The Discipline of Chemistry.¹

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TWO tendencies are clearly visible in the chemistry of to-day, and are profoundly affecting our methods of study and instruction, and also the direction of research. On one hand, chemistry, like every other science, is being split up into a number of distinct specialisms, and workers are tempted or even compelled to confine themselves to a narrow field; on the other, the boundaries between the several sciences are becoming less definite, through the development of border sciences, which themselves become new specialisms. In so far as it is possible to arrange the abstract sciences in a linear series, chemistry may be said to depend upon physics, as the biological sciences in their turn depend upon chemistry, the theoretical part of each being built up on the established laws of the preceding science as a basis. Physics has gone far to provide the required basis for chemistry, and each new advance in physics suggests new ideas in chemistry. Chemistry in its turn is providing a basis for biology, although more slowly than had been hoped. Great as have been the triumphs of organic synthesis and of investigations of the colloidal state, the chemical study of living organisms is still looking to chemistry for more help than it has yet received.

Whether we look at the serious publications dealing expressly with the progress of science or at the mass of popular articles in newspapers and periodicals, we see that the centre of interest at the present day lies in the new discoveries and hypotheses of physics. There is no question but that the structure of the atom, the theories of relativity and of quanta, the existence of the ether, and the results of the examination of crystals by means of X-rays, interest the educated public more deeply than any questions in chemical or, probably, in biological science. On the other hand, there is little public curiosity in regard to the advance of chemical science. A few of its applications, and those mainly concerned with warfare, attract attention from time to time, although the progress of agricultural chemistry, the most important of all from a national point of view, is shamefully neglected, in spite of the admirable work which is being done at Rothamsted and elsewhere. The public interest in chemistry does not extend far beyond poison gases and dyes. The progress of pure chemistry and the development of chemical theory are followed only by a small body of specialists, engaged in teaching or research, and of students whom our present system of scholarships and degrees forces more and more to become specialists, even at a very early stage of their studies. Perhaps this state of things is responsible for a certain attitude concerning the future of chemistry which may be traced, in implication rather than expression, in the work of some chemists at the present day. It appears to be thought that chemistry is fated to become a branch of physics, and thus to lose its own peculiar discipline, leaving its long-established methods to chemists engaged in operations of a routine character, whilst new knowledge is being acquired by the application of physical

methods of experiment, and interpreted by the methods of mathematical physics.

The knowledge of the internal structure of the atom, and consequently of the manner in which atoms may unite chemically with one another, has advanced with such extraordinary rapidity that it has seemed that chemical facts must henceforth be regarded in an entirely new light. If we accept the view that protons and electrons are the units of which all atoms are composed, the forces between them being purely electrical, and that the whole system of the chemical elements may be built up in a perfectly regular and systematic fashion from these units, whilst the structure of each atom enables us to predict how it will enter into combination with other atoms, then it would seem that chemistry should in course of time become a purely deductive science. If such a state of things were to come about, experiment in chemistry would be unnecessary, since all facts could be deduced from certain general principles and from fundamental physical constants which would by then have been determined with great accuracy. Chemists, however, know that this is not how their science has advanced or is likely to advance. Chemistry is an experimental science, which progresses by the application of a definite discipline, obtaining conclusions by induction from the observed facts, and making use of deduction from a small number of well-tried hypotheses where required.

Granting the theoretical possibility that atomic theory might become so perfect that the facts of the chemical structure of molecules might be deduced from a comparatively limited mass of data, it would nevertheless remain true that the labour of such deduction would be beyond human powers, except in relatively simple cases. We can scarcely imagine the properties and synthesis of indigo being deduced from the internal structure of the atoms of carbon, nitrogen, oxygen, and hydrogen, although it is possibly true that the one is implicit in the other. Human intelligence is not equal to the task, nor does it seem likely to be so in the future.

Chemical science has been responsible for the introduction of a number of hypotheses which have survived to the present day, and it may be worth while to look at them for a moment. The doctrine of atoms was not a chemical invention, but there is a vast difference between its use among Greek philosophers as a means of satisfying their desire to find a consistent explanation of the universe and its scientific application in the hands of Dalton as a means of explanation of the quantitative facts of chemical combination. There has been some discussion as to Dalton's personal attitude on this question, but there can be no doubt that those who did most to establish the doctrine attached no metaphysical importance to it, but used it frankly as an hypothesis to explain known facts and, above all, to predict new facts.

It is probable that throughout the nineteenth century it was a matter of comparative indifference to most scientific chemists whether atoms had a real existence. All that was important was that matter behaved as though it had an atomic structure, and that no fallacies

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or errors were introduced by making such an assumption. The value of the atom to them was quite independent of any possible demonstration of its real existence. Gradually, as the conception of atoms and molecules was found to fit a larger and larger field of facts, confidence grew, and atoms came to be regarded as real, in the only sense in which the scientific experimenter can understand reality. Molecules, built up of atoms according to well-established laws, shared in this confidence, which was thoroughly justified by the remarkable concordance of the determinations of Avogadro's number, the number of molecules in the gram molecule of a substance, as arrived at by a number of totally independent methods.

The discovery of radio-activity, whilst enlarging the conception of the atom, has made it possible to isolate the effects of single atoms travelling at a high velocity, so that the impact of a single α -ray on a fluorescent screen produces a visible effect, and the counting of these rays, which are known to be charged helium atoms, corresponds perfectly with the original hypothesis. When the minuteness of the atom was realised, chemists cannot have dreamed that a day would come when the effect of so extraordinarily minute a particle could be perceived by the eye and even exhibited on a screen to an audience. No more extraordinary confirmation of the soundness of the theoretical views of the chemists of the early nineteenth century could have been received.

Next came the development of structural theory, with reference to organic compounds, associated with the names of Kekulé, Couper, Crum Brown, and Butlerow. Again the assumed arrangements of atoms in compounds were adopted in order to express the reactions of the substances, without reference to the real existence of the chains of atoms represented in the new formulæ. Within the last few years the study of the films of fatty acids and similar substances on the surface of water by Langmuir, Hardy, and Adam has shown that the properties of such films can only be accounted for by assuming the reality of those chains of atoms which served so well the purposes of the chemist, but seemed physically improbable. The examination of solid fatty acids by means of X-rays leads to exactly the same conclusion. The greatest triumph of structural theory, the hexagon formula for benzene, need only be mentioned in passing, since it is only a month or two since the celebration of the discovery of benzene by Faraday, when the wonderful chemistry of the aromatic compounds was eloquently described by Sir William Pope and Prof. Armstrong. Next came the generalisation known as the periodic system of the elements, due mainly to Mendeleëff and to Lothar Meyer, and finally the hypothesis of the tetrahedral arrangement of the atoms around a carbon atom, devised by van 't Hoff and Le Bel to account for optical isomerism. Modern X-ray methods show that the structure of crystals of the corresponding substances is fully accounted for by assuming that the benzene hexagon and the tetrahedral linking of carbon are actually present, and the interpretation of crystals has been made possible and unambiguous by the existence of so great a mass of fully established chemical data.

The point which I wish to make is that these hypo-

theses, of the chemical atom, of the molecule, of the chains and linkings represented in the graphic formulæ of organic compounds, of the hexagonal ring in aromatic substances, and of the tetrahedral carbon atom, were introduced without reference to any metaphysical conception of the nature of matter, and were independent of any dogma concerning reality. They were intended as working hypotheses, connecting and co-ordinating facts which had been discovered by the classical methods of chemical experimentation. That they have been confirmed by entirely independent physical means shows how sound was their foundation, and encourages us to suppose that the same methods which have served so well in the past may again be trusted to lead to new discoveries in the future.

The remaining example which I have mentioned, the periodic law, was regarded by many chemists as a convenient means of arranging the facts of inorganic chemistry, but was expressly stated to be only empirical, since a theoretical basis was inconceivable. The work of Moseley, the discovery of the radioactive elements, and the conception of isotopes, have shown the periodic classification to be the most fundamental thing in the chemistry of the elements, and the atomic number has been found to have greater theoretical significance than the atomic weight. Reference to isotopes reminds us that this discovery also was made by chemical means, although its investigation appears almost to have passed out of the hands of the chemist into those of the physicist, since the introduction of the positive ray method of analysis. It was the chemical work of Soddy, Russell, Fleck and Fajans, establishing the fact that two or more elements, differing in atomic weight but identical in chemical properties, could occupy the same position in the periodic classification, which opened up this new and extraordinarily important and interesting field of research.

The development of the theory of atomic structure, due mainly to Bohr, has necessarily affected modern views of chemistry. The theory was devised to explain the phenomena of radiation, and later proved to accommodate itself in a wonderful manner to those of chemical union, making use for the purpose of Werner's doctrine of co-ordination. In its new form it promises to do much to reduce to order the facts of inorganic chemistry, still so far behind the organic part of the science in the perfection of its logic. The static atom of Langmuir, now abandoned, played an important part in bridging over the gap between the planetary arrangement, chiefly suited to the explanation of spectra, and the present highly developed system.

Whilst recognising the immense value of the new ideas, may I once more venture to utter a word of warning? The modern student tends to specialise in his scientific studies at a very early stage, and, if introduced in detail to the new conceptions while still engaged in learning the elementary facts of chemistry, is likely to suppose that the facts depend on the theory, instead of the opposite being true. The danger may seem to be exaggerated, but it is nevertheless real. I would submit that the facts should be known to the student before he applies to them this interpretation, which may prove so fascinating as to distract his attention from the experimental basis of the science.