Cohesion.

By DR. HERBERT CHATLEY.

WHEN one turns from an account of the discovery of a "dark star" by celestial dynamics to an investigation of the properties of the excessively minute whirling electrons in an atom, the impression is gained that within these limits at least there is but little more than relatively unimportant detail to learn. Such a notion is quite erroneous. More is known of the mechanism of plants on one hand and of electrons on the other than of the most ordinary and apparently simple mechanical phenomena. The most expert physicist can make only a near guess as to the motion of a billiard ball under given conditions as to stroke, weight, etc., since there is an imperfectly known factor, friction, in the problem. Similarly, although he can calculate with great precision the force with which one piece of iron attracts another when they are a foot apart, he cannot say with any accuracy from first principles what is the tensile strength in each piece of iron. Engineers similarly have made countless experiments and have also obtained very many data from constructional experience which give average values from which, by allowing a liberal margin for uncertainty, structures can be safely designed; but that is all.

Doubt still prevails as to the nature and laws of the force or forces causing cohesion. Lord Kelvin concluded that Newtonian gravitation would explain cohesion if it be supposed that the particles are exceedingly close. Sutherland and Nernst have regarded cohesion as identical with chemical affinity, and therefore with electrostatic force. Tolver Preston believed it was due to some mysterious dynamic action arising from the oscillation of the particles. Crehore, an American physicist, deduces it from a residual electromagnetic effect of the omnipotent electrons. Most recent students, following Sutherland, regard it as a residual electrostatic effect of the opposed charges in the atoms which, although in electrical equilibrium, are not coincident in space; some, however, prefer to consider it as largely electromagnetic.

The only satisfactory method of commencing a scientific investigation is to state all the known particulars and formulate hypotheses on the basis of the apparent facts. Proceeding so, we may note that:—

(1) All solids, being such, cohere to an extent which changes with their composition, physical structure, and temperature. Broadly speaking, cohesion varies with density and decreases with increase of temperature. It is quantitatively of the order of one millionth of a dyne per molecular pair.

(2) The range within which cohesion is effective is very small, not greatly exceeding one molecular diameter. Two pieces of material when pressed together cohere only when great force is used, if they are very highly polished or if they are so soft that they readily interpenetrate. Solids, with very few exceptions, break by tension when stretched 25 per cent. of their length, implying that the particles need to be separated only by less than one-and-a-quarter times the usual distance from centre to centre for cohesion to become inappreciable. Even the exceptional substances, such as rubber, break when stretched but little more than twice their length, and do not change much in volume. Solids at the fusing point become liquid with negligible change of temperature and only from 5 to 10 per cent. increase of volume.

(3) Solids in general, with the exception of the so-called plastic materials, extend with tension and shorten with compression proportionately to the force employed within certain "elastic limits," and are stable within those limits. The volumes increase slightly up to the elastic limits.

(4) Beyond the elastic limits the tensile and compressive strengths increase but slightly, and when the strain (extension or compression) becomes appreciable the strengths decrease.

(5) Liquids and gases show a slight "molecular pressure" or internal attraction, varying approximately as the inverse fourth power of the distances between the centres of the molecules.

It should perhaps be pointed out that an inconsistency is involved in the notion of "failure by compression." It is obvious that compression can do nothing but bring the particles into closer proximity, and if lateral expansion is prevented ultimate failure is inconceivable unless there are internal voids. Ordinary compression causes failure either by oblique sliding ("shear") or by lateral expansion.

It is required, then, to find a force which has no external resultant under natural conditions (save perhaps the normal gravitational attraction), resists tension and compression proportionately to the displacement of the particles for small ranges, and has but a limited power to resist tension which ceases at a moderate range and a great power of resisting compression. It is difficult to conceive of one force having all these properties, but perfectly simple to imagine an attraction and repulsion combined that will do so, provided that *the attraction decreases more slowly with separation than the repulsion.* A series of papers by the present writer to the Physical Society of London (1915–19) and a paper in the *Phil. Mag.* (August, 1920) attempt to deal with the problem on these lines. When the solid is at rest the attractions and repulsions balance. If a tensile force is applied the particles are separated, but since the attraction diminishes less rapidly with separation than the repulsion, there is a surplus of attraction which provides a tensile resistance. If the applied force is increased, the resistance will also increase up to a certain value, depending on the rates at which the attraction and repulsion respectively change. Further strain causes failure. On the other hand, if a compressive force is applied the particles are brought together and there is a surplus of repulsion which, like the surplus of attraction, varies with the amount of the strain, but differs in that it may be indefinitely great for very high proximity of the particles.

As to the rationale of the process little can be said. The dynamic energy of the oscillating particles and the consequent rigidity of the atoms and molecules seem to provide a kinetic basis for the repulsion. As is well known, most solids contract when they lose heat, and, since heat is electronic, the fact that most solids increase in cohesion when cooled would be quite consistent with atomic and molecular oscillation or rotation, provided that such motion is the cause of repulsion.

Whether the attraction is electrical, chemical, dynamic, or unique is not fully determinate, but since there is a fairly consistent hypothesis in terms of electrical theory, a bias in that direction is natural so long as no practical objections occur. Kelvin's gravitative theory seems to be baseless, for it leads to inconsistent results when the actual spacing of molecules is considered; but there is no intrinsic objection to an hypothesis which would make gravitation the residual of cohesive attraction. The writer has developed an empirical formula on these lines which gives a continuous expression for cohesion and gravitation. Newton's great discovery was that gravitation varies as the product of the masses concerned divided by the square of the distance between their centres, and the success of this law in explaining the motions of the heavenly bodies proves with overwhelming certitude its accuracy for all distances but the smallest, and possibly also the enormously great. When, however, the distance is comparable to the usual distance between the centres of the atoms or molecules in a solid a strong doubt as to the applicability of Newton's law arises, for it would appear that when two molecules are separated to twice their usual distance in a fluid the mutual attraction in the second position falls away much more rapidly than Newton's rule implies, and the attractions are quantitatively enormously greater. We may of course suppose, as did Sutherland, that gravitation has nothing to do with cohesion, but this does not satisfy the craving for continuity.

Here, then, is a field for investigation of the highest practical importance. If cohesion can be properly connected to other physical properties it is conceivable that new compounds of great strength, due to a critical state of cohesion artificially produced, would be found. Chemistry, crystallography, metallurgy, and engineering would all benefit by such an advance in knowledge of the ordinary properties of matter. Somewhat paradoxically it would appear that a complete solution of the macroscopic properties of matter would also solve the question of the inner structure of the molecules and atoms.

International Conference of Chemistry.

THE International Conference of Pure and Applied Chemistry held at Brussels at the end of June was nominally the second of these conferences, that at Rome in 1920 being the first; but there were at least two earlier assemblies in London and Paris which led up to the organisation, which seems now to be firmly established.

More than twenty countries are included in the organisation, Germany, Sweden, and Austria being the principal ones which are not yet represented. A number of well-known chemists took part in the conference:—Profs. Chavanne, Crismer, Swartz, and Timmermans (Belgium), Billmann (Denmark), Conant and Mackall (United States), Moureu, Béhal, Matignon, and Urbain (France), Pope and Lowry (England), Garelli and Nasini (Italy), Halvorsen (Norway), Holleman and Kruyt (Holland), Guye and Pictet (Switzerland), and several representatives of industrial chemistry, including M. Kestner, to whose energy and determination the organisation is so much indebted.

Each of the countries concerned has a council corresponding to the British Federal Council for Pure and Applied Chemistry, and the various national councils appoint members of the International Council and send in addition delegates to the annual conferences. So far as Great Britain is concerned, the Federal Council has invited its president, Sir William Pope, Prof. Philip, Dr. M. O. Forster, Mr. E. V. Evans, and the two honorary secretaries, Prof. H. E. Armstrong and Dr. Stephen Miall, to serve on the International Council for the next three years.

The work of the International Conference is divided among a number of commissions dealing with specific subjects or proposals of an international character. Among these the Commission on Chemical Elements will replace the former Commission on Atomic Weights. It was felt that the exact determination of atomic weights and their publication to several places of decimals has now lost a good deal of its scientific significance in view of the work of Dr. Aston and others, and that exact atomic weights are now becoming factors of analytical calculation rather than features of a chemical hypothesis. The isotopes or atomic numbers are taking the premier place, and the atomic weights—often representing merely the average of a mixture of isotopes—will be of practical rather than theoretical interest. The