flowers, fruit and leaves. So the 'off' year disappears.

Fertility is also closely connected with the variety of crop plant cultivated. Wheat is commonly supposed to resent much nitrogen, and if heavily manured it 'lodges'. This is true of some of the wheat varieties grown in England, for example, Squarehead Master, but not of others, such as Chevalier, and if such varieties were grown more generally and amply manured, the average yield of wheat, high as it already is, could be made to equal the yields obtained, for example, in Holland.

Apart from the power of nitrogen to give increased yields, at a low cost, the use of it, and that of mineral plant foods, is essential for producing the kinds of food that will maintain and improve the health of man. Recent experiments tend to show that a moderate use of these materials doubles the yield of protein from grass, and that this increase is attended by a corresponding increase in carotene, the precursor of vitamin A. Nitrogen-treated grass that has been dried by artificial heat has been found a perfect substitute for a large part of the concentrated food (now imported) that is usually fed to stock in winter, and the butter made from the milk of cows fed on this grass is far richer in carotene than that made from the milk of cows fed on the ordinary winter ration; it has the deep primrose-yellow colour characteristic of the best dairy butter (see *Emp. J. Exper. Agr.*, 1, 68; 1933).

There is much more yet to be learned of the parts played by vitamins and minerals in nutrition. Pasture-land appears to require but very little lime; probably because much of it returns to the soil when the grass dies. Although 'nitrogen grass' contains less lime than ordinary grass, the milk yielded by cows that eat it is the richer in lime.

This suggests that the lime in the green plant may exist in either a metabolic state, in which it can be handed on from the grass through the cow to the milk, or in an inert state, in which it can be handed on less surely. Similar possibilities are attached to other elements, of which silicon may prove to be one. The lack of carotene in ordinary winter butter suggests that influenza and yet graver maladies may be prevented by supplying food lacking none of the essential vitamins and minerals. Tuberculosis, both human and bovine, may prove to be a deficiency disease which is encouraged by the lack of vitamins. At any rate, it seems certain that an ampler provision of vitamins in the milk, butter, cheese, eggs and vegetables consumed by the people in winter is an essential step in improving national health. There are numerous examples in the plant world of diseases due to deficiencies, such as of potash in apple trees, of sulphur in the tea plant, of magnesium in fruit trees, and of iron, manganese, boron and copper in other crops. In fact, one might almost say that imperfect nutrition is responsible for all disease.

If there is any truth in the conjecture that in the past the earth has passed through alternate phases of nitrogen plenty and nitrogen scarcity, a new and revealing light may be thrown on evolution. The path of evolution is strewn with its victims, but it is also illuminated by all the beauty of animate things. Is all this beauty only a casual by-product, or is it an enduring memento of the times when the earth was endowed lavishly with nitrogen? Nature unaided contrives here and there oases of plenty in a world of want, and beauty is born there. Man can make, if he will, the whole world an oasis where want is unknown and beauty reigns supreme.

Crystals of the Living Body*

By SIR WILLIAM BRAGG, O.M., K.B.E., F.R.S.

IT has continually happened during the recent development of X-ray analysis that its first results have been confirmations of the conclusions of the organic chemist, and have been followed immediately by closer definitions and fuller knowledge. The chief feature of the structure of proteins has been supposed, on chemical grounds, to be a chain-like arrangement of amino-acids. These bodies may be obtained in the laboratory by breaking up

in detail. Two of the simplest are glycine and alanine.

They are characterised by the presence of an amino-group, NH_2 , on one side of a certain carbon atom and of a carboxyl group, COOH , on the other. One has a positive character, the other a negative: the two groups have not only a general attraction for one another, but can also be made to combine in the manner shown below:

Glycine and Alanine.

the natural proteins. There are many kinds of them, and they can be separated and examined

Two hydrogen atoms and one oxygen have dropped out. Willstätter supposed that such combinations could take place in regular alternations

*Continued from page 13.

of the two amino-acids, thus forming a chain of indefinite length.

Now alanine and glycine can be obtained from the decomposition of natural silk. If this regular structure is the cause of the X-ray photograph of silk, the numerical details that can be obtained from an examination of the photograph must fit in with the structure proposed by the chemist. This is remarkably verified. Previous X-ray work has shown that a chain-composed of two carbons and one nitrogen in regular succession would probably take the zig-zag form well known as a characteristic of long chain compounds. The following formula shows how the silk protein would be represented.

From the X-ray analysis of many organic compounds, we have learnt the dimensions of the atoms of carbon and nitrogen, and we can assert that the distance along the chain at which the pattern (two carbons and one nitrogen) repeats itself should be about 3.6 Å. Now the interpretation of the X-ray picture, though hazy in some respects, is exceedingly precise in one at least. It shows that some arrangement exists along the fibre, based on a pattern which repeats itself at intervals of 3.5. The coincidence is striking. The X-rays show not only that there is arrangement among the molecules in the silk, but also that there is agreement with chemical theory as to the existence of a repeat in each chain. They show also that the chains—this also is one of the details which can be examined in the picture—are arranged more or less parallel to one another and to the direction of the fibre. This is the sort of arrangement which we should expect.

Silk fibroin is one of the simplest of the proteins. There are innumerable other possible combinations, because there are many different amino-acids and kindred bodies which can be strung on to the chain in various ways. There is, for example, cystine, which clearly can be inserted

into the chain by either of its ends. This group contains the sulphur which occurs in hair.

To return now to the keratins which, as I have said, do not give the same diffraction pattern as silk and other proteins. Hair, feathers, horn and the like give photographs which are comparable with each other. Astbury has made the surprising discovery that a hair when stretched gives a picture resembling that of silk. The stretching

alters the arrangement of the molecules. If the hair is allowed to resume its former length, which it readily does if the operations are carried on in warm water, the first form of picture is again obtained, so that the effect is reversible. Silk does not possess any capacity for complete recovery after extension. Hair recovers completely after 30 per cent of extension; beyond that there is only a partial recovery though it will stand an extension of 70 per cent before breaking.

Astbury has pointed out that these effects can be readily accounted for by supposing that the chain which forms the backbone of all the proteins is similar to that of silk. But in the keratins the chain is somewhat crumpled up. Tension pulls the chains straight without breaking them, so that the contractile forces, whatever they may be, can restore the chain to its old form, and the process of extension and contraction may be repeated indefinitely. Beyond the 30 per cent of elastic extension there is a possibility of further extension by means of the slipping of molecules past one

FIG. 4.

another. This is practically the only form of extension possible in silk: it is not reversible.

A comparison of the two kinds of X-ray photographs supports this conception. The distance of repeat along the chain in stretched wool is only a very little less than that of silk, which is correct if the stretching of the wool is due to the stretching of the chains, while the repeat in the unstretched hair is 30 per cent shorter than in the stretched. Other geometrical deductions from the photographs, some very definite, others less definite, are also in general agreement with the hypothesis.

But why should some keratin chains tend to crumple up while others do not? A plausible explanation can be readily given. The amino-acids and other pendants of the chain have a certain attraction for each other, at least if there are some which contain acid groups, while others have a basic character. All such attractions tend to shorten the chain.

A rough model can be made to illustrate this point by stringing a number of wooden bars along a piece of flexible material (see Fig. 4). Elastic threads join the ends of the bars as shown and tend to draw them together. The attractions simulated by the elastic links tend to shorten the

chain, but an applied tension may break the connexions so formed and give the chain its full length. This sort of thing cannot be expected to happen in the case of silk, because glycine and alanine have no attraction for each other, built as they are into the chain.

The same hypothesis gives a good explanation of the fact that hair and other keratin structures are so very resistant to chemical actions such as the attacks of enzymes. The crumpled chain protects itself in several ways. Its susceptible points are masked, partly by its compactness, partly by the previous satisfaction of tendencies to combination either in respect to groups belonging to the same chain or to different chains. Thus hair, horn and similar materials acquire a peculiar permanency often illustrated by the state of the remains in ancient tombs.

All these facts are illustrative of the statement with which I began, namely, that not only does the arrangement of the atoms in the molecule decide the characteristics of the molecule but also the arrangement of the molecules with respect to each other in the solid decides the behaviour of the solid. Arrangement of the protein molecules among themselves is essential to their function in the living body.

These general deductions regarding protein structure are only an earnest of what may be expected to follow from the precise measurements of position which we are now able to make. They are no more than indications of the directions in which knowledge of living structure may be able to advance as a consequence of the new methods of inquiry. Like any other new tool, X-ray analysis has to be in use for a certain time before its capacities are understood.

Besides the direct applications of X-rays which I have been describing, there are certain other ways in which the substances of the living body have been studied by their aid. A most interesting example is the examination by J. D. Bernal and his colleagues of the crystal structure of the separate amino-acids, of the vitamins and similar bodies. When such bodies can be crystallised, valuable hints can be obtained as to the arrangement of the atoms and molecules, even if the structure cannot be fully determined. Chemical considerations suggest various possible arrangements, the choice from which may be narrowed down by the result of X-ray measurement. Thus, for example, Bernal showed that the formula proposed for sterol must be incorrect: in consequence, a search for the proper formula was instituted and has seemingly been successful.

Bernal's investigations of the structure of these compounds are an example of one of the two lines along which, broadly speaking, X-ray work is advancing. A series of like compounds is examined, and the various members are compared with each other. Information is derived from observations of the changes as the composition is varied step by step. In this particular research some twenty different substances have

been compared. They are all members of a family of the greatest importance biologically. Their X-ray pictures show that they possess certain common characteristics of a structural nature, and the comparison of gradually changing quality with corresponding changes in certain dimensions gives important hints as to constitution.

A new method often gives new force to older methods, and this is happening now. The optical, magnetic and other constants of a crystal show remarkable dependencies on the crystalline form. When we are able, as in this case, to determine the contents of the unit of pattern, and sometimes are able to go so far as to find the position of the atoms and molecules in the unit, the constants in question can be connected directly with the contents of the unit. Several years ago, W. L. Bragg showed how the refractive indices of calcite could be calculated in terms of the refractivities of the atoms and the arrangement in the calcite crystal which had just been discovered. So also, electrical displacement takes place with much greater ease in the plane of the aromatic benzene ring than normal to it. Consequently, the velocity, within the crystal, of light in which the vibrations are perpendicular to the ring is greater than that of light in which the vibrations lie in any other direction. This principle can be used to help in the determination of the arrangement of the molecules in the crystal.

There is a second line of advance which is being followed; and the two modes of research support each other. In this other method the arrangement of the atoms in very simple crystals is worked out to the bitter end. The method is very laborious and cannot at present be applied to complicated cases. Molecules are chosen for investigation containing the atomic groupings which occur so widely, hydroxyl, carboxyl, benzene linkings and so on. Experiment shows, so far as it has gone, that the relative positions and orientations of the atoms in these common groupings are always the same or nearly so. If they are exactly determined from the examination of particular cases, the resulting rules can obviously be very helpful in the determination of structure, and also we may confidently hope, in the discovery of the *why* of a particular structure as well as the *how*.

On these lines several detailed investigations have been completed recently. One of the results has been a better understanding of the details of the linkages between carbon atoms. It is of especial interest in the study of organic compounds, and will serve as an illustration. It is well known that carbon linkages are not all the same; we speak of a single bond, a double bond, and so on. According to the measurements we are now able to make, there are at least two kinds of carbon linkage differing primarily in the closeness of approach. There is the diamond linkage in which each carbon atom is at a distance of 1.54 Å. from its four neighbours: and the graphite linkage where the distance is 1.42 Å. between each atom and its three close neighbours. The difference

between these is far greater than can be put down to experimental error. The former kind occurs also in the fatty acid chains, where each carbon also has four neighbours, two carbons and two hydrogens. The latter is found in anthracene and naphthalene, the basis of these substances being the benzene ring: in these the carbon has three neighbours as in graphite. It may prove to be the case that the former kind of bond is peculiar to the 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.

What has been said above may serve to show how eagerly the new powers of detecting molecular arrangement in the solid are being used. With the knowledge gained in this way we may learn more of the forces which bind all atoms and molecules together, and in particular consolidate and give form and function to the various constituents of the living body.

Biometric Studies of Twins

A MEMOIR with the title "A Biometric Investigation of Twins and their Brothers and Sisters", by Dr. Percy Stocks assisted by Mary N. Karn, printed in the *Annals of Eugenics* (vol. 5, Jan. 1933), forms part 2 of a paper of which part 1 was published in the same *Annals* in 1930 and was noticed in *NATURE* of November 15, 1930 (vol. 126, p. 766).

Part 1 dealt with the characters, height, weight, head length, head breadth, head circumference, interpupillary distance, blood pressure, pulse and respiration rates, colour of eyes and hair, degree of facial resemblance and finger prints. In the present part, the measurements of strength of grip, acuity of vision, colour vision, cutaneous sensibility and upper limit of auditory sensibility are analysed by the same technique, the mental measurements are discussed, and two special problems are also dealt with: (1) asymmetry in relation to twinning, (2) correlation between physical measurements in the same individual, and the question whether this is any different in monozygotic twins from the value found for other children. For the methods of distinguishing monozygotic twins from dizygotic twins, when the twins are of the same sex, reference must be made to the previous memoir: the decision is made partly on the basis of finger prints and partly on the basis of physical characters.

Monozygotic twins were found to have a stronger mean hand grip than other children of the same ages, as might be expected from their superior height. For dizygotic and monozygotic twins respectively the correlations between members of the pair, corrected for experimental errors and day to day fluctuations, were found to be of the order 0.4 and 0.7. The former implies resemblance to the same degree as for ordinary siblings, and the power to grip seems to be relatively dependent on inherited constitution and environmental influences in about the same proportions as in the case of blood pressure, pulse and respiration. For visual acuity, cutaneous sensibility and sensitive-

ness to sounds of high frequency, dizygotic twins again resemble each other to the same degree as ordinary siblings, the coefficients being of the order 0.25-0.3. For visual acuity the coefficient for monozygotic twins is higher, about 0.5; but for the other sensory tests this result is more doubtful. It is clear, however, that heredity plays some part in the development of these characters. No evidence was found for an increased tendency to symmetry-reversal in monozygotic twins, when tested either by strength of grip of the right and left hands or by acuity of vision for the right and left eyes.

The results of the mental tests are of special interest, as they have an emphatic bearing on the interpretation of these tests. The coefficients of correlation between members of the pair are about 0.85 for monozygotic twins, 0.65 or more for dizygotic twins of the same sex, and about 0.45 for siblings. As the authors state, it is difficult to account for the high degree of resemblance in dizygotic like-sexed pairs without admitting that the close association of one twin with another plays an important part in producing like responses to these tests: the responses appear to be a measure, not as is often assumed of virgin intelligence, but of intelligence and the effect of experience superposed.

Height is more highly correlated with weight and with head dimensions in monozygotic twins than in others, though for most characters there is no regular or significant difference. The authors argue that, if monozygotic twins arise by the primary division of a single fertilised ovum, it might be expected that, unless the primary division of every component of the cell occurred with exactness, there could result a lower correlation between different characters in the same individual amongst monozygotic twins than amongst the other types. But is this conclusion necessary? If two characters are determined by $a + b$ genes and $b + c$ genes respectively, the b genes being common to the two, the genetic correlation is dependent