, Davis, Inc., set to work to purify and analyse the antibiotic, as a preliminary to making it in large enough quantity to try out on human patients. They too had luck. They found the mould would grow well in submerged aerated culture and could be thus cultivated on a large scale. The filtrate from such fluid culture gave up its chloromycetin after fairly straightforward chemistry as crystals – light-yellow needles and plates – and the second stroke of chemical luck was that it turned out to be a relatively simple organic chemical substance, and one which, unlike penicillin and streptomycin, can be synthesised in the laboratory and the factory. It is an unusual substance for a living thing to make – a derivative of nitrobenzene, with some chlorine atoms in a side-chain.

Meanwhile the first medical tests took place in Mexico in January 1948 when Drs Smadel and Ley had enough to treat a few typhus patients during an epidemic, with promising results. Then a couple of months later they had the opportunity of trying out the new drug in Malaya with the help of the Institute for Medical Research at Kuala Lumpur. Since 1924 outbreaks of Japanese river fever, or tsutsugamuschi fever, or scrub typhus as it is also called (it is caused by a species of rickettsia, introduced into the blood by the bite of a mite) have been occurring on and off in Malaya. During the war of 1939-45 there were 25,000 cases of the illness amongst Allied forces; and very nearly one in every six scrub typhus patients dies. Dr Smadel and his American colleagues flew to Malaya with one pound of Chloromycetin, the world supply at that time, and went to a rubber estate where an explosive outbreak of the disease had occurred. They treated forty cases without a death, and many of the patients were noticeably better 24 hours after starting treatment.

Since then further experience has confirmed the value of the new medicine in typhus, and various doctors have also had promising results when using it against the unrelated disease typhoid (due to bacteria). In Britain the Ministry of Health has conducted careful trials which suggest that chloromycetin may become the standard treatment for typhoid. Unlike penicillin it is taken by mouth, which is convenient and pleasant, and it acts fairly quickly if it is going to at all. So far it appears to be harmless to humans, and no reports of germs becoming resistant to its action have yet appeared. But since it is still less than two years old we probably have a great deal yet to discover about it.

At the time of writing, Aureomycin ('Duomycin', is a trade name) is another chlorine-containing antibiotic, which is not unpromising, but chemically still of unsettled formula. It is reported to be active in typhoid, and in a rickettsial disease (Rocky Mountain spotted fever), and it is made by *Streptomyces aureofaciens*, another of these soil moulds.

What is Cybernetics?

IN a book published last year by Professor Norbert Wiener of the Massachusetts Institute of Technology is a new word for an old subject, which previously never had a name to itself. Cybernetics, from the Greek word for steersman, is the science of control and communication mechanisms in machines and animals. Note this link-up in the definition, because what has excited Wiener is certain similarities between the way some machines are made to work and the way animal and human brains function, and he believes that knowledge used in designing modern calculating machines ('electronic brains') and other apparatus may help us to an understanding of the nervous system and the heart beat.

At the Royal Society's conversazione earlier this year there was a machine which defeated some of the Fellows at noughts and crosses. That is to say, except on an occasion when it broke down, it always won if it was possible to win, and never made a wrong move. In a note at the end of his book Wiener remarks that it would be possible to build a machine which would play a fair game of chess, with some power of thinking two or three moves ahead and thereby avoiding an opponent's threats, and even perhaps securing a mate on its own account.

This sounds terrifyingly like the beginning of the Age of the Robots, so let us be quite clear about one thing. This chess-playing machine could act only from the information built into it by the designer – a man who understands chess. If the machine were to foresee two or three moves, the opponent's threat developing, it would be only because the designer was aware of all the possible sequels to certain opening gambits, and had so made his machine that it could recognise certain pattern layouts of pieces and respond accordingly. If the designer himself is only a poor chess player, the machine can be no better.

In the same way the modern electronic calculating machine which solves mathematical problems unsolved

since the 17th century, does so only because it can do with lightning rapidity a sum which a man with paper and pencil can do only slowly. The problems it solves are not so much difficult as long and laborious. These machines are designed by mathematicians, of whom Wiener is one, and their 'brainpower' is never greater than that of their designers.

During the war, a machine was developed which watched an enemy aircraft by radar, plotted the plane's movements for a few moments and then made a prediction where it would be a few moments hence; this information it signalled to an anti-aircraft gun which automatically moved and pointed in the given direction. The prediction here was really the designer's. He had built into the machine the ability to guess that an aeroplane moving along a certain curved path at a certain speed, would (if it did not suddenly change course) be at a certain point in space so many microseconds hence. The path and the speed it learned through its radar eye. A machine can of course also be made to see daylight – for example, the modern television camera, which can view scenes quite like the human eye.

The Robot Men from Mars of popular fiction are conceived as vaguely human in form, stumping about on great metal legs. This conception has deceived us. A machine to read a book to the blind can be made, so they say, but it will not have a great metal head with photocell eyes, which would be an unnecessarily clumsy design. No doubt it can be designed to close the book at the end of the chapter and go out to the kitchen and make a cup of tea – but no engineer in his senses will expect it to walk if it can run on wheels, or some kind of caterpillar track.

In fact the robots have been with us some time, only we have failed to recognise them because they look so different from Galatea – or the Venus de Milo. The automatic telephone exchange, the photocell which counts the crowd going through the gate, the governor of an engine which regulates its speed, are all old friends. How about the typewriter which prints letters faster than human hand can write in response to jabs from our fingers, and rings a bell when we reach the end of the line? Have you ever seen a teleprinter at work, mysteriously typing messages by itself without a sign of human intervention?

These new machines are amusing, they are useful, but on reflection they are seen to be quite harmless. And on the other hand, philosophers and scientists have been talking of man as a machine since the 18th century. The analogy of the brain and the telephone exchange has been common talk in popular science since exchanges were invented. What then is there special about Wiener's Cybernetics?

I think it resides in this: physiologists learn to understand living processes in terms of non-living phenomena, and the right sort of mechanical model can be mentally very illuminating in suggesting new experiments and new physiological hypotheses. Lord Kelvin used to say that he could never understand a physical idea until he could make a model of it. Physics has passed this stage now, but physiology is still in it.

What Wiener is doing is pointing out that modern communication engineering offers much better models than anything hitherto. These machines have a limited function of memory, they have trouble in keeping their memories pure and distinct (i.e. without distortion), they work by a process of symbolisation. If they hear or see, they do so by converting the sequence of light waves or sound waves which reach their photocells and microphones into a sequence of electrical pulses: so do we. When they work out complicated mathematics, they start by converting the figures into electrical pulses: perhaps we do too. Wiener's ideas have led him, in conjunction with a physiologist, Dr Rosenblueth of Mexico, to make new physiological experiments as well as many stimulating suggestions, and any approach which does that must be respected. If they shake up other workers' ideas on neurophysiology likewise and suggest new lines of investigation to them, they will have justified their christening of the new baby. But it is still such a young baby that it

would be rash to prophesy that it will live and grow up. We will have to come and have another look at Cybernetics in two or three years' time.

Astronomers Talking

It is not often the outsider gets an opportunity for even a partial picture of the way a subject is tending, but last year's meeting of the International Astronomical Union, the first for ten years, taken in conjunction with recent papers does give some indication of current astronomical interests.

The sun seems to take pride of place just now. Partly it is the theoretical interest stimulated by Professor P. M. S. Blackett's ideas on magnetism. It will be remembered that he postulates a relation between the angular momentum of a revolving heavenly body and the strength of its magnetic field. The magnetic measurements of the sun made at Mount Wilson observatory were an important basis for this theory, but last year both Mount Wilson and the Hamburg observatory announced that, using the very apparatus which had measured the solar magnetic field before, they could now no longer even detect it. Whether this means that the solar magnetism is changing or that there is present an unsuspected source of experimental error is not clear, but the failure is stimulating further enquiry into a vital point.

Many new methods are being applied to the study of the sun. The V2 rocket in its modified improved version rises high enough away from the earth to clear the greater part of the atmosphere which absorbs ultraviolet radiation, and spectrographs with cameras fired to 100 miles high can photograph the true ultraviolet spectrum of sunlight, for the first time unmodified by the air. Visual observations of solar prominences, the great sheets of flame leaping thousands of miles from the sun's disc, are giving way to high-speed cinematography, which records every leap and flicker for subsequent study in detail in slow motion, and has shown that these great jets of glowing hydrogen and calcium leap 60,000 miles out into space, and then fall back again along the same path to the sun. Furthermore, these prominences of the sun's corona which could formerly be properly studied only during the few minutes of total eclipse, can now, thanks to Professor Bernard Lyot of Toulouse, be studied at almost any hour of any day through his polarisation filter, which reduces the amount of sunlight to something the human eye can tolerate.

Particular attention is being paid to solar flares, first described in 1931 as brilliant eruptions from the chromosphere in the neighbourhood of active groups of sunspots. These flares last anything from five minutes to an hour, and may cover over five thousand million square miles of the sun's surface. They begin as an intense burst of light, then slowly decay, and in contrast to the prominences remain stationary. They occur irregularly, unpredictably, and their appearance is always linked with effects in the earth's atmosphere, which is one reason why extreme interest is now being shown in them.

There are two kinds of effects. One group occurs more or less at the same time as the appearance of a flare, the other follows about 26 hours after. One of the immediate effects is a burst of radio noise in the 1–20 metre wave-band, with a maximum around 5 metres. This radio emission is strongly directional and makes the loudest noise when the aerial is pointing at the sun. At the same time there are geomagnetic 'crochets', sudden small variations shown in the earth's magnetic field as recorded continuously on observatory instruments. Also short wave radio reception on 10 to 50 metres may show a sudden fade out, lasting a minute or so.

These changes are explained by the sudden arrival of unusual radiation from the sun, and they are confined to the sun-lit side of the earth. The ultraviolet light of extreme intensity which is given off by a solar glare, excites oxygen in the upper atmosphere, and some of the atoms become ionised and form a non-reflecting layer which absorbs short waves – hence the fade-out. This layer is believed to be about 70–90 kilometres up. But the other layers, which exist

normally and do reflect radio waves, are also interfered with, and measurements suggest that one of them may be forced down ten miles or so. The whole process is complicated, and is still the subject of analysis.

The later effects are intense magnetic storms, accompanied by the aurora, and are due to the arrival of an intense blast of ionised particles fired out of the solar glare at 1600 kilometres per hour (about 1000 m.p.h.).

Thus observation with instruments of all that the sun sends us shows that our eyes miss most of what is going on, and is helping to change our knowledge of the stars in general, for the sun is a very average star. These flares it shows from time to time are thought to be analogous to lightning flashes, sudden high concentrations of electrons liberating energy, and they are probably produced by most stars in the universe.

*FACTS FOR INDUSTRY**

Electronics and Machine control

Many women in the Boston area of Lincolnshire are said to suffer from defective sight through the strain of 'pea picking' or sorting of peas as they pass on a band conveyor. An operation of this kind, at once monotonous and calling for close attention, obviously involves fatigue causing inefficiency at the end of the shift. It offers, therefore, an ideal opportunity for the application of automatic electronic devices.

On twenty-four machines installed at a canning factory in Worksop, near Sheffield, each and every one of the more than 124,000,000 peas canned every day by Batchelor's Peas Ltd is individually inspected by photoelectric cells so that blemished peas may be rejected.

Peas are picked up singly by one of thirty-six suction 'ferrules' or rods on each machine and passed through soft

*This section is selected from a monthly news letter of the same name.

light. Mirrors reflect the light to lenses with blue colour filters sensitive to the brown patches on imperfect peas. These blotches reduce the total amount of light falling on the photoelectric cells and this slight variation is enough to vary the electric current it actuates and thus bring into action a device which rejects the blemished pea.

Automatic counting is no longer an electronic problem. To replace existing electro-magnetic machines with speeds of 500 or 1,000 a minute, electronic instruments are available that will count 10,000 articles *per second*. The problem is now to find a way of feeding articles into the counting mechanism at a sufficiently high speed. Compressed air has been used to blow them in, but the speed is still inadequate.

With an instrument called the Nephoscope it is possible to detect sedimentation in beer, milk or other liquids in proportions as low as one part in 100,000. Such a degree of sedimentation would be quite imperceptible to the human watcher, and the Nephoscope's warning enables processing faults to be corrected long before the quality of the product is affected.

A perception head fitted to cutting or printing machines observes pre-printed marks and enables them to be registered or cut within a few thousandths of an inch. Such a paper-positioner, costing less than £100, ensures perfect accuracy in paper cutting or printing register. Another instrument counts printed matter coming off the press – an improvement on counting devices dependent on revolutions of the cylinder, whether or not paper is fed over it.

If a single one of the 800 threads passing through a nylon spinning machine breaks, the whole machine is stopped. This is effected by means of sixteen perception heads, each of which watches fifty threads.

Many other actual and potential uses of electronic devices may be mentioned, including a photocell apparatus for stopping machinery when a workman inadvertently strays into a danger zone, an automatic switch for adjusting artificial illumination to the degree of daylight, devices for

cutting into lengths plastic rods extruded at variable rates from the heads of an extrusion press or for cutting paper or fabric webs emerging at variable rates and – perhaps most remarkable of all – a machine tool which is now being designed to operate from the 'instructions' as to dimensions, tolerances, etc, fed in on punched cards.

Radioactive fire alarm

Discovery of an outbreak of fire in its earliest stages requires an efficient smoke detector. The photocell devices sometimes used for this purpose are not wholly satisfactory because fortuitous air currents may carry the smoke away from light falling on the cell, and also because the instruments are somewhat cumbersome.

Developing the ten-year-old idea of a Swiss inventor, and in collaboration with a Swiss firm, Electronic Instruments Ltd have now perfected the Minerva smoke detector which combines an electronic relay with a radioactive ionisation chamber. The device, only 6 in. long and 3 in. in diameter, consists of two chambers, one of which contains a fragment of radium. The alpha particles emanating from the radium render the air in the chamber conductive, and a minute current flows across the chamber from the voltage applied to it. When smoke particles enter the lower section of the chamber they absorb the alpha particles, causing a decrease in the ionisation current and therefore a rise in the voltage which may be as much as 30 volts. This initiates the primary discharge in a cold cathode tube, operates the electronic relay and actuates the alarm.

A single power supply will feed up to fifty smoke detectors, and each unit will protect from 20 to 50 square yards of floor area. A time delay device is fitted to ensure that the relay is not actuated by fewer than three puffs of smoke in a minute – a safeguard against the humorist with a cigarette; and small accumulators make the device independent of mains electricity. Many of these detectors are already in use in military and government establishments in Switzerland.

Heat-resisting paints

Butyl titanate is the basis for paints that resist temperatures of 1,000 deg. F., developed by the Australian Council for Scientific and Industrial Research (now to be known as the Commonwealth Scientific and Industrial Research Organisation). Tested on the inside of a flue stack, one of the paints was little affected after 32 weeks, although corrosion is normally so great that 1 oz. of steel per sq. ft. is removed every six weeks. The new paints are also highly resistant to salt-water corrosion. Butyl titanate can be added to linseed paints to confer resistance to weathering and 'chalking' (flaking off as a white powdery residue). It can also be used to give a matt finish to nitrocellulose lacquers.

How to design a motor car

To please the overseas buyer, British car manufacturers have sunk hundreds of thousands of pounds in tools to transform their once individual, though no doubt unfashionable, car bodies into scarcely distinguishable variations of the beetle with a chromium grin which is the American motorist's ideal of modernity. It is an ideal which even the intelligent American has begun to regard as somewhat bogus. Nothing has so effectively brought out the difference between genuine design and meretricious styling as the contrast between two recent papers. One author approaches the subject from the point of view of safety, the other is concerned solely with appearance.

In *Medical criticisms of modern automotive engineering* Dr F. D. Woodward offers detailed suggestions for modifications in design which would, he asserts, prevent many deaths and injuries. Because speed is a factor in two out of five fatal road accidents, he advocates the use of governors which would restrict speed to 55 m.p.h.

Windscreens and rear windows ought to revert more nearly to the vertical, to give better visibility. Doors should be standard, with windows large enough to serve as escape

hatches and high enough to prevent the passenger resting a protruding elbow on the ledge. To give the driver a better view of the road and freedom from reflections the bonnet should be made lower and shorter, its top painted matt black and all chromium parts eliminated. The steering column should move forward hydraulically under an impact of 100 lb. to prevent chest injury, and crash pads should be fitted to the dashboard and the backs of the front seats. Bumpers should be mounted on oleo shock absorbers similar to those on aircraft landing gear. Tubes proof against blow-outs should be used in tyres, even at the expense of some riding comfort. The windscreen ought to be of polarised safety-glass, and the additional cost could be offset by eliminating 'clocks that don't run, radios, radiator ornaments and other useless gadgets'.

Dr Woodward's opinion of the vogue for streamlining is expressed in his comment that 'The only influence of aircraft design apparently so far adopted by automotive engineers is the erroneous one that the aerodynamic principles of a jet-propelled aircraft should be applied to a vehicle the speed of which should be limited to 55 m.p.h.', and he quoted the view of A. W. Stevens, president of the Automobile Safety Association, that 'Automobiles should be redesigned to stress safety rather than speed and appearance'. A poll taken by the American A.A. is said to have confirmed his standpoint. Two-thirds of the motorists interviewed agreed that the driver's view of the road is the most important single factor in body design; fewer than one-sixth voted appearance to be the most important.

And this is how car bodies are in fact designed, according to Raymond Loewy, addressing the Society of American Engineers on 'Styling the Studebaker'.

First, the design problem is explained to the design staff, who are given blueprints of the chassis, dimensions, clearances, and an exposition of the 'design philosophy' established by directives from the management, the practice of competitors and the buying public's preferences. And however much this philosophy may change from year to year, two principles are immutable: Weight is the stylist's enemy; and the car must have styled-in forward motion to appear fast even when it is stationary.

Groups of designers tackle assigned parts of the work, turning in their designs either as rough drawings or as clay models. Ideas are assembled for half a dozen cars, which are modelled quarter-size in clay. Selected models are cast in plaster, painted and trimmed with bumpers, headlights, handles, etc. Then photographs are projected on to screens so that the models may be seen in natural surroundings. Finally, plaster or wooden mock-ups are constructed, the models being revealed suddenly in ordinary daylight to spectators 150 feet away to obtain their first impressions.

And that is how the U.S. industry designs the lethal instrument which is put into the hands of a million boys and girls of the 15–24 age-group who qualify for their driving licences every year. The death-rate in this group is second to that in the 'over 65' group, but many of the old people are pedestrians.

Food Yeast

The food yeast scheme in Jamaica began as an imaginative attempt to solve the problem of malnutrition in regions where monoculture has at the same time destroyed the basis for local food production and led to the accumulation of vegetable wastes from which a high-protein diet supplement can be produced by fermentation. It was hoped that the yeast, *Torulopsis utilis* would supply a good substitute for the meat which West Indians neither produce nor can afford to buy. The project, initiated during 1939–45, met with economic and technical difficulties. Costs were doubled, owing chiefly to a rise in the price of molasses on which the yeast is grown. Engineering difficulties had to be overcome. But to-day the plant is at work, producing 12 tons of yeast a day. Now the scheme faces its third obstacle – the sales

resistance of consumers who reprehensibly judge food by its flavour and not its protein content.

West Indians' reception of the food has hardly been rapturous, and the bulk of the output has been used for famine relief in Malaya. Having learned that malnutrition does not weaken conservatism in diet, the Colonial Office has now to find a propaganda technique for introducing this unfamiliar ingredient into protein-deficient diets. In the meantime, British food manufacturers are to have the opportunity of studying how to use it in their own formulations.

Soups, gravies, meat extracts and invalids' foods obviously lend themselves to yeast enrichment, and its addition to pasties, canned foods, breakfast cereals, proprietary breads, pies, beverages, chocolate, etc, is worth investigating. Supplies of food yeast are available for experiment. The price of the product on the British market is around 1s. 6d. per lb., with the possibility of some reduction for large quantities.

Yeasts replace beasts

It is clear to nutritionists, if not to the masses, that supplies of animal products are not likely to keep pace with the world demand for protein and that, if the growing population of the world is to be adequately fed, yeasts will have to become a staple article of food in many countries. Yeast can synthesise proteins from carbohydrates 144,000 times as fast as the bullock does. At present we are making insufficient use even of the by-product yeast from brewing and distilling; the large-scale fermentation of vegetable wastes and the hydrolysis of wood has hardly begun. Nutritionists' interest in the subject is reflected in several recent papers.

Twenty-eight such papers were read at a conference on yeast in Milwaukee, in 1948. Brewer's yeast (*Saccharomyces cerevisiae*) has long been used as a test organism in biochemical and physiological research, but little is known about other yeasts. *Torulopsis utilis* is employed for high-protein synthesis, *Ashbya gossypii* for high-riboflavin synthesis. Strains could be bred for producing almost any specific diet constituent. Strains have been produced capable of producing 60 per cent of their dry weight as fat.

The four- or six-fold increase of yeast cells during fermentation of beer results in a surplus of ½ lb. of yeast solids for every barrel of beer. Only about a third of this surplus is dried and processed.

The chief objection to brewer's yeast is its unpleasant flavour, due not only to the bitterness of the hops but to the taste of the yeast itself. Recent improvements in processing by debittering, drying and smoking have made it more palatable.

It is probable that before yeast becomes acceptable as a staple article of human food it will be far more extensively used in animal feeding. While it is derived chiefly from the brewery by-product, however, its price will limit its utilisation, for drying trebles the cost of production. There is plenty of evidence of its value in animal nutrition. Addition of yeast to the standard calf ration increases growth by about 30 per cent during the first four months. Central drying plants with a large continuous output are necessary, for smaller breweries produce quantities too small to justify a drying plant.

Yeast is also potentially a starting material for the production of lecithin, glycogen, nucleic acids and a range of technical products such as resins, soaps and detergents.

Continuous butter-making

The American associates of two British companies have developed equipment for processes of continuous butter-making. One of them, Cherry-Burrell Ltd, is already conducting propaganda for its system, chiefly in foreign markets. Manufacture of the equipment, except perhaps of key units, is not contemplated in this country. The other, the Creamery Package Manufacturing Co. Ltd, is still

investigating the prospects for manufacture in this country, both for use by British creameries and for export. Import of the American machinery, except perhaps of prototypes for experimental work, appears to be ruled out by the regulations restricting dollar purchases.

Hitherto, butter has been made by a slow and rather crude batch process, essentially the same as that which has been used from the earliest times. To make the process continuous it was necessary to find a way to accelerate the conversion of an oil-in-water emulsion – cream, into a water-in-fat emulsion – butter. Hartmann, of the Bell Machinery Co., of Australia, demonstrated that this could be done. The Alfa process, developed almost simultaneously in Germany and Sweden and, later, the German Fritz process, were the first systems to be commercialised, and there are at least twenty plants operating by each of these processes in Germany. There are other systems, including one known as the Roth process.

American and Canadian dairy engineers have studied all these systems since the war but concluded that none of them could be adopted without modification. In the meantime, the two American systems have been perfected.

In the Cherry-Burrell process, for which a chain of nine units of equipment is provided, the cream is first heated to 110–120 deg. F., while high-speed centrifugal agitators cause the globules to begin to coalesce, and then the weakened emulsion is broken in a centrifugal separator revolving at 6,200 r.p.m. The fat discharged is pasteurised at 200 deg. F. for a few seconds. In the Creamery Package process, cream that has already been pasteurised is heated to liquefy the fat and decompose the enzymes that would cause rancidity. After concentration to 75–80 per cent fat in a centrifugal separator the material is pumped through a homogeniser at high pressure.

It is claimed for the Cherry-Burrell system that it reduces manufacturing costs by using less steam, refrigeration, labour and floor-space, that sanitation and quality are improved through eliminating manual handling and excluding light and air, that moisture in the butter is more finely dispersed and better retained, and that the fat content is more uniform. Two Cherry-Burrell plants are in operation.

If continuous operation is widely adopted its effects on the dairy industry will be seen rather in countries with highly-developed dairy products exporting industries than in Britain, where the preference for the liquid milk market reduces the amount allocated to creameries. If, however, milk production continues to rise and the purchasing power of the lower-income groups tends to fall, British farmers may find the butter-making price more attractive than it is at present. One consequence of continuous operation is likely to be the concentration of butter-making into larger units, and an increase in the scale of operations to a point at which it becomes economic to collect the whole milk rather than cream from the farms; and to set up by-product plants to deal with the skim milk, now largely wasted in Australia and New Zealand. With the Alfa process, in fact, the collection of milk is essential, for it requires fresh cream. Daily collection of milk, instead of twice or thrice weekly collection of cream, would of course require much additional investment in transport and storage equipment.

Fish distribution survey

Investigators of the Department of Scientific and Industrial Research and the Scientific Advisory Section of the Ministry of Food have been carrying out a survey of the temperature to which fish is subjected at all stages from catching to purchase by the consumer. This is part of a thorough investigation of the problem of fish spoilage, from which it is hoped to develop improved methods of distribution such as rapid pre-chilling of newly-caught fish in chilled, circulating sea-water, better insulation and chilling of fish-holds, reduction of the rise in temperature on landing, filleting and packing for inland distribution, and improved temperature control during transport and retailing.

Dr G. A. Reay of the Torry Research Station thinks that no method of temporary 'buffering' of supplies is likely to supersede stowage in crushed ice. Extension of the preservative powers of ice by inclusion of chemical substances or by gaseous carbon dioxide during storage is not very promising and, in any case, is forbidden by food and drug regulations.

The conditions in which white fish is handled are the most unsatisfactory. At least half the supplies are caught on voyages of three to four weeks, and have to be stowed in the hold for seven days or more. Proper freezing and cold storage facilities ought undoubtedly to be installed. What remains to be done is to find out how to apply the method technically and economically to conditions obtaining at sea.

Vitamin C as preservative

Originally suggested as a preservative in 1945, ascorbic acid (vitamin C) is already being used commercially for this purpose in apple juice, frozen peaches and frozen apricots. It shows considerable promise as an antioxidant for frozen fish, and development work is in progress to test its effectiveness with peanut butter and potato chips. It imparts no objectionable taste or odour, and is relatively cheap. Its effectiveness in retarding rancidity in fish appears to vary with the kind of fish and to be proportional to fat content. In commercial-scale tests water solutions containing 1.5–2 per cent of ascorbic acid have been used for 15–20 seconds. With some foods, for which the use of ascorbic acid is doubtfully justified as an antioxidant, it is worth while for its colour-retention property.

Disillusionment about DDT

Farmers and health officials are re-learning the old lesson that 'the more you spray, the more you may'. Experience with every new economic poison goes through the same phases. The initial success is spectacular. Then it is found that more and more poison must be applied, more and more frequently, to achieve a 'kill' sufficient to save the crop.

Then undesirable side-reactions are noticed. Finally, the poison finds its permanent and limited place in farming practice, and interest switches to a new and incredibly potent chemical.

DDT, benzene hexachloride and the other new synthetic insecticides are going through the same stages, with these differences; firstly, the speed and scale of their introduction into farming practice and the hopes encouraged by the publicity they received have deepened the reaction of disappointment, secondly, many of the adverse effects were predicted and might have been guarded against if the science of ecology were as well developed as that of chemistry.

Adverse reports about the new insecticides began to circulate early last year. Recently they have become numerous. Sales of DDT in America slumped last year, exports being especially disappointing. After a DDT house-spraying campaign in Italy it was found that, in contrast to previous experience, houseflies were not killed, although malaria-carrying mosquitoes remained susceptible. Resistant strains of flies have been reported from several areas in the U.S.A. In one case only 5–10 per cent survived the first sprayings, but at the fifteenth the generation resistance was practically doubled, and it is now hardly possible to apply enough DDT to get a 100 per cent kill. The resistant flies are larger, darker and more active. In Tanganyika the discovery has been made that the irritant effect of DDT, used as a house-spray, causes mosquitoes to fly away before they have absorbed a toxic dose, from which the inference is drawn that the famous residual effect is in this case illusory.

While DDT loses its popularity, benzene hexachloride (the gamma isomer form of which is known in this country by the trade-name of Gammexane) is gaining ground. In the Tanganyika trials just referred to, Gammexane's killing power persisted for 13 weeks against the mosquito *Anopheles gambiæ*, and not one live insect was taken in the window traps. But of benzene hexachloride there have been many reports of taints in food grown in treated soil. It has been

found to flavour tea, potatoes, and milk from cows fed with the potatoes, and peaches, the flavour being pronounced in canned fruit. Reports that DDT is accumulated in the tissues of animals and may reach a harmful concentration in milk have culminated in a recommendation by the U.S. Department of Agriculture that the insecticide should not be used in dairying. Pyrethrum and methoxychlor are suggested as alternatives. A week after the announcement the Department issued a second statement to reassure the public that the recommendation was intended as a precautionary measure and that 'there is no evidence that the use of DDT in accordance with the recommendations of the various Federal agencies has ever caused human sickness due to DDT itself'.

Concerned about the 'relatively large quantities' of DDT that may be transferred during a few months' storage to wheat flour, soya flour, groundnuts, cocoa beans and other finely divided and fatty foodstuffs from sacks which have been impregnated with the insecticides, D. E. Butterfield, E. A. Parkin and Miss M. M. Gale have evolved a method for determining the amount of DDT present in such foods.

On the other hand, Dr E. L. Holmes, of the American Institute of Baking, states that fears that DDT and chlordane may contaminate bakery products have proved unfounded. With proper precautions there is no danger of food poisoning – or at any rate far less than from insecticides like sodium fluoride which have been used in the past.

Traces of DDT and parathion have been found in the peel but not the pulp of oranges, lemons and grapefruit six months after spraying and in olives eight months afterwards, stated F. E. Gunther et. al. (University of California). Residues of DDT do not penetrate the skins of apples and pears, and no parathion has been detected in cider made from sprayed apples.

A. E. BLAKE

XEROGRAPHY

A NOVEL development in the reproduction of printed and similar documents has recently been reported in America. The method is an interesting application of two well-known physical phenomena: firstly, photoconductivity and, secondly, the electrostatic attraction of positively and negatively charged particles. Its most striking feature is that it is an entirely dry process making use of neither chemical developers nor printing inks, hence the name 'Xerography' which has been coined from the Greek words *Xeros* meaning dry and *graphos* meaning writing.

The accompanying fig. 25 illustrates how the method works. The fundamental element consists of a photoconductive plate, which corresponds somewhat to the film or paper used in ordinary photographic methods of copying. The plate requires special preparation, but once made it will last indefinitely, though used repeatedly. It consists of a metal such as aluminium upon which a thin layer of photoconductive material is coated. In the dark this coating is a non-conductor of electricity, but becomes conductive when exposed to visible light. One such material is anthracene, and research into the development of more sensitive compounds is proceeding.

When the coated plate is rubbed briskly with a cloth in the dark and in a dry atmosphere, the coated surface becomes positively charged and remains so as long as the plate is kept in the dark. An alternative method of charging the plate is to pass it under a taut thin wire connected to a very high voltage d.c. generator. (See diagram a). Under these conditions, the wire is surrounded by an electrical discharge known as a corona, since it glows in the dark, and the surface of the plate becomes positively charged.

The entire plate covered with a uniform charge of positive electricity (diagram b) must now be treated with the same care as an ordinary photographic film and placed in a camera or copying frame.

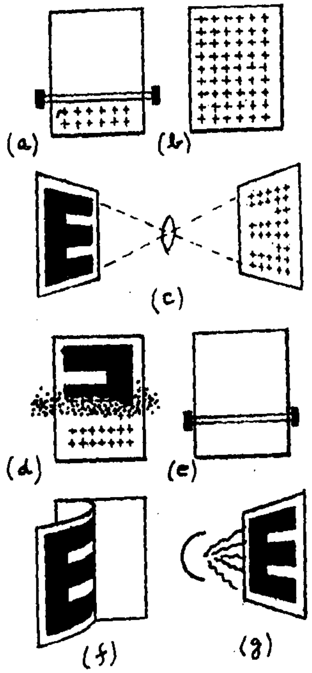

Fig. 25. – How Xerography works:

(a) Plate being charged by passing under wire;

(b) Charged plate;

(c) 'photographing' picture;

(d) Dusting plate;

(e) transferring image to paper;

(f) Peeling off paper with picture on it;

(g) Fixing the print.

The image of the document to be copied is focussed by a lens on to the sensitive plate, as in an ordinary camera. In diagram c, E represents the original to be copied and the plus marks indicate the projected image, which, being dark, retains the positive charges of electricity, whereas the light or exposed parts have become conductive and the charge has leaked away to the under-lying metal plate. The image, of course, is invisible and requires development. This is accomplished by dusting the plate with negatively charged powder (diagram d). This powder adheres to the part of the plate on which the positive charge remains, but runs off the uncharged exposed parts. In practice, this powder consists of two components, one a relatively coarse material and the other a superfine synthetic resin having a low melting point.

The plate now holds a mirror image of the original, and this image must be transferred to a sheet of paper in order to make a permanent print. The plate with the sheet of paper on top is again placed under the corona spray device and the particles of powder are attracted from the plate to the paper. (See diagram e). By this simple process the image is changed from an invisible positive reverse image on the plate to a visible positive on the paper (diagram f). This now requires to be fixed.

Fixing is accomplished simply by heating the paper for a second or two, by infra-red lamps or by passing through an oven. The heat melts the resin and fuses the granules to the paper. (See diagram g).

The process has the advantage not only of being dry but of being rapid as well, the exposure in the camera being much the same as for ordinary photographic materials.

In the present state of development the process is most suitable for re-reproducing printed matter, drawings and line illustrations or documents. Experiments are proceeding on the reproduction of continuous tone images from photographs. One development envisaged is a camera from which a finished xero-print can be taken out within a few seconds of snapping the shutter. Another proposal is that typists may no longer need to make carbon copies, the original letter being placed in a xeroprinter and any number of copies quickly obtained by merely pressing a button.

The process is still in its early stages of development, but the simplicity of the principles involved and the convenience with which they can be applied might well render it one of the most important of the copying methods of the future.

G. A. MCMILLAN

Analysis of Psychological 'Fields'

DR JOHN COHEN

Theory and Practice

'THERE is nothing more practical than a good theory,' once said the late Professor Kurt Lewin. I think it is also true to say that a bad theory is not nearly so unpractical as no theory at all. Industrial life, for example, is above all a sphere in which the changing situation constantly demands practical decisions affecting men and morale as well as machines. Yet it is here that any kind of theoretical understanding of the social situation is noticeably lacking. When a costly piece of industrial equipment is out of order, a technician is invariably consulted, but disturbances in the social relations of a factory are usually dealt with by rather crude trial and error. The economic position of Britain has focused attention on these more elusive aspects of industrial affairs, on the so-called human 'imponderables'. It has become increasingly evident that the old 'hit and miss' methods of facing human problems of industry are quite inadequate if productivity is to be raised and sustained at a new high level. Recent work in psychology, in the development of field theory and the experimental work associated with it appears to hold promise of a more fruitful approach to these problems.

The 'Field' Theory of Human Behaviour

The extension of field theory into social psychology follows its successful use in a wide range of laboratory studies, including experiments on the nature of perception, human and animal learning, the thinking process, the effects of brain injuries, and even such elusive topics as levels of aspiration and frustration effects. The effective starting point of this work may be said to have been Wertheimer's famous demonstration in 1912 of the fact that apparent movement is perceived when two visual stimuli are presented *successively* at an interval of about 60 millisecs. This is the so-called *phi*-phenomenon.

The field concept in psychology, on the analogy of gravitational or electro-magnetic fields in physics, assumes that the behaviour of a person or group is due to the distribution of forces in the social situation as a whole, rather than to supposedly intrinsic properties of the individual.[1]* The field is regarded as an organized system of energies and is not the mere sum total of its parts. The parts are dynamically inter-related, a change in any one part affecting all the rest. Field forces are regarded as vectors, i.e., magnitudes with direction, and the 'strength' of a vector is determined by the total distribution of energy in the field.

The relationships within a situation may be represented by the general formula:

Behaviour = function of (Person, Environment)

This means that we must look for an understanding of behaviour to all the interacting forces which operate in the situation in which the behaviour arises. The situation itself is regarded as being a 'person-in-an-environment'. Let us take a very simple example as represented in Fig. 26. A worker (P) is moved by ambition to improve his skill and status. The vector (V) denotes his ambition; the goal (G) with its positive attraction (+) is the better job, to which he aspires; the barrier (B) represents a hypothetical obstacle, e.g., inability to afford further training.

* This and subsequent numbers refer to books and articles listed on page 158

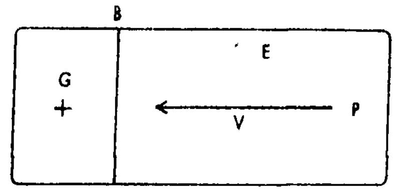

Fig. 26. – Diagrammatic representation of a simple psychological field.
E = Environment G = Goal V = Vector
P = Person B = Barrier
(the + sign indicates positive attraction or valence)

Field theory attempts to elucidate first what a person (or group) *can* do and second what he (or it) *will*, in fact, do. In order to determine what is possible for a person to do in a given situation we must examine the various forms of *locomotion* or change of position which he can make in that situation. These changes may take place in quasi-physical, quasi-social or quasi-conceptual regions of the life space. For example, a change of job and a change of attitude towards the foreman are just as real psychologically as a change of position in physical space. Field theory rejects any kind of *atomistic* approach to a social situation in which a single aspect is isolated without regard to the situation as a whole.

The methods of psychological analysis employed in this approach make use of topological and vector concepts, chiefly developed by Lewin. These concepts are based on the assumption that psychological and social phenomena can be represented in psychological or social 'space'. So we speak of the 'life-space' of an individual or of the 'social space' of a group. The life space of an individual and the social space of a group may be regarded as systems which are stratified into regions. These regions vary qualitatively and are separated from one another by boundaries more or less previous. Everything that has an effect on a person is part of his life space.

Mental Measurement

The scientific status of a discipline is often assessed by the degree to which its subject-matter lends itself to measurement as understood in physical science. Since the beginnings of experimental psychology its exponents have aspired to bring to the study of human behaviour the same principles of measurement which have found so striking a success in the hands of physicists and physiologists. The early formulation of the Weber-Fechner law, which states that the perception of equal differences between successive stimuli depends on geometric not on arithmetic increments in the stimuli, held out great hopes for the future. But this ardour was later dampened by the realization that human behaviour is far more complex than was earlier suspected.

The difficulty is not simply one of devising psychological yardsticks with equivalent units. We cannot abstract or isolate psychological qualities as easily as we can physical ones. In mental or social measurement it is as if we were trying to measure the weight of a piece of coal embedded in a substance compounded of cloth, water, days, cheese, electric currents and so on. Mental and social processes are not merely far more complex than physical ones; they are also constantly interacting and woven into a single whole; and, although we give names like intelligence, judgement, altruism, aggressiveness, to different qualities or performances, the use of these words should not mislead us into supposing that there are isolable processes or entities corresponding to them. Some of these difficulties may be overcome by designing better experiments and by the use of new statistical tools.

The increasing use of *operational* definitions in psychology is also making possible a scientific study of problems previously bogged in a verbal morass. For example, 'intelligence' may be defined as that which is measured by certain tests, the tests themselves being first validated by correlating their results with independent criteria of what it is intended to measure.

A quantitative analysis of psychological material often presupposes a qualitative one. The difference between a boy and a girl, for example, is primarily a qualitative one, and no attempt to measure masculinity and femininity can be made without drawing this qualitative distinction. Scientific exactitude is, in the first instance, the result of correct analysis rather than measurement, 'for thinking depends upon analysis and not all analysis is numerical'.[2,3] The topological and vector methods are analytical procedures of a mathematical character without being numerical. Psychologists have, of course, long used the non-metric method of ranking a series of persons or objects in an 'order of merit'.

The Problem of Isolates and Neutrality

It is in meeting the most basic requirement of scientific measurement, namely, the need to *isolate* that which is to be measured, that psychology faces its most difficult task. This is especially the case when economic phenomena impinge on the situation, as happens so often in studying human relations in industry.

The problem of measuring isolates in the mental and social sciences is not unlike that in the physical sciences. For example, an object which appears red in white light, in blue light appears black. The object has changed only in colour, not in weight or shape or any other respect. Our task is to find out what makes the object appear red in one light and black in another. We have to find a neutral, permanent isolate – something that does not vary with the environment.[4]

The need for isolating the system under investigation is the same as the need to define the limits or boundaries of a psychological field. The preservation of an isolate for scientific study requires that the measuring instrument or yardstick should neither affect nor be affected by the system being measured. Since the psychological investigator entering a factory acts as a 'measuring instrument' he must ensure his own neutrality to the system he proposes to study or measure. In psychiatry, too, the observer is only an 'imperfectly understood tool some of the uses of which may be misleading'.[5] Is this requirement of neutrality met in the study of morale or employer-employee relations in industry?

It is usually assumed that the industrial psychologist can enter a factory as an impartial observer, that he can stand apart from the industrial conflict he proposes to examine. It is also often assumed that he can co-operate fully with management because management is neutral. But neither of these assumptions seems justifiable. The investigator may, implicitly or explicitly, have sympathies with one or other party to the dispute. That they are inarticulate does not mean they are less real. Similarly the neutrality of management may often be little more than a convenient fiction. As the American sociologist Robert Lynd observes, 'Burnham's plausible thesis of the managerial revolution has been seized upon by business ... But behind the fiction of the "manager class" so conveniently sterilized from the taint of special interest stands the same old power. "The voice is Jacob's voice, but the hands are the hands of Esau"'.[6] Field investigators in America have recently stated clearly their point of view on this subject: 'Pretty theories of an independent industrial managerial class, disinterested and detached from both employers and labour, find no support in actual enquiries'.[7] It does not seem surprising, therefore, if workers often seem to be sceptical about the neutrality of management.

Industrial psychologists are themselves often suspected by the workers of a lack of neutrality. In the past, the investigator has tended to be identified in the worker's mind with the employer or management. Again, the employer or manager has usually felt that he and the investigator belonged to much the same 'class' and that they therefore shared the same general points of view or standards of value. It is of interest to note signs in this country of this identification being inverted. Some employers are beginning to suspect the investigator of lacking neutrality because his sympathies may now lie with the workers. These difficulties will be overcome only when the industrial psychologist is able to determine the conditions of his neutrality and recognizes his role in the field of force in which he is placed.

'Unreal' Situations

The objection is sometimes raised that social situations cannot be studied experimentally in a laboratory because the 'artificial' situations so studied bear no relation to real life situations outside the laboratory. There is no substance in this objection. As Rashevsky has recently pointed out, this is precisely the practice of the physicist, i.e., to study idealized systems such as 'material points', 'absolutely rigid bodies', 'ideal fluids', etc., the like of which do not exist in nature. Yet the physicists' conclusions are not thereby made less applicable in the real world.[8]

Multi-disciplinary thinking

One distinctive feature of field theory is that it ignores arbitrary academic classifications. The life space may include physical, economic and physiological as well as purely psychological influences. Hence field theory encourages the development of multi-disciplinary concepts, which may be more powerful analytical tools than concepts derived from partial aspects of a person or situation. Let us consider a few illustrative cases.

(i) *Mental Economics.* There has already occurred some fusion of psychological and economic concepts, due to the penetration into psychology of concepts developed in economics, and *vice versa,* as the following examples seem to show. Note that the borrowing of concepts may be uncritical.

The idea of 'mental economics' has an important place in the psycho-analytic study of unconscious mental processes, an idea based on the assumption that a person disposes of a fixed amount of emotional energy (or 'libido'). This system of energy may be distributed in various ways, for example, by *displacement*, as when a frustrated person kicks the cat, or by *projection*, as when he suffers delusions of being persecuted. Neurotic disturbances are more likely to occur at periods such as puberty and the climacterium, when delicate readjustments in the distribution of energy take place.[9]

The notion of 'investment' of emotional energy derives from the same source. It is likely that such 'investments' conform roughly to a J-shaped curve. That is, there is a tendency for people to have much affection for a few selected persons, with relatively smaller amounts of affection for an increasingly larger number of persons.

In the measurement of abilities, too, a similar economic hypothesis is employed. Spearman, in describing his Two-Factor theory of intelligence, speaks of a "central *fund* of mental energy" which explains individual differences in all-round general ability, on the one hand, and in specific aptitudes, on the other.[10]

(ii) *Spivery.* The notion of 'spivery' is one which lends itself to a multi-disciplinary elaboration. The classic type of spiv is recognized as one who is economically an unproductive unit, one who consumes without producing, and, psychologically, as a wastrel. Public administrators have been much concerned with the spiv group as an economic problem, but psychologically there is reason to suppose that spivery is a widely distributed variable extending beyond the group so designated. There is no more ground for postulating a distinct spiv type than there is for demarcating the criminal as a discrete type, for we are probably dealing with a statistically continuous variable like stature.

On this view, the non-productive consumer or spiv is to be regarded as different in degree not in kind from the rest of the population. If it is correct to say that there is a widespread aspiration (or 'vector') to become like him, or rather like the leisure class to which he belongs, radical

cultural changes in the attitude towards work seem to be called for.

(iii) *The optimum.* Perhaps the best example of a concept which cuts across the arbitrary frontiers of disciplines is the concept of the 'optimum', a concept first introduced into psychology in connection with such matters as the length of the working-day, size of the work-unit, size of the work-team and so on. This approach was directed towards the question of what is best for the individual over a vaguely unspecified period of time. The criteria of the optimum were essentially psychological in character, in terms of fatigue, accident rate, and satisfaction of the worker. But in so far as the worker's output or the efficiency of a factory as a whole was taken into account the criteria were composite. That is to say, they were at the same time economic as well as psychological. I do not think the concept of the optimum has developed sufficiently along these multi-disciplined lines. This possibly explains, as Professor Pear has pointed out, why the late Dr C. S. Myers insisted on asking the question: 'Best (or optimum) for what?'[11]

The concept of the optimum has also recently been introduced into social psychology. Professor C. A. Mace has defined democracy as 'the optimum distribution of responsibility and power'.[12] The writer has elsewhere discussed the place of the concept of the optimum in the field of health.[13] It may be said that the task of applied psychology is essentially a search for optima. There is presumably an optimum 'load' of discipline in childhood, an optimum combination of diverse subjects in the school curriculum, an optimum balance between work and leisure, an optimum length of time for sleep and relaxation, an optimum amount of sexual activity, and so on.

(iv) *Obsessional practices.* Some industrial practices are conceived as having only an economic end in view, the psychological effects being more or less ignored. So-called 'scientific' management is often looked at exclusively from the standpoint of apparent organizational efficiency, though from a human point of view there may be much that is lacking. There is sometimes an obsessional element in management in which the spontaneity of the worker is ruled out, and every process, procedure or situation is provided for in scrupulously precise fashion. This can perhaps best be illustrated by conduct in the sphere of child-management, as reported by the psycho-analyst Anna Freud. A nursery worker was giving tea to a large group of children in her charge. Milk and sandwiches were handed out to every child, and the nursery worker stood in the centre of the group instructing the children to 'sit straight', 'be quiet' and prepare to start the meal. When all preliminaries were completed in this fashion, the order was given: 'And now, chew.' In such cases, an extension of multi-disciplinary thinking would evidently serve a wholesome purpose.

Such rigidity in the industrial sphere may in the long run lead to reduced efficiency through limiting the initiative of the worker and unduly restricting his *locomotion* in his own life space or in the social space of his group.

(v) *Demand, Consumption and Production.* The economist's concept of 'demand' might also with advantage be broadened. Psychological considerations which might be taken into account include the factors which determine changes in group taste, and sex differences in taste and demand. Similarly, the concepts of 'production' and 'consumption' may be scrutinized from this point of view. Economists are fortunate in having a measuring scale with equivalent units, namely, money. Every £1 has the same market value as every other £1. But the economist's material is not always homogeneous, and in calculating the national income he adds the money value of alcohol produced to the money value of volumes of Shakespeare produced.[14]

Just as everything that is manufactured, whether it is an agricultural tractor or a pin-table for a gaming saloon, is counted as economic 'production', regardless of the social uses to which the objects produced are put, so the economist uses the term 'consumption' to cover such diverse activities

as buying tickets for a symphony concert or for a dog race. On psychological grounds, this classification of production and consumption seems to be not very meaningful. It may be that attendance at a concert is a more *productive* task than the manufacture of pin-tables, which we might regard as essentially wasteful consumption. We need new concepts of production and consumption which are operationally defined in terms of psychological as well as economic effects.

(vi) *Wages and Savings.* The following examples bring out the hidden psychological effects of an economic practice. We can think of the frequency with which wages are paid, daily, weekly, and so on, in relation to the individual worker's time span. By time span I mean the extent to which a person's horizon extends into the past and future. A daily wage means a daily time span, a weekly wage means a weekly time span. It is conceivable that the pattern of working men's habits and social attitudes might be changed by altering the wage time span, that is by paying wages at monthly or quarterly intervals instead of at weekly intervals.

A distinctive feature of mental growth from infancy onwards is a gradual extension of the time span. The baby lives entirely in the present, unable to look into the past or future. Slowly consciousness begins to extend backward and forward in time. The infant is unable to relate a current event to occurrences more than a month previously or ahead. Ideas of 'morning' and 'night' come to most children at about the age of four. Understanding of one's own age comes at about five years; of 'to-day', 'yesterday' and 'to-morrow' at about six years, and of clock time at about eight years. Temporal aspects of history are almost meaningless before the age of eleven when orientation towards the passage of time begins to be appreciably enlarged. The inability to appreciate causal sequences that stretch beyond the time span of the particular age has important pedagogical implications in regard to the effects of rewards and punishments in learning.

Perhaps the effect of the frequency with which wages are paid may be such as to reduce or extend the time span or temporal horizons of the person. If one is being paid at widely spaced intervals one is perhaps more likely to be concerned with events ahead than if one is paid at more frequent intervals.

Similar considerations arise in connection with saving habits. The concern of people with their future either in this life or in a possible after-life has varied in human history with different religious, economic and cultural influences. The widespread notion that good deeds and their rewards could be accumulated as a sort of capital fund on which to draw interest in a future life is the theological counterpart of the modern habit of saving, rooted in the Puritanical virtue of thrift. The very word 'save' used to denote the accumulation of money is redolent of salvation, and the mercenary character of the habit has acquired a clandestine spiritual significance. What we need is an examination of the psychological foundations of saving habits. What is the effect on mental stability of voluntary and compulsory saving? What anxieties or stresses are experienced by those without the benefits of superannuation schemes (apart from national social security) as compared with those who are covered by such schemes? Do those who save have a longer 'time-span'?

In this connection it is of interest to note the effect on the worker's time sense of several years unemployment. Investigators report that 'time had lost its characteristic fixed points of reference, so that unpunctuality was the rule, even for meals. Of 100 men 88 carried no watch. Very few newspapers and books were read. There was a far-reaching absence of any form of planning.'[15]

Incentives

In the light of the foregoing the concept of incentive assumes a totally different significance. This concept suffers from certain limitations so long as it is artificially treated as an economic inducement and isolated from the psychological field of force within which alone it can have scientific meaning. The word 'incentive' derives from the Latin *incentivus* – setting the tune – apparently first used in musical context. To respond to an incentive would be to play according to a set tune. We are still apt to think of the worker as a kind of piper who, paid as he is by the employer, plays the tune called by his master. The word incentive occurs in English first in 1603 in Holland's Plutarch's *Moralia* – 'Pythia, the priestesse of Apollo, being once come down from her thrice footed fabricke, upon which she receiveth that *incentive* spirit of furie, remaineth quiet'. The word next appears in a treatise by Amyraldus – 'Embellish'd with many beauties *incentive* of our love'.

As often happens, the word has acquired a wider connotation. Strictly speaking, it denotes a stimulus which has a positive attraction or 'valence' when a person experiences an urge, appetite, or drive. Thus we may speak of food as an incentive when we are in a state of hunger, but not when we are in a state of satiety. If we employ this definition when considering incentives in industry we shall have to accept that few of the factors commonly termed 'incentives' are so in the psychological sense.

It should now be clear that, from the standpoint of field theory, workers' productivity is not likely to be raised by introducing this or that specific incentive regardless of the effects of the change on the field situation as a whole. The field situation partly affects all industries as a result of common forces operating on them, e.g., methods of taxation or availability of consumer goods, etc., partly it is something which varies from industry to industry, and partly something which varies from factory to factory within any industry. In any given case the field situation embraces all the positive and negative forces or vectors which impel or discourage the worker, and all the barriers which impede free movement from one region to another within the personal or social space.

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GLOSSARY

CARCINOGENIC: Cancer-producing.

MANOMETRIC METHODS: A manometer is an instrument for measuring changes in the pressure of a gas. Many physical and chemical changes in the inorganic and the living world are associated with pressure changes and can therefore be studied with the manometer's help.

MILLIARD: A thousand million.

PERITONITIS: Inflammation, normally the result of infection, of the peritoneum, the smooth glistening membrane which lines the body cavity and covers many of the abdominal organs partly or completely, e.g. the spleen, liver and intestines.

RUSSELL-HERTZSPRUNG DIAGRAM: A scheme of the evolution of stars, first put forward in 1913, in which young giant stars are red, become hotter and whiter as they shrink, until they are very dense, and then begin to cool and turn red again as they continue radiating away their mass into old age.

SHAMANISM: From Shaman, a mediumistic healer, magician or exorcist, who by means of his special relationship with spirits can act as a mediator between his fellow men and the world of spirits. The word is Siberian and is used particularly in connection with Siberian tribes, but by extension is applied to other primitive medicine men. In South America his chief function is the cure of disease.

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