Recent Crystallography*

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BENEATH the immense variety of Nature's structures lie certain remarkable simplicities. Thus the elements used in the building are surprisingly few in number. There are but ninety-two in all, of which only a few are of common occurrence, and many are used very sparingly. Indeed there are one or two of which it can only be said that they should exist, though as yet they have not been found. Oxygen constitutes half of the known world, half the remainder is silicon; aluminium comes next. In living things carbon is one of the most important elements, yet it constitutes only a fraction of one per cent of the world as a whole.

It is becoming clear that Nature is most economical in her designs also. This very remarkable phenomenon is especially evident in the structures of living matter. The proteins which play such a predominant part in the animal are all based upon a certain fundamental pattern, and so is the cellulose which plays a corresponding part in plant-life. The recent discoveries of the biochemists have revealed the existence of several classes of substances, as for example the sterols, which though minute in amount have a powerful effect on life and health. In each class a basic pattern is common to all, and the rich variety is derived from a common theme.

There is a further simplicity in the regularity of arrangement of the atoms and molecules in all substances, or at least in the effort to achieve regularity. It is naturally most in evidence in the solid body. When the solid forms from the melt, or assembles out of solution, or grows from deposited vapour, the atoms and molecules of which it is made settle themselves in orderly array. The process is often sensitive to disturbance of the surrounding conditions, but if it is allowed to go on as it begins, it ends in the production of a visible crystal. The constancy of the angles which the faces of a crystal make with one another is evidence of the regular repetition in space of some fundamental collection which is the unit of pattern of the whole. Crystallographers have long surmised that the crystal is the consequence of such a construction.

The X-ray methods of analysis have made it possible to observe and measure these regular details of the assembly. The methods have often been described; it is sufficient to say now that they depend on the reactions between the fine and regular succession of the X-ray waves and the fine regularity of the crystalline arrangement, the two degrees of fineness being fortunately of the same order. The study of crystalline matter with the help of X-rays is one of the most powerful methods of investigating natural structures. It has contributed materially to the realization of the fundamental simplicities in the choice of design.

When the X-ray methods were introduced, they were first applied to the determination of the simpler crystalline structures—rock salt, diamond and the like. Since then the improvements in technique and in theory have been so great that complicated structures have been completely worked out, such as for example the silicates and some of the less complex organic crystals; and it has been possible to go some way in the examination of the complicated and large molecules which are found in living organisms, such as the proteins to which reference has already been made.

The first of the proteins to be examined in detail was 'keratin', the important constituent of wool, hair and horn. It is a remarkable illustration of the persistent occurrence of regularity in the structures of Nature, and at the same time of the power of X-rays to discover it, that crystalline structure should have been proved to be an important feature of substances which are ordinarily supposed to be anything but crystalline.

The fundamental feature of keratin is the constant repetition in a zigzag line of the atoms carbon, carbon, nitrogen in long succession. The same repetition is found in all the proteins. These atoms carry certain attachments, some of them invariable, others not. In the protein chain when extended to its full length, each nitrogen carries a hydrogen atom, and one of the two carbons in each unit carries an oxygen to which it is joined by a double bond. The other carbon carries a hydrogen, and is also attached by a single bond to one end of a secondary or side chain, which varies from protein to protein, and generally from portion to portion of the same protein. In the accompanying diagram (Fig. 1), taken from Astbury's "Fundamentals of Fibre Structure", the side chains are denoted by R, R, . . . The difference between one protein and another, so far as constitution is concerned, is due to differences in the nature of the side chains.

By X-ray measurements it has been possible to determine the length of the repeat in various forms

* Friday evening discourse delivered at the Royal Institution on January 29.

of keratin, and to show its constancy, and its agreement with the suggested structure and with the values of interatomic distances as found in other organic crystals.

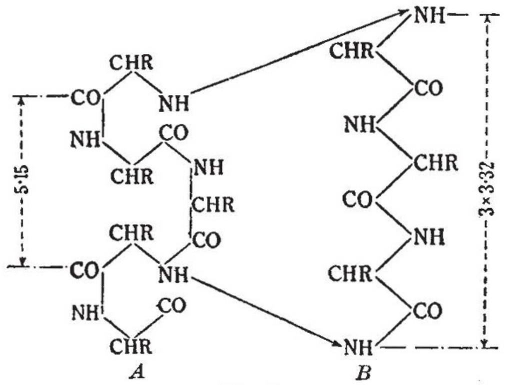

Fig. 1.

A. A KERATIN CHAIN PARTLY COILED UP. NOTICE THE APPROXIMATION AT CERTAIN POINTS OF THE NH AND THE CO. *B*. THE EXTENDED KERATIN CHAIN. (ASTBURY.)

Svedberg showed in 1929 that by means of the greatly accelerated settling of a suspension subjected to centrifugal force, it was possible to estimate the weights of various proteins. He found that nearly all those which he examined had a molecular weight of about 35,000, or a simple multiple of this number. In blood he found certain others of still greater molecular weights, to be counted in millions. The constitution of all proteins is about the same, that is to say, carbon 50–55 per cent, hydrogen about 7 per cent, nitrogen 15–19 per cent, oxygen 19–24 per cent, with traces of sulphur, phosphorus and metals. In keratin the sulphur content may amount to 2 or 3 per cent.

Proteins are assembled in the course of plant life. Animals require proteins for their nourishment, but do not themselves manufacture them to any considerable extent. They must therefore eat plants, or eat animals that eat plants. Emil Fischer showed, at the beginning of this century, that the assemblage of a protein was accomplished by the successive linking of amino-acids into a long chain, water molecules being shed in the process. The amino-acids are long-chain molecules, at one end of which (and sometimes at both ends) are found the basic group NH_2 and the acid group COOH. The linkage is effected by the interaction of the basic group of one amino-acid with the acid group of the next as illustrated in Fig. 2.

It is an accepted hypothesis that two parts of a molecule, separated from each other by a single bond, can be rotated with respect to each other about that bond. The long chain illustrated in Fig. 1*B* can therefore be crumpled up into less extended forms by successive rotations about its bonds. Astbury supposes that the keratin chains of a wool fibre in its unstretched state are shortened into the form of Fig. 1*A*. It is interesting to observe that a nitrogen is now brought near a carbon which is five links away along the chain (Fig. 1*B*). Frank has pointed out that a junction must be effected here between the N and the C; the H belonging to the N passes over to the C=O group, converting it into C—O—H. Groups of hexagonal rings are thus formed.

The side chains of one long-chain molecule can interact with the side chains of another, and it is in this way that the long molecules are tied together into a firm substance like hair or horn. When the chain is coiled up, these side chain attractions are more and more satisfied by interactions in the molecule itself. It is possible that in this way, as has been particularly emphasized by Wrinch[1], something like a ball is formed, which has relatively little attraction for other similar balls. Such may be the case in the white of an egg in its natural state; boiling the egg breaks up

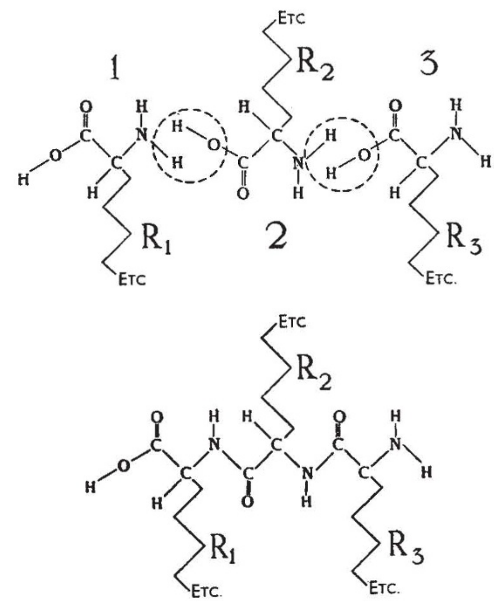

Fig. 2.

IN THE UPPER PORTION OF THIS FIGURE THREE AMINO-ACID MOLECULES ARE DRAWN SIDE BY SIDE, AS IF THEY WERE READY TO BE LINKED TOGETHER. IN THE LOWER PORTION THE JUNCTIONS HAVE BEEN MADE: WITH THE SHEDDING OF WATER MOLECULES FORMED BY THE COMBINATIONS OF THE ATOMS WITHIN THE CIRCLES OF THE UPPER PORTION. THE SIDE CHAINS R MAY VARY IN FORM. IF THEY ARE, ALTERNATELY, A SINGLE HYDROGEN ATOM AND A METHYL GROUP (CH_3), THE PARTICULAR PROTEIN IS THE CONSTITUENT OF NATURAL SILK.

the balls, and the uncoiling chains link together, forming the solid mass of the white in a boiled egg. The substance is said to be 'denatured'.

[1] NATURE, **137**, 411 (1936).

(*To be continued.*)