

Cohesion and Molecular Forces.

IN opening a joint discussion on cohesion and molecular forces between Sections A, B, and G of the British Association at its recent meeting at Liverpool, Sir William Bragg emphasised the change of point of view which the analysis of crystal structure by X-rays has brought about. The older view, in which atoms and molecules were pictured as centres of force exerted in all directions, and governed by some power law of the distance between them, has had some measure of success in explaining the principal features of surface tension and some of the departures from perfection in a gas. But in a solid, except possibly in the case of polar compounds, no satisfactory results have accrued. On the newer view we consider, not the aggregate, but the individual, atom or molecule.

It appears to be necessary to say that the very strong forces between atom and atom, molecule and molecule, are limited in their effective range of action to distances much smaller than we have hitherto supposed. Small, it may even be, compared to the distances between the centres of atoms as they lie side by side in a crystal. A crystal conforms so exactly to rules respecting its angular dimensions that it seems impossible to imagine its form to be merely the result of an average of tendencies. The forces of adjustment cannot, therefore, be thought of as a force between two points each representing one of the molecules. On the contrary, it is nearer the truth to think that the adjustment is made so as to bring together certain points on one molecule and certain points on the other. In considering, therefore, the binding of the individual molecules of a solid, the analogy of the electrostatic attraction of two charged spheres is imperfect, and should be replaced by that of two members of a girder structure adjusted until the rivets can be dropped into the holes brought into true alignment. This is seen well in the recent work by Muller and Shearer, and by Piper and Grindley on the structure of the organic fatty acids and their salts. There is no doubt that the ultimate flakes of the crystals of these fatty acids are the monomolecular films investigated by Langmuir and by Adam, and it would appear that in passing from one acid to a homologue of greater molecular weight, each addition in thickness of the ultimate flake is made in complete independence of the previous length, as if the only thing that mattered was the nature of the attachment of one carbon atom to the next. There is no influence of the ends upon the atoms in the middle. Again, we have the forces different at different parts of the atomic surface, as in the case of bismuth and its homologues, in which the atom is attached to three neighbours on one side by bonds differing from those which attach it to its three neighbours on the other.

With regard to the nature of these binding forces three types may be recognised. First, there is the effect set up by the sharing of a pair of electrons by two contiguous atoms, leading to strong and directed attachment. Next, there are actions of a different and generally weaker type manifested in the binding of molecule to molecule in a crystal. We may be sure that this type plays an important part in metals and alloys. Lastly, there are the pure electrostatic central actions. In the case of the polar crystal Born and Landé have made some progress in calculating the effect of this.

One well-known fact in crystal growth is that the faces have different rates of growth, indicating that there may be great differences in the ease with which molecules slip into their places. Into this the

element of time may enter, because a molecule may come nearly into its right place and be held there sufficiently long to get settled in by thermal agitation or otherwise. We may suppose that the formation of the crystal begins correctly enough, but that errors of adjustment creep in until the surface becomes somewhat disordered, and the growth ceases because fresh molecules cannot find their proper places to slip into. Without a more detailed knowledge of the active forces localised at various points of atoms and molecules we cannot build up a complete theory of cohesion.

Dr. Rosenhain, who followed, dealt with the simple monatomic bodies—the metals—in which the development of strength and ductility is so pronounced. In his opinion it has now become possible to sketch certain principles from which a general theory of the nature of alloys may arise. The first is that the atoms of two metals in solid solution are built on a simple space lattice, the atoms of the solute metal taking the places of a corresponding number of atoms of the solvent metal, the lattice remaining essentially unaltered. The presence of a "stranger" atom produces a certain amount of distortion which is responsible for the changes in the hardness, strength, melting point, and other properties of the metal. The second principle is that the inter-atomic distance through which interatomic cohesion is appreciable is strictly limited. When increased by any means—thermal expansion, mechanical stress, or "stranger" atoms—a limit is soon reached when the lattice breaks down suddenly with the formation of another phase. On heating, such a change is simply melting; on straining, it is the breakdown of elastic behaviour; and on alloying, we have the limit of solid solubility resulting in the formation of crystals of a new type. In many metals cohesion phenomena are complicated by the occurrence of intra-crystalline slip, which results in plastic deformation under stress by the process of slip along certain planes within the crystal. At the surface of slip there must be a rapid exchange of partners without loss of continuity of bonding. It is interesting that the phenomenon is confined to metals crystallising in the two most symmetrical systems, in which, presumably, the distribution of atoms is sufficiently uniform to permit the passing on of bonds to take place.

The mechanism of ductility by means of slip is intimately connected with diffusion in solid crystals. In Dr. Rosenhain's opinion the process of diffusion of one metal into another, the structure of which is already that of closely packed lattices, may be due to movement or slip of atoms in rows, the requisite stress, which at high temperatures need not be great, being provided by the lattice distortion arising from a concentration of "stranger" atoms in a solid solution of non-uniform concentration. On this view ductile metals should allow diffusion far more readily than brittle. It is well known that brittle metals, like antimony and bismuth, show no appreciable diffusion until quite near the melting point. Moreover, it is known that nickel and copper—two very similar atoms—exhibit extremely slow diffusion as compared with zinc and copper. This fits with the above view and is at the same time not to be expected on the view that metallic diffusion is a kinetic phenomenon similar to that of liquids and gases. On the same principles, a crude picture of the constitution of an amorphous solid fitting the facts in a general way may also be formed.

With regard to the method of binding of two crystal lattice systems growing towards one another,

one is struck by the fact that the junction of crystal to crystal is not a region of weakness, but is in fact the strongest part of a crystal aggregate. Metals, when forcibly broken in the cold, normally break through the crystals and not along the junctions. There are a large number of experimental facts supporting the view that the gap between two adjacent lattices is bridged by a region of irregularly arranged atoms constituting a layer of amorphous material of excessive strength.

Finally, while in solid solutions we find that the interatomic distances, though varying a few per cent., are roughly constant, in well-defined intermetallic compounds the interatomic distances are sometimes greatly reduced. Thus, in aluminium, the distance is of the order of 4.3 Å.U., but in the compound CuAl_2 , aluminium atoms are found with a centre distance of only 2.42 Å.U. In this case, therefore, the nature of the interatomic binding must be quite different, and this probably constitutes the real difference between a compound and a solid solution.

Dr. A. A. Griffith, who followed, pointed out that while at first sight the correlation of data on the breaking strengths of materials with the magnitude of cohesive forces derived by physical method should be comparatively simple, this is far from being the case. One reason for this is that the majority of structural metals are ductile, so that under ordinary stress systems, which almost invariably comprise shearing stresses, the primary failure of the specimen does not involve atomic separation at all but is a failure in shear. Now the mode of collapse of a space-lattice in shear is a subject which has been studied very little by physicists, so that practically no information from the point of view of molecular cohesion is available to engineers.

In the case of certain materials, for example, glass, stone, and hard steel, which exhibit brittle fractures running perpendicular to the direction of the greatest tensile stress, some progress in the subject has been made. Calculations show that in such cases the observed tensile strength is only a small fraction of the calculated molecular tenacity. This discrepancy may be avoided if one assumes the existence of minute cracks in the material fracture being due to the very severe concentration of stress at the corners of the cracks. A formula may be developed which gives results of the right order of

magnitude if the radius of the corners of the cracks is taken as two or three molecular spacings. There is another type of fracture obtained with brittle materials, namely, cracks running obliquely to the principal stresses, the best known case being the crushing fracture obtained by simple compression. This may be treated in a somewhat similar manner by the assumption of a large number of minute cracks oriented at random in the material.

With regard to the breakdown of ductile metals, Dr. Griffith and Mr. Lockspeiser have worked out a theory of plastic strain in which the conclusion is reached that plastic strain is simply the external manifestation of phase changes occurring within the material. This view in itself is not new, but the novelty arises from the fact that deductions are made regarding the number and nature of the distinct phases concerned in the action. The question arises whether it is likely on physical grounds that phase changes can occur as a result of the application of a shear stress; given that this is so, the evidence is more in favour of a resultant change in relative orientation of the atoms than of their configuration.

Prof. Lindemann considered that the assumption made by previous speakers that atoms or molecules are either bonded together, or not bonded, is premature, and cited the fact that fairly definite evidence for intramolecular attraction without definite bonds is to be found in the Sutherland correction to the temperature coefficient of the viscosity of gases, derived by assuming mutual attraction of molecules and verified experimentally.

Prof. R. W. Wood mentioned an interesting experiment requiring explanation. A crystal of rock salt placed in hot water can be immediately bent by the fingers, and remains deformed when removed from the water. The range of temperature over which this has been observed is small and the phenomenon does not occur in the case of immersion in hot oil.

To sum up, the discussion brought out clearly the fact that we are still only at the beginning of a complete explanation of the general phenomena, and there was point in the somewhat facetious remark of Sir Oliver Lodge that it was an extraordinary fact that, after all these years, three important sections of the British Association should be gathered together to discuss why, when one end of a stick is raised from a table, the rest of it also comes up.

Paris Meeting of the International Council for the Exploration of the Sea.

THE sixteenth annual meeting of the International Council for the Exploration of the Sea was held in Paris, on the invitation of the French Government, on October 1-5. By the courtesy of the Administrative Council, accommodation was provided for the Council in the Institut Océanographique, founded by the late Prince Albert of Monaco. The following countries, members of the Council, were represented: Belgium, Denmark, Esthonia (for the first time), Finland, France, Great Britain, Holland, Norway, Portugal and Sweden. Representatives of the Irish Free State attended as visitors.

The usual committees and sections for hydrography, plankton, statistics, herring, plaice, cod and haddock, limnology, the Baltic Sea and the Atlantic Slope were assembled, and a new committee, named the North Atlantic Committee, was formed.

It is important to observe that all committees and sections are now instructed to formulate precise programmes of work, allotting to each country concerned a definite part in the programme, which it undertakes to perform. Each country is called upon afterwards to report to the Council on the work it has

carried out in accordance with these undertakings, and the effect of these reports is embodied in a general progress report submitted to the Council at each meeting. The tendency to present excellent but unrealisable recommendations is thus discouraged.

For the most part the committees reaffirmed their existing programmes in respect of which generally satisfactory progress was reported. It will be observed that there are three committees for the study of particular fishes. The Plaice Committee, the recommendations of which for the protection of the plaice fisheries were adopted by the Council in 1922, and are now under the consideration of the participating Governments, is chiefly engaged in watching developments and checking its own conclusions.

The intensive investigations of the plaice having thus come to a pause, the study of the herring, cod and haddock is being vigorously prosecuted, in accordance with comprehensive practical programmes adopted in 1921, and afterwards modified in the light of experience. Unfortunately, owing to the difficulties of the time, many of the countries concerned are