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CRYSTALS OF THE LIVING BODY.*

IN the living body, there is a preferential distribution of the various kinds of atoms as for example phosphorus and calcium in bones and teeth, and sulphur and nitrogen in hair. Besides this differentiation, there is a greater one of the molecules into which the atoms are grouped, thus, the several kinds of proteins function differently as constituents of the many organs of the body. A further requisite is order in the arrangement of the molecules. To cite an instance, in hair, the long narrow arrangements of molecules fastened somewhat loosely like bundles, endows it with the property of directive action. This direction is nearly the same as that of the axis of the hair so that it grows in a particular direction and is flexible and strong. If the molecules were distributed in all directions, there is no reason why hair should possess these properties. All processes in the living body follow the laws of physics and chemistry and consequently, function which is connected with orientation means method in molecular arrangements. No artificial arrangement of atoms and molecules has ever been endowed with life nor can an indiscriminate one extend and grow in one direction more than in another. All the parts of the body such as nerves, muscles and tendons possess arrangements which are fitted for their purpose not only by shapes but also by the internal arrangement of their molecules. Hence it is very essential to understand the arrangement of molecules in the living body if we are to understand their functions properly.

* "Crystals of the Living Body"- Friday evening discourse delivered by Sir William Bragg, O.M., K.B.E., F.R.S., at the Royal Institute, January 20, *Nature*, **132**, 11 and 50, 1933.

Chemical analysis tells us very little of this arrangement. We are only aware of the bricks of the house with very little knowledge of the exact plan of the home of which they form parts. The arrangements of atoms in molecules have come in for wide study by the organic chemists but the relative arrangement of the materials with reference to one another is also of great import. Especially is this so of solids where directive properties come into play. In this study, the x-ray has proved an extremely useful weapon.

The study of solid crystals suggests itself readily because the crystalline form is the result of the molecular arrangement. Thus the properties of crystals of zinc blende on heating and those of resorcinol when suspended in liquid air are exactly those that can be expected in a molecule of the type studied and the x-ray pattern reveals the same characteristics but whatever is true of the whole is true of the unit imbedded in it. It does not mean that the individual unit will behave in this way if taken out of its environment.

This is an important point. The study of a crystal furnishes information regarding a small group of molecules say one, two, three or four. If we determine the arrangement of molecules in this group and of the atoms in the molecule, we can correlate properties and arrangements and thus contribute to one of the greatest problems of physics, namely, the relation between the properties of a substance and the atoms of which it is built. Conversely, using the knowledge, we can apply it to other units by the examination of crystals of which these units form parts. So the position of the various atoms in the molecule determines the characteristics of the molecule; the position of the molecules in a solid determines its crystalline form. In a living body there must be arrangements of molecules of various kinds to various extents. X-ray patterns help us to understand these arrangements.

X-ray studies have generally confirmed the conclusions of the organic chemists and have also further extended their knowledge to greater completion. Thus two amino acids like glycine and alanine each possessing a carboxyl and an amino group of opposite character can condense together with the elimination of water. Willstatter supposed that such combinations can take place in regular alternations yielding chains of indefinite length. Now silk on hydrolysis gives both alanine and glycine. If this regular structure is the cause of the x-ray photograph of silk, the numerical details of the photograph should fit into the chemist's conception. From x-ray studies of various crystals we know that the distance along the chain at which the pattern (two carbons and one nitrogen) repeats itself should be 3.6 A. Although the x-ray pattern gives a very hazy picture of the position, measurement shows a regular repetition of pattern at a distance of 3.5 A which is a remarkable coincidence with the calculated value. The x-ray photographs also show that the chains are arranged in a row parallel to the direction of the fibre–an arrangement that we ought to expect.

It is well known that the hair stretches and photographs in a manner resembling that of silk though its chemical structure is similar to those of horn and feathers. Astbury explained this phenomenon by supposing that the chain which forms the backbone of all the proteins is similar to silk. In the keratins they are crumpled up somewhat; tension pulls them straight without breaking them and on release, the contractile forces draw them again together. But beyond the breaking point, the molecules slip past one another and so cannot be restored to their original state. These suppositions are practically demonstrated by x-ray photograph which, for example, in wool, shows repetition at intervals a little less than silk, whereas in hair it is 30 per cent less; and hair recovers completely after 30 per cent of extension.

The same hypothesis gives an explanation of the resistance of these substances to enzyme attack, for the crumpled chain protects the molecule from breakage. The compactness masks susceptible points and this is helped by the mutual satisfaction of opposite groups. This only illustrates that not only do the molecules of a chain determine its character but the arrangements of the molecules themselves decide the behaviour of the substance. Arrangements of the protein molecules among themselves are essential to their function in the living body.

These are but the beginnings of future interesting revelations that will follow more precise measurements. The x-ray is a new tool and needs wider application in more cases before it can be properly used and its full capacities understood.

A most interesting example is the examination by J. D. Bernal and his colleagues of the crystal structure of the separate amino acids, vitamins and similar bodies. When such bodies can be crystallised, valuable knowledge of the arrangement of atoms and molecules can be studied. Chemical considerations suggest many possible arrangements which x-ray studies narrow down. Thus Bernal showed the former formula for sterol to be incorrect and later search has been successful in proving his point. Bernal's results indicate the possibility of studying the changes as the configuration is altered step by step, and the comparison of the gradually changing quality with corresponding changes in certain dimensions gives important hints about the constitution of the substance. The optical, magnetic and other constants of a crystal show remarkable dependencies in the form and now we are able to determine the contents of the unit of pattern and sometimes go as far as to find the position of atoms and molecules in the unit: the constants can then be connected directly with the contents of the unit. Another method of arriving at the same direction is to work out the arrangement of atoms in simple crystals to completion. The laborious task cannot at present be applied to complicated cases. The effect of relative positions of various groups can be worked out and the knowledge thus obtained applied to other cases.

Several investigations have been recently done along these lines. One of the results obtained is a better understanding of the details of linkages between carbon atoms. We speak of the single bonds and double bonds. There are two linkages, the close diamond linkage and the wider graphite linkage. X-ray studies show differences between the two linkages that is beyond experimental error. The former is found in fatty acid chains and similar compounds where each carbon atom has four neighbours, two carbons and two hydrogens. The latter occurs in naphthalene and anthracene, the basis of which is the benzene ring; in these carbon has three neighbours as in graphite. It may prove to be the case that the former kind of bond is peculiar to aromatic substances and the latter to the aliphatic. The heats of combustion of diamond and graphite are very nearly the same: so that it takes as much energy to break down the four bonds in the diamond as the three in the graphite. In such a comparison the heat spent on breaking the weak bonds between the network layers of graphite is taken to be negligible.

Such accurate measurements as these encourage the hope that there are exact rules as to distances apart of the atoms, and very probably as to their mutual orientation. Knowledge of these rules will greatly facilitate the determination of structure.