*A Century of Chemistry.**

A LECTURE DELIVERED ON FEBRUARY 19TH, 1947, AT A JOINT MEETING OF THE ROYAL SOCIETY OF ARTS AND THE CHEMICAL SOCIETY TO COMMEMORATE THE CENTENARY OF THE FOUNDATION OF THE CHEMICAL SOCIETY.

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THIS evening Fellows of the Chemical Society have made a pilgrimage, not, it is true, a very long or hazardous one, although in this year of grace 1947 we shall return by torchlight, to John Street, Adelphi, to the Royal Society of Arts, the birthplace of our Society. We have come like the pilgrims of old, who made much longer journeys, in a spirit of piety to the place that holds such a high place in our memories, to pay our homage to the Society that gave us hospitality for our first meetings. It was on February 23rd, 1841, thanks to the initiative of Robert Warington and the kindness of his friend Arthur Aikin, formerly the Secretary of the Society of Arts, that twenty-five chemists, including Aikin, met in this building to consider founding a Chemical Society, and here its first regular meeting took place on March 30th, 1841.

The Society of Arts had been established for nearly a century, and its Secretary Aikin was a very remarkable man. He had been one of the founders of the Geological Society, but his abiding enthusiasm was for chemistry, thanks to his early friendship with Priestley, and he became the first Treasurer of the Chemical Society and its second President. So we started life with a close personal link between us.

However, the fledgling Society soon wanted to try its wings, and in six months it left the nest to go to the Westminster Literary and Scientific Institution in Leicester Square. There was some fear too that chemical experiments might not be welcomed in these august precincts. But migration was found to have its drawbacks; oddly enough there were difficulties about heating; they missed this warm nest, and in 1842 the Society was back in John Street, where it enjoyed the hospitality of the Society of Arts at the modest rent of £25 a year until 1849. The Annual Reports reveal the general satisfaction of the members with this arrangement, and indeed in 1844 the Council reported " that the arrangement . . . continues to be satisfactory to both parties, and especially to ourselves, as we have not only acquired a convenient habitation, but have avoided the expenses included in the word establishment so often ruinous to young Societies ". Happy indeed is the institution that has no overheads !

But by 1849, when the Society got its Charter, it had outgrown the limits of your kind hospitality, and needed rooms for its library and collections, which it found in the Strand. And so ended this happy connection between us, for which the Chemical Society will always be most grateful.

This year in July the Chemical Society is celebrating, somewhat belatedly, its centenary, and tonight we come here to commemorate its first meeting in the building where it took place. It is my privilege, in this joint meeting, to try and sketch the achievements not of the Chemical Society, for that is the task of the President, but the achievements of our science since 1841—what it has done, with the help of its sister sciences, to give man control over the materials on which his well-being depends, and to throw light on the complexities of living matter.

Chemistry in 1790—1840.

1841—just over half a century since Lavoisier had given chemistry its modern form in his great Treatise of 1789, his autobiography of one of the simplest and most decisive revolutions science has known. Lavoisier applied to chemistry not only the balance but, being skilled in affairs, the method of the balance sheet. The idea of the chemical equation dominated his mind, and his first chemical equation dealt, as the Bible tells us, with one of the earliest and one of the most significant chemical reactions known to man. It runs :

Le moût de raisin = acide carbonique + alkool.

We owe to Lavoisier the first clear distinction between physical and chemical change. With Laplace he laid the foundations of thermochemistry. We owe to him the idea of organic combustions by which he was the first to determine the quantitative composition of the products of living processes. When he was guillotined in 1794 he was setting his course towards the Atlantis of biochemistry.

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After Lavoisier in 1808 came Dalton with his Atomic Theory. It was one of those flashes of genius that crystallises an idea that had been floating in men's minds for centuries, and gives it the simple concrete form that makes it a powerful instrument in the hands of mankind. Lavoisier's analyses and his nomenclature could then be translated into atomic formulæ, the chemist's shorthand.

The next landmark was Davy's verification of Lavoisier's prediction of the existence of the alkali metals; their isolation by electrolysis laid the foundation of electrochemistry and of the association of chemical affinity with electrical charges. Davy also redressed the balance of Lavoisier's over-estimate of the central position of oxygen by showing that the essential element in an acid is hydrogen and not oxygen.

And then, just as chemistry was attracting more and more attention and new chemical facts were being discovered so rapidly, came the Swede, Berzelius—the most massive figure in the whole of its history. In a few years he determined single-handed with amazing skill and sagacity the atomic weight of every known element and the composition of many compounds, thus giving added reality to Dalton's theory. He too substituted for Dalton's geometrical symbols the initial letters of the names of the elements, which we use to-day. Berzelius had an encyclopædic mind, and he embodied in ten volumes the whole compass of chemical knowledge enriched by many of his own discoveries. Conservative as to the ideas which had served him well, he had the intuition to see where there was a common pattern in diverse chemical phenomena, and we owe to him the generalisations of isomerism and catalysis and their names.

For twenty years Berzelius was the accepted authority and the influence he exerted through his Annual Reports on current literature and through his friendships with the younger generation of chemists was immense. Meanwhile the younger men like Liebig, Wöhler, and Dumas were laying the foundations of organic chemistry by making series of derivatives from natural products with inorganic reagents. The new facts they discovered were difficult to reconcile both with the dualism and the theory of radicals which Berzelius had inherited from Lavoisier, and with his own view of the dependence of chemical affinity on electrically charged atoms. By 1841 his authority was seriously challenged. His formulæ were discredited, even his atomic weights were largely replaced by equivalents, and there was a drift from theory towards empiricism.

Founding of the Chemical Society.

So the Chemical Society was founded at a most opportune moment, when the number of young men doing research was rapidly increasing and the opportunity for discussion and publishing their results was badly needed. For the next twenty years chemistry was to be in a state of flux, without any generally accepted theory. It was a time of bitter controversy, when the older chemists resented criticism and the younger men like Gerhardt and Laurent suffered persecution for their views. In their heroic battle against authority, which they ultimately won, Pope's lines, often spoken in jest of our profession, came literally true:

> " The starving chemist in his golden views
> Supremely blest, the poet in his Muse ".

Laurent died as a result of privation.

From 1840 to 1860 the work of most outstanding chemists lay in organic chemistry. It was a period of rapid growth, when experiments were almost bound to lead to discoveries. Each chemist had his own theory of which he was tenacious, as it meant much to him; it was in a sense the scaffolding which enabled him to make his own contribution to the structure of chemistry. And so it is not surprising that by 1859 a whole page of Kekulé's text book was filled by the different formulæ proposed for such a simple substance as acetic acid.

As the technique of organic reactions was gradually developed, each year brought an increasing harvest of new compounds and there was a growing need for some new system of classification to include them all. Laurent and Gerhardt, with their logical French minds, had each been seeking a new basis of classification along rather different lines, and their partnership led eventually to Gerhardt's type theory in which all organic compounds were derived by substitution from four simple inorganic substances, hydrogen, water, hydrochloric acid, and ammonia. Gerhardt's theory was an unconscious recognition of the different combining powers of the atoms and groups, and led inevitably to Kekulé's theory of atom linkage. It had been a long struggle, and Laurent died in 1853, but Gerhardt lived until 1856 to taste success and see his views adopted by the younger chemists.

The early meetings of the Chemical Society during that stormy period must have been lively and stimulating, with men like Lyon Playfair, Graham, Brodie, William Odling

(Gerhardt's *l'ami Odling*), and Williamson, to whose classic paper on ether and alcohol Gerhardt owed so much. And there were in London during those years young German chemists of great ability—Kolbe came in 1845, to infect the young Frankland with his interest in the synthesis of organic compounds from simple molecules. Hofmann came in the same year to teach at the new College of Chemistry in Oxford Street, and Kekule in 1853 as assistant to Stenhouse, the Chemist to the Mint. Kekulé often said that his theory of the structure of organic compounds started in his dream about atoms on the top of an omnibus one night between Islington and Clapham Road where he lodged. So in those days London and the meetings of the Chemical Society which took place in this building from 1841 to 1849 were a focus of chemical thought.

Cannizzaro and Kekulé.

These two decades of uncertainty and divided opinion ended almost abruptly after 1860, thanks to the constructive thinking of two men. In 1860 the first international conference of chemists was held at Karlsruhe at Kekulé's suggestion, with the object of arriving at some agreement about atomic weights and molecular formulæ. Nearly all the active workers in each country were present, but as at other international meetings progress was slow. Committees were appointed which grew larger and larger, there was jockeying for position and eventually the Congress broke up in a chilly mood, having accomplished practically nothing. But copies of a thin paper-covered pamphlet on atomic and molecular weights by Cannizzaro, the Professor of Chemistry at Palermo, were given to some of the delegates. His exposition of the existing difficulties and their solution by the consistent use of the laws of Avogadro and Dulong and Petit was so clear and convincing that as Lothar Meyer said when he read it " the scales fell from my eyes, doubts disappeared and were replaced by a feeling of certainty ". It was not long before there was a general agreement among chemists about the weights of the atoms and the number of atoms in a molecule, which, as Kekulé had foreseen, was a necessary preliminary to a general theory of the constitution of molecules.

The other decisive factor was Kekulé's theory of atomic linkages, each atom having a definite combining power—hydrogen one, oxygen two, nitrogen three, and carbon four. On this basis, recognising that atoms of carbon, unlike other elements, could unite to form stable chains, or rings like the six-membered benzene molecule, Kekulé was able to assign definite structures to organic compounds, and this gave an immense impulse to the advance of organic chemistry.

When these major controversies were over, chemistry advanced rapidly on a wide front in the years from 1860 to 1900 which form the next epoch.

Organic Chemistry, 1860—1900

Kekulé's theory of atomic linkage had presented chemists with an almost unlimited number of possible arrangements of carbon atoms in straight or branched chains, or in rings with intermediate links of other atoms which could also form part of closed-ring structures. These possibilities chemists were quick to explore, both by building up new molecules by synthesis in the laboratory, and by trying first to ascertain the molecular structure of natural products and then to synthesise them in the laboratory. Outstanding examples of this were the syntheses of alizarin in 1869 and of indigo in 1880. In this way many new compounds were made and described, and the technique of organic reactions was continuously extended. Between 1856 and 1910 the number of known organic compounds increased from 3,000 to 200,000.

In this period of rapid development there was one episode of outstanding importance, the simultaneous recognition by van't Hoff and Le Bel of the need to take into account the arrangement of the atoms in three dimensions. Kekulé had realised this, but he was sceptical about the power of chemistry to reveal the actual structure of the molecule, although he thought physics might do so. Pasteur in 1845 had already proved from the rotation of light passing through them that in certain cases the same atoms could form either a right- or a left-handed molecule. Van't Hoff and Le Bel showed that this was due to the presence of one or more carbon atoms combined with four different groups which could be arranged spatially in right- and left-handed forms. In addition, the arrangement of the atoms in space could account for a number of other unexplained phenomena. All their predictions were quickly verified, and since 1874 stereochemistry, the arrangement of the atoms in space, has been a potent factor in the progress of organic chemistry.

During these years it was in Baeyer's laboratory that most of the foremost organic chemists served their apprenticeship. It was there that Emil Fischer, the younger Perkin, Willstätter, and many others learnt the simple technique of the test tube and glass rod with which so many discoveries were made before the elaborate technique of modern organic chemistry became necessary. The sugars, the terpenes, and the alkaloids yielded the secrets of their structures. Some of the many new compounds that were synthesised were only of scientific interest, while others yielded new dyes or new perfumes or new drugs like eucaine and veronal, so called because Emil Fischer happened to wake up and look out of his carriage window at Verona after a visit to Baeyer to discuss its properties.

Inorganic Chemistry, 1860—1900.

The advance of inorganic chemistry naturally took a different course. In 1860 sixty-four elements were known and many attempts had been made to classify them in families with very limited success. When agreement had been reached as to the relative weight of the atoms a new line of attack was opened, and in 1864 both Newlands and Lothar Meyer pointed out that if the elements are arranged in the order of their atomic weights, elements recur at regular intervals with similar properties, apparently belonging to the same family. Four years later Mendeleeff, using more accurate atomic weights, developed the Periodic System in much greater detail and predicted by means of it the properties of three undiscovered elements which were missing from the system. The accuracy of his predictions was shown by the discovery of gallium in 1875, scandium in 1879, and germanium in 1886. The invention of the spectroscope by Bunsen and Kirchhoff in 1859 had given chemists a powerful new instrument, and the discovery of further new elements, rubidium, caesium, and thallium, soon followed with its aid, to fill other gaps in the Periodic Table of the elements. But even though it provided a basis for the classification of the elements in families, many puzzling problems in the Table remained unsolved.

Physical Chemistry, 1860—1900.

Meanwhile the influence of physics on chemistry was being felt more and more, both in the use of new techniques like the spectroscope and in various applications of physical theory. Here again van't Hoff was the pioneer in a dual attack by applying both molecular theory and the laws of energy to the analysis of chemical phenomena. The laws of energy or thermodynamics are laws of experience like Newton's law of motion, independent of any hypotheses as to the nature of matter, and affording therefore a useful test of the truth of such hypotheses and of classifying and forecasting certain chemical phenomena. Willard Gibbs had been the forerunner in this field in 1876—1878, but van't Hoff was the first to show the wide applications of thermodynamics to chemistry. At the same time he was analysing the kinetics of chemical reactions and the nature of chemical equilibrium in the light of molecular theory, and showed their dependence on the behaviour and properties of the individual molecule. Thus in the 'eighties a new subject, Physical Chemistry, was taking shape, especially in the field of solutions, where Arrhenius gave it a fresh impulse with his theory of electrolytic dissociation which related the electrical conductivity of solutions to the dissociation of molecules into electrically charged ions. That again had applications in many fields, and with the help of Ostwald and Nernst physical chemistry quickly became a powerful new instrument.

And so in the 'nineties, when I and my contemporaries were learning chemistry, organic chemistry gave us a tidy logical picture in which the agreement between properties and structure showed clearly that the model represented a close approximation to the truth. In physical chemistry we got a picture of the dependence of chemical reactions and equilibria on the kinetics of the individual molecule or ion, and of the value of thermodynamics in giving generalised laws independent of any theory. Inorganic chemistry was more difficult; by then there were so many isolated facts to be remembered, and while the Periodic Table was a great help, there were many anomalies still to be explained.

Nineteenth-century chemistry had been based on the Newtonian atoms, those small, hard, indivisible, elementary particles of which all matter was thought to be composed, and its development was mainly that of an experimental science. The whole picture of molecular constitution had been built up by inference from macroscopic experiments, and there were no means of investigating the fine structure of matter to give some clue as to the nature of the atoms, of their chemical affinity that caused their reactions, or of their valency that determined their combining powers. The evidence of their spectra certainly suggested that their structures were far from simple.

Then suddenly there came a rapid succession of discoveries that threw an entirely fresh light on the whole subject and by 1914 had given chemists a new conception of the unity and sub-mechanics of their science.

The Period of Great Discoveries, 1895—1913.

In 1897 J. J. Thomson discovered the negative electron, showing that electricity is atomic and that the electron is common to all atoms. Becquerel had already discovered radioactivity in 1896, and Madame Curie isolated radium in 1898. These discoveries, together with Rutherford and Soddy's systematic investigation of radioactive charges, gave the first clue to the nature of the atom.

Roentgen's discovery of *X*-rays in 1895, with wave-lengths approximating to atomic dimensions, in the hands of von Laue and the Braggs proved a most powerful means of investigating the arrangement of atoms and ions in crystals and later the arrangement of the atoms in the molecule.

In 1911 Rutherford's discovery of the dimensions and nature of the nucleus led to his theory of the nuclear atom consisting of a small central positively charged nucleus with electrons rotating in orbits around it. Moseley in 1913, by examining the frequencies of the *X*-rays emitted by different atoms, proved that there are ninety-two elements with ordinal numbers corresponding to the number of charges on the nucleus, thus throwing an entirely new light on the Periodic Table. As a proof of the thorough way in which nineteenth century chemists had done their work, it is worth noting that of that complex and hitherto mysterious group of elements, the rare earths, fourteen had been separated and recognised as elements before Moseley's law was known, leaving only one of extreme rarity to be found.

The full significance of Rayleigh and Ramsay's discovery in 1895 of argon, the first of the rare gases, followed by Ramsay's discovery of the rest of the family, was now apparent. The arrangement of the electrons in their atoms was so stable that they showed no tendency to combination, and this was the basis of G. N. Lewis's and Kossel's theories of valency as dependent on the stability of an octet of electrons in the outer shell of the atom.

In 1901 Planck had shown that radiant energy had a certain atomic character, as it could only be emitted and absorbed in discrete quanta, the size of which was proportional to the frequency of the vibrations. The fundamental significance of this discovery to chemistry was not at first obvious, until Bohr in 1912 showed that the application of the quantum theory to the electron orbits in Rutherford's atoms could explain the structure of their spectra, the actual wave-lengths of which could be calculated in simple cases.

Then, just as all the tools for future development were in the chemist's hands, came the war of 1914, the first chemists' war, in which chemistry played a vital part in making explosives, in making synthetic products to counter the effects of a blockade and in the military use of gas and smoke. The effect of this was to intensify the effort directed to chemical research after 1918.

Chemistry in the Inter-war Years.

Demobilised from their war activities, chemists returned to their laboratories with fresh zest to take up again the work that had held so many exciting prospects in 1914. I remember Rutherford saying to me in 1919: " What's the use of going back to chemistry when Bohr will soon to able to calculate anything you can find out? " But Rutherford was the last person to dissuade anyone from experimenting, and it was in his own laboratory that the science of nuclear physics was born.

During the inter-war years chemistry has progressed with amazing speed, and its influence has been felt increasingly in the sister sciences of physiology, botany, agriculture, and geology. The main factors in its progress have come from physics, both from new physical techniques and from new physical theories. Progress has been on such a wide front that it is impossible to summarise, but there seem to me four outstanding achievements in the fields of atomic and molecular structure, of nuclear physics and isotopes, of the kinetics of chemical action, and of the organic chemistry of living processes.

Atomic and Molecular Structure.

Chemistry owes to physics the detailed knowledge that we now possess of the structure of molecules, derived from measurements of their *X*-ray diffraction, electron diffraction, Raman spectra, dipole moments, and their spectra from the infra-red to the ultra-violet. There has been a continuous development both of the technique and of its application in each field since 1919. Thanks to this we now know the distances between the centres of the atoms in any linkage, the position of the atoms relative to one another, the nature of the linkage, the heat of formation of the linkage and its resistance to deformation.

Simultaneously with this advance on the experimental side there has been a remarkable development on the theoretical side which has stimulated experiment and has explained the causes underlying the behaviour of the atoms and molecules.

Till 1925 the Bohr–Rutherford atom held the field, the positively charged nucleus with electrons rotating round it in various orbits. From the purely chemical side it gave a qualitative explanation of the valencies of the elements, it distinguished between electrovalent, covalent, and co-ordinate links, and it explained most of the regularities of the Periodic System. It gave a quantitative basis for calculating the spectra of atoms and simple molecules, and with the hypotheses of electron spin and molecular vibration it accounted for the fine structure of spectra and their behaviour in a magnetic field.

But difficulties arose with the model atom as the electron sometimes appeared to behave as a particle and at others as a wave motion, a dilemma that was the basis of Heisenberg's Uncertainty Principle. The difficulty was solved by the new calculus of quantum mechanics, in which the properties of the atom are described by equations which admit of no simple physical interpretation such as a model. The test of their validity is the wonderful accuracy with which they can predict the behaviour of single atoms. Unfortunately in more complex systems great mathematical difficulties are involved in a rigid solution, and various methods of approximation have to be adopted. However, in spite of this, quantum mechanics has provided a new stimulus and a new interpretation in many fields, particularly in regard to valency. It enables the direction of the valencies of any atom in space to be calculated, and provides a much more subtle differentiation of the various types of linkage. The periodicity of the properties of the elements with increasing atomic number can be shown to be a necessary consequence of the geometrical symmetry of the electron fields. It explains too the quantum restrictions as a necessary consequence of the wave characteristics of the electron.

Isotopes.

The nucleus itself is mainly the concern of pure physics, but there is one important exception, the existence of isotopes, atoms with the same atomic number but with nuclei of different mass. By means of his mass spectroscope Aston showed that the chemical elements are nearly all mixtures of istopes, and by measuring the amount of each present and its atomic weight he explained why chemical atomic weights are so far removed from whole numbers. The actual separation of the isotopes with identical chemical properties by physical means was one of the most laborious experimental problems with which chemists have been faced.

But a new significance was given to isotopes when the physicists found it possible by bombarding atomic nuclei with various particles to transmute them and often to produce isotopes with radioactive properties differing from those of the parent atom. Quite apart from their therapeutic importance, such isotopes could be used as tracer elements in chemical reactions and in living processes to track down the course followed by the atom in question.

Physicists also discovered the particles of which the nucleus is composed, the positron, the positive equivalent of the electron, and the neutron, whose unique properties as a projectile in nuclear bombardments makes possible the utilisation of atomic energy.

The Kinetics of Chemical Change.

This brings me to the next main field of progress, the kinetics of chemical reactions. It is generally true to say that no phenomenon is as simple as it seemed to the original discoverer, and of nothing is this so true as of the equations used to represent chemical reactions. Only last year our President's Bakerian Lecture was devoted wholly to the complexities of that first schoolboy equation: $2H_2 + O_2 = 2H_2O$.

The investigation of reaction rates has given scope for much ingenious experimental and mathematical treatment. It has involved the study of the lives of the individual molecules, the circumstances under which they can acquire a critical amount of energy, the effect of radiation, the effect of catalysts, and the significance of chain reactions. Great progress has been made, which has given us a much more intimate picture of the actual mechanism by which chemical reactions take place. The results are of profound interest for both theory and practice, as so often it is the rate of change that determines what is possible.

Organic Chemistry.

And lastly there is organic chemistry, when we must go back to where we left it about 1900. Its outstanding achievement has been the light it has thrown on the great systems of the materials and processes of living organisms. Organic chemistry has thus returned to the task for which it was originally equipped by Lavoisier and for which he meant to use it, the discovery of the chemical reactions of the living body. Its success has been to reveal their complexity. With the techniques that have been developed by organic chemists for over a century they can now break down or build up the most complex structure of carbon atoms and the groups attached to them with a certainty that leaves no doubt as to what that structure is.

Here again physical methods have played an important part. *X*-Ray analysis of crystalline or regularly orientated material has revealed the details of its atomic and molecular structure. Infra-red spectra have made possible the identification of minute quantities of material differing only in small details of their structure. The modern methods of chromatography, the selective adsorption of substances in various media, allow of the separation of the constituents of complex mixtures available only in small quantities which otherwise could not be resolved. The ultra-centrifuge too has helped in the separation of complex molecules and the determination of their molecular weights. The technique of microchemistry, the handling and analysis of small quantities of organic material, has made possible the investigation of substances available only in small quantities and quickened the pace at which investigations can proceed.

The problem for the chemist, in conjunction with the physicist and the biologist, is to unravel the processes by which Nature builds up the structure of living organisms, and provides the materials that discharge the functions of their various parts.

The plant is the first stage in Nature's economy, as plants alone can assimilate the carbon dioxide of the air and nitrogen from inorganic sources and synthesise from them the carbohydrates, fats, and proteins that form the food of other organisms. The first success of chemists in this field was the determination of the structures of the simple plant products, such as the sugars, vegetable oils and fats, essential oils like the terpenes, rubber, alkaloids, and various dyestuffs and colouring matters like the anthocyanins. Many of these were synthesised in the laboratory, and *X*-ray analysis has confirmed the correctness of the structures assigned to them on the ground of chemical behaviour. A comparison of these structures shows that Nature makes use of the economy of prefabricated construction, as many of them are built up by different arrangements of the same groups of carbon atoms. Thus the carbohydrates are all built up of chains of six carbon atoms, but C_3 may be an intermediate stage in this grouping, as the groups $C_6 - C_3$ and $C_6 - C_3 - C_6$ frequently occur in plant products. The vegetable fats and oils are mostly built up of C_6 units forming chains containing twelve, eighteen, or thirty atoms, joined together by the C_3 of glycerin. The structural units C_6 and C_3 recur again in a number of substances where the chain of six carbon atoms has been converted into a ring as in the oil of cloves and similar substances. Two $C_6 - C_3$ groups provide the skeleton of many others, and with the addition of C_6 the skeletons of the catechins and anthocyanins. The aromatic oils, resins and rubber have been formed by a different route; they are built up from a C_5 unit with a branched carbon chain which may either condense to rings like the terpenes or polymerise to a long chain as in rubber.

But in spite of these regularities we have little knowledge of the methods by which Nature marshals these units in the living cell. Her catalytic methods are so specific in their actions and work so cleanly compared with ours that she is able to marshal these structural units to form complex molecules under the influence of surface forces exerted as it were by a template of existing molecules. The ease and certainty of Nature's methods is so intriguing and tantalising to the chemist working in a non-living environment.

It was quickly realised that many of the main constituents of living organisms, the polysaccharides and the proteins, had vastly greater molecules than these simple plant products, and here again *X*-rays have rendered decisive help. Cellulose, for instance, was found to consist of hundreds or thousands of glucose residues united in a straight chain, and forming the chain bundles which are the predominant structural element of the plant kingdom. In rubber the long carbon chains are folded higgledy-piggledy around one another, straightening when the rubber is stretched and giving it its elasticity. The discovery of formaldehyde phenol plastics by Baekeland in 1909 soon resulted in the synthesis of similar giant molecules in the laboratory and the study of their behaviour. Carother's classical investigation of the linkages which would produce these giant molecules led directly to the discovery of nylon, a nitrogenous synthetic fibre that is competitive with Nature's products.

Of all these giant molecules the proteins, which in one form or another enter into almost every living process, are the most significant. Emil Fischer's pioneer investigations showed that they all consist of various amino-acids linked together to form long chains. *X*-Ray analysis revealed the regular order in which the amino-acids alternate in the chains of different proteins and the position in space of the side groups, the projections from the chains that determine so largely the specific properties of each. The proteins are divided into two great families, the fibrous and the globular, those in which the chains are extended like fibroin, the spider's web, and those in which they are coiled in a regular manner like albumin and hæmoglobin. The former class has again two main families, the keratin-myosin-fibrinogen group, including wool, hair, skin, nails, whalebone, muscle tissues, and the coagulating constituent of blood, and the collagen group including tendons, connective tissue, and cartilage. The knowledge of their chemical structure reveals something of the principles of Nature's engineering, of the way in which she provides for the necessary mechanical properties of the parts of an organism. And further it is beginning to throw light on the processes of growth, the synthesis of giant molecules by contact catalysis in living matter.

Great advances have been made in our knowledge of enzymes, those complex colloidal catalysts formed by living cells which enable the chemical changes that accompany and condition living processes to take place rapidly at ordinary temperatures. The isolation of some of them like urease, trypsin, and pepsin in a crystalline form was a great achievement. Some have proved to be pure proteins, while others, such as those responsible for the oxidation of food in the body, are proteins associated with various complex groups which can act as oxygen acceptors.

Then there are substances such as the vitamins, hormones, and auxins, small quantities of which exert such an immense effect on living functions. Vitamins are essential to normal life and healthy growth, and are all derived from foodstuffs. Their identification has played an important part in the modern treatment of nutrition, and the constitution of most of them is now known. Hormones are the chemical messengers, produced in one part of the body and exerting a most potent influence on others. Some of them, such as the sterols, and the active principles of others, such as adrenalin and thyroxin, have been isolated; their structures have been determined, and some of them have been synthesised. The knowledge gained in this way has been of the greatest value in curative medicine.

Lastly, there are the viruses, those minute carriers of disease that have been so hard to track down and isolate. Some of them have now been obtained in a crystalline form and have been shown to be nucleoproteins.

In addition to throwing light, in these and many other ways, on the complex molecules and the complex secrets of the chemical reactions on which the existence of life is dependent, chemists have synthesised many new substances which have important biological applications. Ehrlich's discovery of salvarsan in 1910 was an outstanding triumph. Its name "606" emphasises the number of attempts before a molecule was found that would destroy the spirochæte of syphilis without killing the patient. Later came the sulphonamides with their specific reactions against certain types of bacteria. Their power of stopping growth suggests that they are absorbed on the catalytic surfaces in place of some of Nature's prefabricated units of similar shape, and thus prevent the completion of the pattern and the formation of a new molecule. Their action has been likened to the jamming of a lock by a key that does not quite fit.

D.D.T. and gammexane come in another category. They are synthetic products of outstanding effectiveness in killing insect pests without hurting men or animals. Similarly a range of substances has been found which will kill weeds (dicotyledons) without damaging the growing crops which are monocotyledons.

One of the greatest triumphs of chemistry in the chemotherapeutic field has been the isolation of penicillin, and the elucidation of its structure, the last details of which were revealed by *X*-ray analysis, and finally its synthesis.

All these examples, and they are but a few of many, go to show what an effective instrument chemistry has become, working with her sister sciences in revealing both the possible combinations and permutations of the elements of which the world is made, and the nature of the processes associated with living organisms. But in addition, chemists have a great record of achievement in the application of all this accumulated knowledge to the service of mankind. And this brings me to the progress of chemical industry during the last hundred years.

Chemical Industry.

Our industry is, I know, of special interest to the Royal Society of Arts with its wonderful record of almost 200 years of activity devoted to the encouragement of the practical applications of scientific discovery. The progressive stages of civilisation have in fact been largely conditioned by the materials available to mankind. From the Bronze Age to the present age of light alloys and plastics there has been a steady advance in the exploitation of natural materials to serve the needs of man, and in this the chemist has played the decisive rôle.

Chemical industry in 1841 was still in an embryo stage; it had not yet felt the effects of the great industrial expansion of the nineteenth century, or of the impact of science on industry. It was mainly concerned with the manufacture of acids, alkalis, and mineral salts, with the extraction of natural products like sugar and dyestuffs, and with various fermentation processes.

The first major development came from the progress of organic chemistry. Perkin's discovery in 1856 of mauve, the first synthetic dyestuff, started a new industry. One result was the first displacement of a natural product, when alizarin was synthesised in 1868, and the synthetic material quickly supplanted the cultivation of madder. Baeyer's synthesis of indigo in 1880 again led to the gradual displacement of the indigo crop.

With the rapid advance in the discovery of improved and faster colouring matters and the discovery of synthetic drugs like phenacetin and sulphonal, the organic industry grew rapidly. Although it had started in this country with Perkin, and Germans like Caro and Otto Witt came here to serve their apprenticeship, it was not long before Germany had secured the lead, mainly owing to her lavish investment in research. The scientific basis on which the organic industry had developed undoubtedly had a considerable influence on the development of the chemical industry as a whole.

In the heavy chemical industry the decisive episode in this country was I think the courageous and far-sighted decision of Ludwig Mond and John Brunner in 1872 to use the Solvay process for making soda. Their means were slender and several firms had already had to abandon the process. But Mond saw its possibilities, and for the first two years at Winnington he watched the process by day and night. The scientific control of the plant by which he achieved success and his skill in plant design marked the birth of chemical engineering in this country.

Other major factors were now at work to expand the scope of the industry. First came the demand for artificial fertilisers to meet the food demands of the rapidly growing industrial population. Then the availability of electrical energy from the dynamo gave a new impetus to the use of electrolytic methods to produce metals like aluminium, magnesium, and sodium, and alkali and chlorine, and of the electric furnace to make calcium carbide and other products.

The demand for explosives and the invention of gun cotton, dynamite, and high explosives built up another section of the industry. The peaceful uses of cellulose products—nitrocellulose, cellulose acetate, and viscose—provided another field of development, and in each new field the links between science and industry were drawn closer.

The successes of chemical engineering were achieved by plant design and process control. The design of plant was based on accurate quantitative knowledge of the reactions concerned, on securing maximum heat economy, on the use of an ever-increasing range of anti-corrosive materials, and on the use of the most efficient catalysts. Continuous control of processes was obtained by recording instruments at each stage and by analysis. The study of catalysis led to revolutionary changes first in the manufacture of sulphuric and nitric acids and ammonia and later in the whole range of the industry. The catalytic hydrogenation of vegetable oils was an outstanding contribution towards the supply of the world's demand for fats.

Then came the war of 1914, in which the chemical industry became almost a decisive factor by the production of explosives and fertilisers. In fact, without the Haber process for making ammonia, the blockade would quickly have compelled Germany's surrender. The war thus demonstrated the strategic importance of the chemical industry. To quote a sentence from the report of the Mission which I had the privilege of leading in 1919 to investigate the war uses of the German chemical factories: " In the future it is clear that every chemical factory must be regarded as a potential arsenal, and other nations cannot, therefore, submit to the domination of certain sections of chemical industry which Germany exercised before the war. For military security it is essential that each country should have its chemical industry firmly established ". The lesson we learnt then was not forgotten.

As in pure chemistry, the inter-war period was a time of rapid development. The earlier development of synthetic chemistry had largely been in competition with Nature. Steinmetz, the genius of Schenectady, once said to the head of the I.G., " Bosch, I know you can make indigo cheaper than God, you may some day make rubber cheaper than God, but you will never make cellulose cheaper than God ".

With the discovery of plastics and the vast possibilities of the synthesis of large molecules there has been some competition with natural products, such as nylon with silk, and synthetic rubber with the plantation product, but much progress has also been made in processing and upgrading vegetable products, such as cellulose, starch, and vegetable oils, and in the use of farm by-products. The processing of foodstuffs, including crop drying, is another field in which chemical industry and agriculture are establishing a new community of interest. These developments are of great significance, as it means that industry is drawing increasingly on the revenue account instead of the capital account of the world's resources for its raw materials.

I must not omit, however, some reference to the remarkable technical progress of the petroleum industry in the inter-war years. The refining of crude oil was revolutionised by the use of catalysts, and most recently by the use of the so-called fluid catalyst, small particles suspended in a current of the reacting gases. In addition to making petrol of high octane value and other fuels, a new industry has been built up on the hydrocarbon gases from the cracking process and the natural gas from the oilfields. From them an immense variety of chemicals are now made, such as *iso*octane, synthetic rubber, and solvents of all kinds. Under the pressure of autarchy oil was made from coal, by hydrogenation and by the Fischer–Tropsch process, which is now expected to produce petrol and hydrocarbon gases at a price competitive with crude oil, starting from natural gas and using a fluid catalyst.

Once again we have seen how war has tested the resources of the chemical industry, when it proved its ability to produce, at a cost, whatever was needed from the available raw materials, whether it was aviation fuel, rocket fuel, synthetic rubber, or synthetic fibres. Chemical engineers too played a great part in the vast organisation, with all its attendant difficulties, necessary to separate the quantities of uranium 235 and plutonium in the state of purity needed for the atomic bomb. And their work opens up a vista of possibilities of the use of atomic energy for peaceful purposes.

Conclusion.

Thus in its industry, as in pure science, chemistry has a great record of achievement. Looking back at the state of knowledge when our Society was founded here in 1841, we see a wonderful century of progress. And in this the Fellows of the Society have always played a leading part. But it is well to remember that that swift advance has depended on the efforts of men in many countries working together with a common aim, with no tariffs or visas to hinder the flow of new ideas.

And I cannot help reflecting on the contrast between this record of achievement and the sorry state of the world to-day. Is it not paradoxical that with the understanding we have won of Nature's secrets, with our power to control nature in action, that the majority of mankind should still be suffering from malnutrition and many from endemic disease? This seems to me a challenge to science and not least to chemists. Is sufficient effort being devoted to the application of the knowledge we already possess? What should be the priorities? How can we ensure that the same concerted effort is made to use that knowledge for the peace and contentment of the world as made it such a potent factor in the war? That is the thought I would leave with you at the beginning of our second century.