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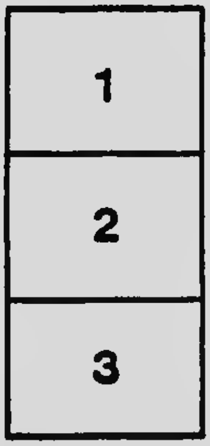
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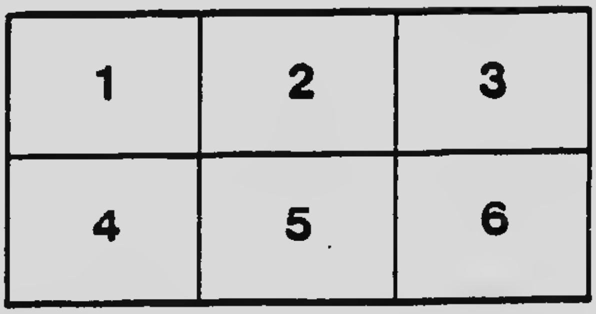
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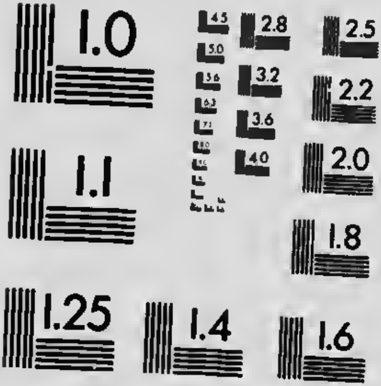

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A CENTURY OF CHEMICAL PROGRESS

INAUGURAL ADDRESS

DELIVERED JANUARY 26th, 1901

BY

W. R. LANG, D.Sc.,

PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF TORONTO.

Reprinted from the "University of Toronto Monthly,"
Vol. I., No. 6

TORONTO:
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A Century of Chemical Progress.

BY PROFESSOR W. R. LANG.

THERE are few branches of science which have progressed so rapidly in the last hundred years as the one I have the honour to profess in this University. Looking back over this period one sees in existence a very different state of affairs, socially, commercially and otherwise, than is now with us, and it is no exaggeration to say, that much of the present comfort enjoyed by all classes, is due to the advance of physical and chemical science. Biology even, electricity certainly were in their infancy in 1800. Chemistry, as we know it now, almost equally so. The old alchemistical idea of "phlogiston" had received a decent burial, though its memory was kept green by Priestley till his death in 1804, and the medical chemists, whose search for the "elixer vitæ" had occupied their attention since the middle ages had given up the quest for more profitable inquiry. The search for the "philosopher's stone," which was to convert all baser metals into gold, had been the main object of the experiments of a certain class of chemists, but such men as Black, Cavendish, Scheele, Priestley and Lavoisier—who fell a victim to politics during the French Revolution—were studying the composition of matter for the sake of knowledge itself. That science was on the verge of entering on a new era is evidenced by the fact that in 1800 the Royal Society (founded 1663) commenced its "Catalogue of Scientific Papers." Chemical knowledge at that period was limited to a few isolated facts. Oxygen and hydrogen had been prepared, and the composition of air and water and of a few minerals was known, and a right understanding of the general characters of acids, bases and salts had been only recently arrived at.

At the present day, when the electric current is now used so extensively in many chemical operations and manufactures, it is of interest to note that the first experiments towards the decomposition of water into its constituent elements, oxygen and hydrogen, by this means were made in 1800 by Nicholson and Carlisle. Following on this Humphrey Davy, who in 1801 was appointed Professor of Chemistry at the now famous Royal Institution of London, applied the current from his galvanic battery to the decomposition of damp caustic potash and soda. In this way he obtained at the negative pole metallic globules, which by subsequent experiments he found could be reconverted into the alkali from which they had originally been prepared. By similar means he isolated the elements barium, strontium and calcium from the common "earths," and found that these in combination with the gas chlorine—discovered by Scheele—gave soluble saline bodies, of which common salt may be taken as the type.

Davy was at that time instrumental in proving that oxygen, which had been considered the acid-forming element, was not necessarily a constituent of all acids. Chlorine was supposed to be an oxide of hydrochloric acid, but all experiments which he performed to find oxygen in chlorine proved decisively that it was an elementary body. About this time also Curtois, a Parisian soap-boiler, when preparing soap with alkali obtained from sea-weed found indications of a substance hitherto unnoticed. This he sent to Davy, who discovered its elementary character and its resemblance to chlorine, and thus iodine came to be added to the rapidly growing list of simple substances. In 1826 Balard added one more to the number by his discovery of bromine in the mother liquor or "bittern" left after the removal of sea-salt from sea-water by evaporation.

Contemporaneously with Davy's earlier researches, John Dalton, a Manchester schoolmaster, enunciated his famous theory, which has remained the fundamental hypothesis of chemistry to this day. According to this doctrine, matter is composed of minute particles or "atoms," each with a definite relative weight, and compounds are formed by these atoms of different elements becoming closely united to form a homogeneous whole. Other chemists had noticed that the same compounds always contained the same elements in the same proportions by weight, and that when more than one compound could be got containing the same elements, but in different proportions, the proportion in which the one element combined with the other in the second case was a multiple by a whole number of the proportion in which it combined in the first case. All this Dalton's hypothesis accounted for. Thomas Thomson, the professor of chemistry in the University of Glasgow, was the first to teach Dalton's views, and he incorporated these ideas into his "System of Chemistry," published in 1805. In his "Chemical Philosophy," published a few years afterwards, Dalton expresses his ideas thus: "Chemical analysis and synthesis go no farther than to the separation of particles one from another, and to their reunion. No new creation or destruction of matter is within the reach of chemical agency. We might as well attempt to introduce a new planet into the solar system, or to annihilate one already in existence as to create or destroy a particle of hydrogen. All the changes we can produce consist in separating particles that are in a state of cohesion or combination, and joining those that were previously at a distance." Thomson, Berzelius, Prout, Stas and Dumas all proceeded to determine what these constant weights were in which the elements combined together, and a series of numbers was obtained and termed atomic weights, or more properly, equivalent weights.

Hitherto little notice had been taken of the volume relation in which elements combined. Gay-Lussac and Avogadro noticed the definite proportions in which gases combined together, which later became extended to elements in the gaseous state that were at ordinary temperature liquids or solids. To enter into further particulars, however, regarding the facts relating to atomic weights, made evident by careful study of those volume relations, would be beyond the scope of this lecture. Equally so would be any detailed explanation of the facts established by the researches of Dulong and Petit regarding the relation between the atomic weights of the elements and their capacity for heat Suffice it to say that this relation has proved instrumental in ascertaining those relative numbers, a true knowledge of which is indispensable alike to the physicist and the chemist. The theory enunciated by Avogadro, previously referred to, that equal volumes of gases contained an equal number of particles or molecules, received confirmation from the researches of Thomas Graham, of University College, London, into the subject of gaseous diffusion. Experiment showed that the rate of the diffusion of different gases through some porous material varied inversely as the square roots of their respective densities. Graham also contributed greatly to our knowledge of liquid diffusion, and his researches and views on the constitution of the phosphoric acids are now classic.

At the beginning of the century Germany had produced few chemists; at any rate none of the first rank. Liebig may, perhaps, be considered its first great man, and he in his youth received his instruction in the laboratory of a French chemist, Gay-Lussac. In 1837, when her late Majesty Queen Victoria of sacred memory ascended the throne, he was in the height of his fame. To him we owe much of the impetus which was given to the study of scientific chemistry in England, and to him the physiologist, the manufacturer and the agriculturist are indebted for a great portion of their present knowledge of the practical application of it to their varied needs. He it was who devised the method still in use for the determination of the composition of "organic" compounds. Wöhler showed at this time by his synthesis of urea—a substance hitherto considered as purely the result of vital action—that "organic" chemistry must be regarded as the chemistry of compound radicles. Liebig and Dumas were at one with Wöhler in this, and formally announced their adhesion to his doctrines at a séance of the Académie des Sciènces de Paris in 1837. The enormous strides made in the development of this branch of chemistry cannot but strike the most callous observer as one of the marvels of the century. From the synthesis of urea in 1828 by Wöhler, and of acetic acid by Kolbe in 1845 down to the present day, when dyes of every shade and tint, explosives of all kinds, drugs, sugar, and even indigo can be built up in the laboratory by artificial processes, the development of this department has been phenomenal. And how has this come about? The conception of radicles led to an incalculable amount of research into the constitution of organic compounds, and the ways in which radicles were linked together and to elementary atoms. Compounds were broken down and again reconstructed, and the methods of causing these combinations to take place gradually became perfected. It may safely be said that the manufacturers of to-day owe much, if not all, of their success to the investigation following on these theoretical conceptions of the distinguished chemists I have named.

The old system of formulæ, based on Dalton's atomic hypothesis, came in for reconstruction about the middle of the century. Gerhardt (1843) was the first to seriously discuss the question, closely followed by Williamson (1850). It was some time, however, before the system deduced from their views was generally accepted. Hofmann was the first to adopt it in his lectures, and in 1864 Dr. Odling, the President of the Chemical Section of the British Association, congratulated the section on the agreement that had been arrived at amongst chemists as to the combining proportion of the elements and the molecular weights of their compounds. Observation of the natural families into which the elements grouped themselves led to the enunciation of what is now known as the "Periodic Arrangement of the Elements." In 1864, Newlands, of London, showed that when the elements were arranged in the order of the numerical value of their atomic weights, their properties, physical and chemical, varied in a recurrent or periodic manner. Thus it was seen that the element eighth in succession from another usually resembles it closely. Newlands termed this arrangement the "Law of Octaves." In 1869, Mendeléeff, of St. Petersburg, contributed further facts concerning this periodic arrangement of the elements and their study at this day is based on that now fully recognized system of classification. Both Newlands and Mendeléeff predicted the existence and physical and chemical properties of many undiscovered elements which would go to fill the blanks in the table. When gallium, scandium and germanium were isolated they were found to correspond to the elements predicted by Mendeléeff, and to which he had assigned the names, "eka-boron," "eka-aluminim" and "eka-silicon."

The phenomena exhibited by many substances in their action on polarized light has led to ideas regarding the arrangement of atoms in space. To Pasteur, and more notably Le Bel and van't Hoff, is due the credit of bringing before chemists a hypothesis which has had an enormous influence in the progress of organic chemistry.

The study of substances in solution has provided a means of determining molecular weights. Pfeffer, the botanist, in 1878, performed an important series of experiments with membranes deposited by chemical means in the pores of unglazed earthenware, and found that if weak solutions of salts were placed outside such a vessel water would diffuse through while the dissolved substance would not. This was due to the "semi-permeability" of the membrane employed. Van't Hoff, in 1887, in studying the theory of dilute solutious, found that the semi-permeable membranes served to measure the pressure due to the dissolved substance. From an accurate study of substances in dilute solution and of their behaviour with regard to their passage through extremely thin porous membranes it is now evident that there exists the closest possible analogy between the state of substances in solution and the same in the gaseous condition. As the result of experiments on the conductivity of substances in solution for electricity, Arrhenius (1888) has shown that when an electrolyte, such as common salt, is dissolved in water it dissociates partly into the separate *ions*, a name devised by Faraday, and signifying the "things that go," namely sodium and chlorine. These views have been strongly upheld by Ostwald and others, and are supported by the facts rendered apparent by the behaviour of substances in solution as regards diffusion, the lowering of the vapour-pressure and the depression of the freezing point of the solvent.

Davy, it has been pointed out, obtained the alkali metals by electrolytic decomposition of their compounds. Electrolytic methods of analysis and the application of electricity to commercial processes and to more purely scientific research have gradually become of more and more importance and interest. If electricity is passed through a conductor, such as a metal bar, the current passes along or through the metal which itself does not move or suffer any apparent alteration. But when a current is passed through an electrolyte it is transported by the moving *ions.* The theory before referred to, that a portion of the substance in solution is in a dissociated state, goes far to explain the phenomena attendant on electrolyses. Though it seems difficult to imagine that in the case of a solution of sodium chloride there can exist sodium and chlorine in the free state, especially as the metal sodium has such a violent chemical action on water, yet, according to the electrolytic dissociation theory, we must consider that the different constituents of the sodium chloride do exist as separate atoms but having enormously high charges of electricity. When, keeping to sodium chloride as our example, a current is passed, the sodium atoms charged with positive electricity travel to the negative pole and there give up their charges, appearing then as molecules of sodium possessing the properties usually associated with that element. Similarly the chlorine *ions* charged with negative electricity travel to the anode, or positive pole, give up their charges and appear as ordinary chlorine.

While these principles were gradually being unfolded and the newer ideas concerning matter were becoming more familiar, fresh discoveries of new elements were being made, It must be remembered that the compounds of many elements were known while as yet the elements themselves had not been isolated. Alumina and silica were known long before the elements aluminium and silicon were isolated; so also with fluorine, one of the chlorine group. Fluorine was known to exist widely diffused in nature in many minerals and in small quantities in plants and animals, but on account of its great chemical activity it had not been isolated, as had been its neighbours, chlorine, bromine and iodine. Davy and Scheele had both recognized its resemblance to these elements, but it was not till 1886 that Henri Moissan, professor of chemistry at l'École de Pharmacie in Paris, succeeded in electrolyzing a mixture of hydrofluoric acid and hydrogen potassium fluoride in a platinum vessel. In 1897, when the British Association met in this city, Professor Méslans, for many years assistant to Moissan, gave a demonstration of the properties of fluorine here in this lecture-room.

The last decade has been fruitful in the discovery of other elements hitherto unsuspected, notably the new atmospheric gases, argon, neon, krypton and xenon. In 1775, Cavendish in his "Experiments on Air," published in the *Philosophical Transactions*, pointed out that in the air there was a small quantity of a gas, "not more than 1/120 of the whole" of what we now call the nitrogen of the atmosphere, which could not be made to combine with oxygen. The question as to what this was lay unanswered for more than a century, when, in 1894, Lord Rayleigh and Professor Ramsay solved the problem by isolating argon from atmospheric nitrogen. They were led to this discovery by noticing that atmospheric nitrogen was denser than nitrogen prepared from chemical sources, such as ammonium nitrite. By passing a stream of atmospheric nitrogen over heated magnesium the nitrogen was absorbed and a residue remained, which could not be induced to enter into combination with anything. The amount of this new element in the air, whose discovery caused so much excitement in the scientific world, was found to correspond very nearly to the small portion of gaseous matter that remained uncombined after sparking atmospheric nitrogen with oxygen, and which Cavendish had spoken of more than one hundred years previously. This discovery of argon led to a further research into certain minerals, which, when treated with dilute acid, evolved a gas which was supposed to be nitrogen. It proved, however, to be another new element, previously indicated as being present in the sun's atmosphere by Lockyer, and named by him helium. These discoveries did not, however, end here, as Ramsay and Travers, in experimenting with liquid air as a convenient source of argon, discovered three new gases, which they named krypton (hidden), neon (new), and metargon.

Turning now to the interesting subject of the liquefaction of gases, we find that since the beginning of this century numerous experimenters have been trying to reduce the more commonly met with gaseous substances to the liquid condition. The so-called permanent gases, which, up to a decade or so ago. resisted all attempts at liquefaction, have now succumbed to the advance of experimental science. In 1805 Northmore is stated to have liquefied chlorine by compressing it in a brass condensing syringe with a glass receiver. Then in 1822 Cagniard-de-la-Tour observed that certain liquids, such as alcohol and water, when heated and kept under pressure, became apparently reduced to a vapour, occupying from two to four times the original volume of the liquid. This led to the classical researches of Andrews, of Belfast, on "The Continuity of the Gaseous and Liquid States of Matter," set forth in the Bakerian Lecture (Phil. Trans., 1869, Part II). In the following year Faraday succeeded in liquefying chlorine, sulphur dioxide, hydrogen sulphide, carbonic acid, ammonia and many other substances previously known only in the gaseous condition. There only remained hydrogen, oxygen, nitrogen, carbon monoxide, marsh gas and nitric oxide; these were called the "permanent gases." In connection with the liquefaction of carbonic acid the name of Thilorier stands out prominently. By means of pressure alone he obtained this in the liquid form, and by causing it to evaporate rapidly through a narrow orifice obtained it in the solid state. This was the first instance of a substance, gaseous at the ordinary temperature, being seen as a solid. Faraday, in 1845, continued his attempts to liquefy the remaining gases, and in his experiments came very near to anticipating Andrews in his famous researches and the principles deduced therefrom. Briefly stated, Andrews found that there was a certain temperature peculiar to each gas, above which no amount of pressure could cause liquefaction. This he termed "the critical temperature." From this it will be seen why so much difficulty was experienced in attempting the liquefaction of the six permanent gases, as, up to that time, the lowest temperature obtainable had been above the critical points of all of them. Towards the close of 1877 Cailletet, of Chatillon-sur-Seine, and Pictet, of Geneva, communicated simultaneously to the Académie des Sciènces de Paris that they had succeeded in liquefying oxygen, carbon monoxide and nitric oxide Cailletet subjected the gases to considerable pressure, thereby reducing greatly their volume; on suddenly relieving the pressure expansion and consequent cooling took place, and a portion of the gas appeared in the form of minute drops. Nitrogen and hydrogen now alone remained; the former yielded in 1883 to Professors Wroblewski and Olszewski, and hydrogen succumbed in 1895 to Professor Dewar, of the Royal Institution in London. The principle involved in liquefying these gases is as follows: we have seen how liquid carbonic acid, if allowed to expand, is cooled down sufficiently to enable it to become actually solid. Supposing, then, that air or hydrogen is compressed under 180 atmospheres or so (2,500 lbs. to the square inch), and the pressure gradually released, the temperature of the issuing gas will be lowered considerably. By allowing this cooled gas as it issues to pass over a large surface of copper coils conveying the compressed gas from the cylinder containing it to the expansion valve the gas becomes still more cooled down, a cumulative effect is produced, and finally the issuing gas arrives at the point of exit at so low a temperature that it becomes liquid. Different forms of apparatus have been devised by Hampson of London, Linde of Munich, and by Dewar, and are now used for producing liquid air in fairly large quantities, but the principle involved in each is the same. By the rapid evaporation of liquid hydrogen Dewar succeeded in obtaining it as a snow-white solid.

Thus far I have only discussed the development of what might be called scientific chemistry. The field of industrial chemistry is so wide that only a short reference can be made to the advances that have been made during the past hundred years. It must be pointed out, however, that the growth of chemical industry owes much of its progress to the reasonings and researches of the theoretical chemist.

Among the branches of industry which have advanced greatly might be mentioned the soda industry, with which the production of chlorine, and consequently bleaching-powder, is closely associated. The Leblanc process, invented during the Napoleonic wars, at the end of the eighteenth century, for the production of alkali—essential in soap-making and other industries—from common salt has found a strong rival in the ammonia-soda process, first introduced by Solvay in Belgium, and brought to a high state of perfection by Brunner and Mond in England. An electrolytic process is also employed, common salt being converted directly into caustic soda and chlorine. Electricity is also made use of for the production of aluminium, which metal is now extracted in large quantities from alumina, both on the continent of Europe and in Scotland. Its uses are many, and the peculiarly light metal which twenty years ago was looked upon as a curiosity, is now as familiar to us as copper or iron. The electric current is also employed for making calcium carbide from lime and coke. Though known since 1839, this substance had only been produced in the laboratory, and it is merely within the last ten years that it has become of commercial importance as the source of acetylene gas for illuminating purposes. To electricity we are also indebted for the production of chemically pure copper for electro-plating and gilding, and for the production of the highest of all temperatures, that of the electric arc. This temperature has been made use of in the electric furnace, more particularly by its inventor, Henri Moissan, for studying the effect of high temperatures on various substances, and with its aid he succeeded in manufacturing diamonds. Unfortunately, or perhaps fortunately, for if diamonds could be readily and cheaply made, then their value as ornaments would vanish—they can only be obtained very small, but diamonds they are despite their minuteness. The electric furnace is also used in many other departments of chemical industry.

The mineral oil industry, too, is one of great importance. Huge quantities of crude petroleum are found in the earth's crust. The first discovery of it was made by Playfair of Edinburgh in Derbyshire, but that source was soon exhausted. The source of supply is now from this continent and from eastern Europe. The production of oils from the distillation of shales is carried on in Scotland at Broxburn and elsewhere. Shale is a carbonaceous mineral which appears to have been formed from the remains of marine animals mixed with argillaceous mud and consolidated into a slaty mass. The Scottish shales, typical of their class, are below the coal measure along with strata of marl, limestone and sandstone.

To the advance in chemistry the agriculturalist is indebted for the increased crops he is enabled to take off his land. Liebig was the first to introduce the employment of artificial or chemical manures. Nitrate of soda, potash salts, and sulphate of ammonia obtained from gas-works are all employed as fertilizers, and the effect of these manures on crops has been carefully studied on experimental farms by Gilbert and Lawes.

Metallurgical processes, too, have made great progress. The extraction of gold from its ores is no longer carried out solely by the rough and ready mechanical methods by which our forefathers washed the sand of gold-bearing streams or subjected crushed auriferous quartz to the process of amalgamation. Plant for chemically separating gold by means of chlorine or of potassium cyanide is now found all over the world and the so-called "tailings" left from amalgamation processes in large quantities in the vicinity of gold-workings have proved a fruitful source of the precious metal when subjected to present day chemical treatment. The iron and steel industries have kept pace with modern chemical progress, the Bessemer process and the Siemen's-Martin process may be mentioned as examples of improvements in methods. Not only have producers perfected to the best of their ability the processes employed for making iron and steel, but the furnace gases—formerly allowed to escape into the air—are now treated in such a way as to extract from them many useful substances which are of themselves of great market value.

As that of the chief actor in the development of the modern high explosive the name of Alfred Nobel must be a familiar word in all civilized countries. Ordinary black gunpowder is now seldom used except for producing the slow rending action required in blasting the faces of quarries, where a shattering effect would be undesirable. Schoenbein discovered gun-cotton in 1865 and nitro-glycerine was first made by Sobrero in 1847. Nobel made these nitro-compounds his special study, and in 1866, by absorbing nitro-glycerine in a porous siliceous earth known as kieselguhr, produced a brown pasty substance, and named it "dynamite." The chief constituents of the modern explosives, blasting-gelatine, cordite, gelignite and ballistite are gun-cotton and nitro-glycerine. The discovery of blasting-gelatine was accidental and deserves recording. Nobel, when in his laboratory experimenting with nitro-glycerine, cut his finger slightly, and to cover the wound applied collodion, which is a solution of nitro-cellulose in ether, to the part affected. Having done so he emptied the contents of the phial into the vessel which held the nitro-glycerine he was experimenting with. The mixture became gelatinous, and thus accidentally came about the discovery of one of the most used ingredients of modern explosives. Lately we have heard much about lyddite and its effects. This is also a product of the last decade in so far as its use as an explosive is concerned, though it has been employed for dying silk for many years.

I have endeavoured to show in this short address to what an extent scientific and industrial chemistry has progressed during the century now gone. It would be interesting to speculate as to future developments. The atomic theory which has so long been our chemical creed may be overthrown as was the theory of philogiston. Elements may no longer be regarded as simple substances and may even be looked upon as different forms of one ultimate kind of matter, or again as varying modes of motion. Speculation and theories regarding this have even now been advanced by men eminent in the world of science. Chemistry and physics are drawing closer together and the investigation of physico-chemical phenomena is occupying the attention of many workers. Great have been the advances made in pure chemistry, and to no less a degree has the application of these principles to industrial chemistry progressed. I feel I cannot close without some reference to the part that may be taken by chemists in the development of the natural resources of Canada, and more particularly of this province. I see from that useful volume a "Handbook of Canada" published by the local executive of the British Association meeting of 1897 that our province is possessed of almost untold mineral wealth. The metals gold, silver, copper, nickel, lead and iron are in abundance. Of sulphur in combination there is plenty, while coal, mineral oil, phosphates and common salt also are found. The search after the precious metals, mining, the production of copper, iron and nickel are all departments of industry in which many graduates of the University have found and will, I venture to think, continue to find employment. It is to the men we send forth from this institution that we must look for the proper exploitation of our natural resources. While in past years most of our graduates entered the professions of medicine, law or of teaching now a large proportion are going, not only into mining and the other branches of engineering, but also into manufactures and commerce. The future of this country is in the hands of these men. Now that the School of Science has become an integral part of the University and constitutes our faculty of applied science, a stronger tie has been created between this department and that presided over by my colleague Professor Ellis than was possible heretofore. It should be the aim of the departments, then, to give our students a thorough all-round training in the principles of chemistry, not omitting reference to the practical application of these principles to the arts and manufactures. A chemist thoroughly trained in his subject by a course of study such as can be obtained in any of our universities is the man who is most fitted to apply his knowledge to whatever branch of industry he may find himself engaged in after he leaves his *Alma Mater.* I have heard it advocated that the universities and technical colleges should employ special lecturers, expert in their several spheres of chemical industry, to instruct students in the particular branch which it is to their ultimate intention to take up as their life-business. Where, I ask, are such men to be found? Is it likely that a manufacturer will enter into all the details of improvements in his own business that he has, after much experience, introduced for the benefit of his own or his employer's profit? In these days of keen competition, and of earnest striving to gain even a modest competency, any particular detail or device which will ensure a better yield of material or the production of a superior article than one's rivals in trade can produce is zealously guarded, as well it might be.

A general knowledge of the principles of the subject is the first great essential and whether it be metallurgy, brewing, calico-printing or dyeing that the young graduate proceeds to, he will always be able to adapt himself to his new surroundings and be of more use in improving the processes in which he is interested than if his whole time had been spent learning the details of his special work to the exclusion of the great general principles involved in the science. The man with energy and application, but whose academic and scientific training has been nil, has hitherto in many cases succeeded in coming to the front in whatever industry or business he may have taken up, how much more, then, may we expect to see the scientifically trained graduate (*ceteris paribus*) become a successful worker in any of the many great fields open to him.