Crystals of the Living Body*

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IT is obvious that the atoms and molecules of a living body are not thrown together in a haphazard fashion. There is in the first place a certain preferential disposal of the various kinds of atoms. While carbon, oxygen, hydrogen are widely and plentifully distributed throughout the body, the bones and teeth are comparatively rich in phosphorus and calcium, the hair contains sulphur and nitrogen, and so on. But these and other special occurrences are not enough to serve the body's purposes. There is a greater differentiation in the distribution of the molecules into which the atoms are grouped. There are, for example, many kinds of protein molecules which have their several parts to play as constituents of the different organs, and help to endow each organ with its peculiar function. But again this is not enough. There is a further requisite, namely, order in the arrangement of the molecules; which gives directive action to the various composite masses. A hair, for example, is largely composed of a species of the proteins known as the keratins. These are long, narrow, molecular arrangements which we shall presently consider more in detail. The molecules are fastened together, somewhat loosely it would seem, into little bundles, in which the molecules all point nearly in the same direction. The bundles are so disposed that this direction is nearly the same as that of the axis of the hair.

This order in the arrangement of the long molecules would seem to us, now that we have discovered it, to be in accordance with what we might have expected. The long molecules are an important part of the hair, and indicate a disposition of its components which must give to it directional properties. The hair grows in a particular direction to which also its various mechanical properties are related. If the molecules lay in all directions, there would be no reason why the hair should be long, narrow, flexible and yet strong.

All growth in Nature implies extensions in particular directions. Function is connected with orientation, and there can be no orientation without method in the molecular arrangements; for it has never yet been found that a process in a living body moves in contradiction to the laws of physics and chemistry as observed in the laboratory. This does not, of course, imply that any artificial arrangement of atoms and molecules has ever been endowed with life. A mass of molecules so indiscriminately arranged that no particular direction can be distinguished from any other, cannot be expected, even though it is part of a living body, to extend and grow in one direction more than in another.

We have taken a hair as an example, but other parts of the body would have served equally well. Nerves, muscles and tendons all possess arrangement; the bones are not merely shaped externally as an engineer would shape them, but show also in the internal arrangement of their molecules an orientation for a definite purpose which the engineer must envy.

Clearly, if arrangement of the molecules is so necessary to enable the body to function and to live, the actions of the body cannot be fully understood without taking it into account. The new methods of analysis by radiation of very short wave-length, including, we may now say, electrons as well as X-rays, have provided us with means of examination of structure which are of much greater power than any that we possessed previously. These latter have been indeed very few and indirect. Furthermore, catalytic actions depend on the arrangements of the atoms and molecules on the surface of the catalysing solid; but though this fact may have been appreciated, the details of the arrangement have been out of reach. In fact the new methods open up possibilities which are also new.

Our chemical methods, it must be pointed out, do not reveal the nature and details of molecular arrangements. When we employ them for the analysis of a material, we begin by pulling the material to pieces and so destroying that very arrangement of molecules which we should be glad to examine. We knock the house down, and discover the numbers and natures of its components; so many bricks, so many slates, so many planks and so on; but we have lost the plan of the house. We must differentiate between the arrangement of atoms in the molecule, and of the molecules with respect to one another. The former has long been the study of the chemist, and especially of the organic chemist. In such studies the molecules are free and approachable from all round, being either the constituents of a liquid or in solution in a liquid. A liquid has no permanent directional properties except, possibly, at its surface. On the other hand, the mutual arrangement of the molecules in the solid is fundamentally concerned in those directive properties which are characteristic of the solid; it is this arrangement which is now open to our examination.

As illustrations of the effects of mutual arrangement among the molecules, we may first consider the case of two soap bubbles, which may be rubbed together—not too violently—without coalescing. The material of the film is contained between two surface borders of long chain molecules which are arranged so as to present their methyl (CH_3) terminals to the outside of the film. Thus a 'methyl face' of one bubble rubs against a similar

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face on the other. There is very little action between methyl groups, and so the films remain separated. The active ends of the molecules are all turned inwards, and so are kept out of each other's reach.

The solid crystal naturally gives the readiest examples of molecular arrangement, since the arrangement is the cause of the crystalline form.

FIG. 1. Diffraction photograph of kalliophilite.

Every face presents only some selected part of a molecule to the external world. Zinc-blende may be looked on as an assemblage of molecules composed each of one atom of zinc and one of sulphur, all lying parallel to one another. Two opposing faces, both perpendicular to the direction in question, and forming parts of the crystal boundaries, differ in their behaviour because one is associated with zinc atoms in the same way as the other with sulphur. It is well known that if the crystal is heated, one such face is electrified positively and the other negatively. There are four such directions in each crystal of zinc-blende and four corresponding methods of picturing the assemblage of molecules.

Resorcinol possesses the same property to a high degree. The molecule is unsymmetrical, being a benzene ring in which two of the hydrogens at points 120° apart are replaced by hydroxyl (OH) groups. The arrangement of the molecules in the crystal has not been determined exactly, but we know that it is at any rate insufficient to give the crystal a high order of symmetry. The symmetry is certainly higher than that of the molecule itself, as is usually the case. There still remains a strong polarity which is revealed by the form of the crystal. The upper end of the crystal is very different from the lower; the faces that form naturally at one end are not those which form at the other. The polarity can be very simply demonstrated by suspending a couple of crystals

in liquid air, whereupon they develop opposite electrical charges at their ends, so strong that the two behave to one another like small magnets. The strong electrification of resorcinol and similar bodies is sometimes used to clear liquid air of foreign particles.

The behaviour which is thus exhibited is the behaviour of the unit of pattern in the crystal. The unit can be shown by the X-ray methods to contain four molecules: arranged in a way which, as the term 'unit of pattern' implies, is repeated indefinitely in the structure of the crystal. Mere multiplication cannot alter the properties of the crystal: whatever is true of the crystal as a whole is true of the single unit as it lies embedded in the crystal. That does not mean, necessarily, that the single unit would behave in the same way as it does in the crystal if it were free of its environment.

This is an extremely important point. We obtain from observation on the crystal information respecting the properties of a certain small company of molecules, generally not more than two, three or four. These properties are various: magnetic, electric, optical, thermal and so on. If we determine the arrangement of the molecules in the unit, and of the atoms in the molecule, we may correlate properties and arrangements and so contribute to the solution of one of the great

FIG. 2. Diffraction photograph of silk.

problems of physics, namely, the connexion between the properties of a substance and the atoms of which it is built. Conversely, knowing relations between the properties of one or more unit and the details of their structures, we may use our knowledge for the determination of the structures of other units by the examination of

the properties of the crystals of which such other units form part.

To sum up what I have said so far, the positions of the various atoms in the molecule determine the characteristic of the molecule: this is well known and has been widely studied. The positions of the molecules in the solid are equally important, especially if there is any regularity in their arrange-

FIG. 3. Diffraction photograph of sea-gull's quill.

ment, in other words, if there is any attempt at crystallisation. In a living body there must be arrangements of various kinds to various extents. We want to know what these arrangements are and their effects.

The X-rays demonstrate to us any such arrangements. It is now well known that a pencil of X-rays which passes through any substance where

molecular arrangement exists gives some sort of diffraction pattern, which may be examined photographically or electrically. From the character of the pattern, information can be obtained as to the nature of the arrangement. When there is much arrangement and great regularity, the pattern is sharply defined. As an example, we may take the photograph of the mineral kaliophilite (Fig. 1) obtained by F. A. Bannister of the British Museum (Natural History). When the arrangement is less regular, the photograph is less definite. When the first photographs were obtained from silk and wool, nerve and muscle, they were in comparison exceedingly vague and it seemed that it would be difficult to make any useful deductions from them. However, both technique and skill in interpretation have increased materially and conclusions can now be drawn which are of great interest. The two photographs of proteins in Figs. 2 and 3 were obtained respectively from silk and from the quill of a sea-gull's feather. These are due to W. T. Astbury and Miss Marwick. The detail is sufficiently pronounced to give valuable information to the experienced observer.

In the first place, it is clear that there must be quite a considerable amount of arrangement in both cases. The silk is largely composed of a protein known as fibroin. It is remarkable that similar photographs are obtained from a great number of proteins, drawn from different sources; there is in fact a characteristic protein photograph which implies that there are elements of structure common to protein forms. Fig. 3 is an example of the diffraction pictures obtained from a peculiar class of proteins known as the keratins; their connexion with the main body has recently been beautifully demonstrated by Astbury.

(To be continued.)

The Ionosphere

By R. A. WATSON WATT

SINCE Teisserenc de Bort established the fact that at heights of the order of 10-15 km. the more or less regular fall of air temperature with height ceases, and that for some distance above this change point the temperature is substantially independent of height, it has become customary to treat our atmosphere as divided into two shells. The inner shell, in which convective motion and turbulence are recognised as the dominant physical characteristics, is now called the troposphere, and is separated from the outer shell by the tropopause, the surface at which this well-defined change of the lapse-rate of temperature occurs. So far as the older meteorological means of measurement were concerned, the outer shell, the stratosphere, must—by mere defect of evidence—be regarded as comprising the whole remainder of the sensible atmosphere.

More recently, however, it has become convenient to admit a not very sharply defined

division of the stratosphere into an inner shell, retaining the name of stratosphere, and an outer, probably beyond a height of about 35 km., called the ozonosphere. This third shell, the dominant characteristic of which is its content of ozone, is, despite the incompleteness of data and the small absolute magnitude of the ozone content, of extreme importance in the radiation balance sheet of the earth, and thence in determining the physical conditions of human existence or non-existence on earth. The most recent addition to this systematic group, troposphere, stratosphere, ozonosphere, is the ionosphere, a shell extending from a height of some 80 km., and having, as its dominant physical characteristics, the special electrical properties which result from a relatively high degree of ionisation in the low-pressure gases which constitute the atmosphere at these considerable heights.

It is now well known that the necessity for