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Inaugural Lecture Series 21

CHEMISTRY  
AND THE  
COMMUNITY

by R. G. R. Bacon



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# 'CHEMISTRY AND THE COMMUNITY'

by

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*Inaugural Lecture Series 21*

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IN THIS RATHER wide-ranging survey I shall relate some of the contributions which chemistry has made to the general pool of human knowledge and experience, and I shall exemplify some practical consequences in universities, in industry, and in everyday life. These two aspects of chemistry, the theoretical and the practical, the pure and the applied, the intellectual and the utilitarian, are closely interwoven. The subject is vast, and a chemist tends to select illustrations from his own area of interest. Mine are largely drawn from organic chemistry, the study of carbon compounds.

Chemistry is concerned, at the atomic and molecular level, with the structure and reactivity of the material fabric of the earth, and indeed of the rest of the universe, in so far as instruments permit its examination. Chemists describe the composition of matter in terms of a limited range of atoms, which combine in precise numbers, and according to precise rules, to furnish a virtually limitless variety of the larger structural units which we call molecules. The dimensions of these units lie far below the range of microscopes. The chemist's description of the invisible has been achieved by deductive reasoning based upon unceasing experimental work. As more and more techniques have been applied to structural problems, without fundamental changes in concepts becoming necessary, chemists have become increasingly confident in the validity of their views on composition, and have delineated atomic structure, interatomic bonding, and the three-dimensional geometry of molecules with increasing precision.

Chemists cannot lecture with clarity unless they can point to details of molecular structure, and I have accordingly brought along a few models and drawings to illuminate my discourse.

The chemist's view of the building units of the Universe is displayed in the periodic table of the elements, here exhibited. It reveals order beneath the apparent chaos of our surroundings; this revelation is one of the supreme intellectual achievements of the human race. But intellect alone did not suffice; chemistry is not advanced by people cogitating at desks but by people working long hours at laboratory benches.

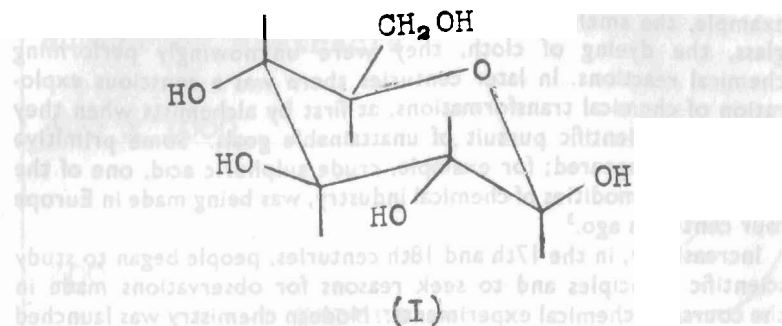
We see in the table the 92 different elements which have been discovered, one by one, in chemical research.<sup>1</sup> They are arranged in order of increasing atomic mass, from the lightest, hydrogen, to the heaviest, uranium, beyond which the sequence is extended by the unstable man-made elements, the actinides, produced in recent years by the nuclear chemists of California. Arranged in periods, the elements show gradations in physical and chemical properties, both horizontally and vertically. This factual representation of the nature and relationships of the elements was probably the most important achievement of 19th century chemistry. The 20th

century brought discoveries of the primary particles within atoms, and quantum mechanics was applied to problems of structure and bonding. In consequence, the chemist now views the gradation and periodicity of the properties of the elements as a reflection of the internal arrangement of their varying number of electrons, occupying orbitals at different energy levels, in patterns of increasing complexity from hydrogen to uranium. Not only are the characteristics of the main-group elements accounted for, but also these of the three transition series, and the lanthanide and actinide series, which complicate the structure of the table.

In a sense, this pictorial array of the symbols of the terrestrial elements, each in a box of equal size, may mislead the uninformed, since it could suggest that they occur in comparable quantities. Unlike the incandescent stars, which are composed largely of hydrogen and helium, the earth does have a full range of the 92 elements, but their distribution is overwhelmingly in favour of the lighter ones. Our atmosphere is mainly nitrogen and oxygen; water is composed of oxygen and hydrogen; the molecules of living organisms are mainly combinations of carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulphur; the mineral matter, which constitutes about 95% of the earth's crust, consists of chains of silicon and oxygen, diversified by the presence of aluminium, iron, magnesium, sodium, and potassium.<sup>2</sup> All the other elements in the table are relatively rare, and some are extremely rare. In our industries we have come to depend upon some or these rarer elements and the earth's limited stocks are rapidly being consumed.

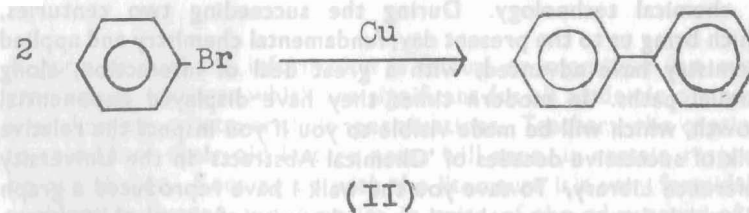
Twin pillars of discussion in chemical courses are the themes of structure and reactivity. A great deal of the materials around us, for example, the minerals of the Campus, are in a relatively unreactive state, but, in all plant and animal cells, in the reaction vessels of our laboratories, and in the manufacturing equipment of chemical factories, there is a ferment of change at molecular level; bonds are broken and formed and new molecular patterns emerge.

For example, this crystalline material is glucose,  $C_6H_{12}O_6$ , the sugar in our bloodstream. I can display this three-dimensional scale model which represents fairly accurately the relative volumes and positions in space of the carbon, hydrogen and oxygen atoms of the molecules as they exist in the crystal lattice. Similarly, I can exhibit this 'stick' model, which has less geometrical accuracy but shows more clearly in a class room the interatomic linkages and bond angles. Also, I can use atomic symbols and structural formulae, chemical shorthand, to represent the structure (I) on a printed page. If these glucose crystals are dissolved in water the molecules become mobile; various interactions with the water molecules occur, some resulting in opening and closing of the oxygen bridge in the glucose



molecule. If I swallow this solution, the glucose rapidly undergoes profound chemical change in my body and some of it is ultimately degraded to carbon dioxide which is exhaled in my breath. Back in the atmosphere the carbon dioxide is available for photosynthesis by plants, where some of it is reconverted into glucose.

This second sample is a liquid, bromobenzene,  $C_6H_5Br$ , which does not exist in nature but can readily be made by a student in the laboratory from benzene and bromine. The model of the molecule shows the flat hexagon of 6 carbon atoms, characteristic of benzene, with bromine at one corner in place of hydrogen. This is a relatively inert compound, but if it is heated with copper to about  $300^{\circ}$  chemical change occurs; it loses bromine to the metal and forms crystalline biphenyl (II)



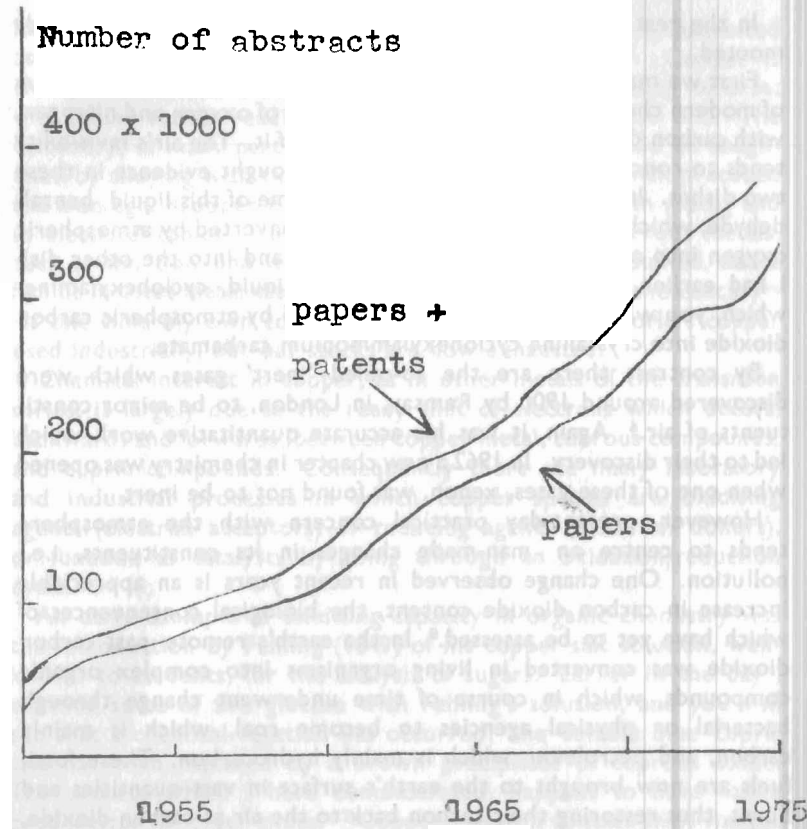
To provide some historical perspective, we need to put a date to the beginnings of modern chemistry. In various parts of the world, from prehistoric times onwards, our ancestors became skilled in crafts through processes of trial and error. In some of these, for

example, the smelting of ores to obtain metals, the manufacture of glass, the dyeing of cloth, they were unknowingly performing chemical reactions. In later centuries there was a conscious exploration of chemical transformations, at first by alchemists when they were in unscientific pursuit of unattainable goals. Some primitive technology appeared; for example, crude sulphuric acid, one of the essential commodities of chemical industry, was being made in Europe four centuries ago.<sup>3</sup>

Increasingly, in the 17th and 18th centuries, people began to study scientific principles and to seek reasons for observations made in the course of chemical experiments. Modern chemistry was launched on its course in the 1770's, just two hundred years ago, chiefly through the experiments and deductions of Scheele in Sweden, Priestley in England, and Lavoisier in France.<sup>4</sup> They discovered one of the key elements, oxygen, studied its properties, identified it as a constituent of air, and showed that combustion is a process of oxidation, a combination between oxygen and other elements. Metallic mercury, heated in contact with a confined volume of air, formed a film of red oxide, and thereby gained in weight, while the air shrank to 80% of its original volume. This oxide happens to be thermally labile; when heated to a higher temperature it decomposed; gaseous oxygen was evolved, similar in volume to the original contraction, and metallic mercury was restored in its original weight. An important feature of this work was the quantitative approach of these chemists; the same method led their successors to discovery of various laws of chemical combination. The quantitative attitude of mind which is essential in experimental work seems not to be instinctive; chemistry teachers spend a lot of their time urging their students to think quantitatively.

The decade of the 1770s was also a period when the industrial revolution was gaining impetus, and this included some developments in chemical technology. During the succeeding two centuries, which bring us to the present day, fundamental chemistry and applied chemistry have advanced, with a great deal of interaction, along parallel paths. In modern times they have displayed exponential growth, which will be made visible to you if you inspect the relative bulk of successive decades of 'Chemical Abstracts' in the University Reference Library. To save you the walk I have reproduced a graph (III) which demonstrates that the annual output of chemical literature has virtually doubled in each decade: from 100,000 entries in the year 1955 to 200,000 entries in 1965, and then to 400,000 entries in 1975.<sup>5</sup> Between the foundation of 'Chemical Abstracts' in 1907 until 1965, i.e. in 58 years, 3.5 millions abstracts were produced; almost the same number, 3.3 millions, resulted in the single decade, 1965-75.

The Abstracts cover all branches of chemistry, pure and applied.



III)

A good deal of the information is factual or repetitive but every year brings advances which are significant for all academic or industrial chemists, whatever their specialisations. Teachers who continue to reproduce their old lecture notes will soon, in certain respects, be out of date. Keeping up with the literature is a very formidable problem in Europe and America in spite of the advantages of an abundance of scientific meetings and easy communication between research groups. The farther one lives from the main centres of innovation the harder the task becomes. Specialist research groups, needing to be well informed on contemporary developments in particular areas, now pay for computer services to retrieve information from the literature flowing into the Abstracts offices.

In the rest of this talk I shall enlarge upon certain topics already mooted.

First we may consider the earth's atmosphere, which the founders of modern chemistry showed to be a mixture of oxygen and nitrogen, with carbon dioxide passing into it and out of it. The air's invisibility tends to conceal its reactivity, but I have brought evidence in these two dishes. Into one I had earlier poured some of this liquid, benzaldehyde, which, you will see, has now been converted by atmospheric oxygen into a crystalline solid, benzoic acid, and into the other dish I had earlier poured some of this second liquid, cyclohexylamine, which, you will see, has now been converted by atmospheric carbon dioxide into crystalline cyclohexylammonium carbamate.

By contrast there are the so-called 'inert' gases which were discovered around 1900 by Ramsay, in London, to be minor constituents of air.<sup>6</sup> Again, it was his accurate quantitative work which led to their discovery. In 1962 a new chapter in chemistry was opened when one of these gases, xenon, was found not to be inert.

However, present-day practical concern with the atmosphere tends to centre on man-made changes in its constituents, i.e., pollution. One change observed in recent years is an appreciable increase in carbon dioxide content, the biological consequences of which have yet to be assessed.<sup>8</sup> In the earth's remote past carbon dioxide was converted in living organisms into complex organic compounds, which in course of time underwent change through bacterial or physical agencies to become coal, which is mainly carbon, and petroleum, which is mainly hydrocarbon. These fossil fuels are now brought to the earth's surface in vast quantities and burnt, thus restoring their carbon back to the air as carbon dioxide, and depleting our subterranean stocks of carbon.

Another problem has arisen through the development in recent years of fluorocarbon chemistry.<sup>9</sup> This has an important industrial application in the production of fluorochloromethanes, or 'Freons', non-toxic and non-inflammable gases which are ideal for use in refrigerators and air-conditioning units and as propellants in household aerosol sprays. Their annual production by the du Pont Company is valued at about 500 million dollars. There is now speculation that, when discharged into the air, these gases may eventually reach the upper atmosphere where they may be decomposed to generate chlorine atoms, and the latter may then destroy some of the ozone which shields the earth from ultraviolet irradiation. This matter is being hotly debated in the United States.<sup>10</sup>

For a second theme I touch upon the chemistry of a typical metal, and what could be more appropriate than copper, which is the chief constituent of the bronze and brass sculpture for which Nigeria is

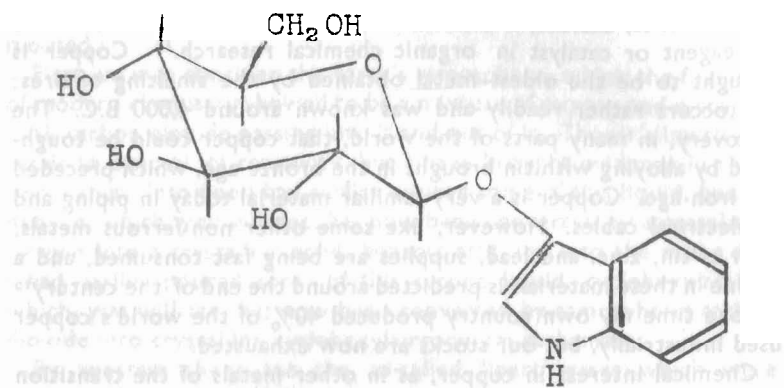
famous? It is, besides, a metal in which I have long been interested as reagent or catalyst in organic chemical research.<sup>11</sup> Copper is thought to be the oldest metal obtained by the smelting of ores; this occurs rather readily and was known around 4,000 B.C. The discovery, in many parts of the world, that copper could be toughened by alloying with tin brought in the bronze age, which preceded the iron age. Copper is a very familiar material today in piping and in electrical cables. However, like some other non-ferrous metals, such as tin, zinc, and lead, supplies are being fast consumed, and a famine in these materials is predicted around the end of the century.<sup>12</sup> At one time my own country produced 40% of the world's copper used industrially, but our stocks are now exhausted.

Chemical interest in copper, as in other metals of the transition series, is largely due to the ready shift of electrons which occurs, backwards and forwards, between copper metal, cuprous compounds, and cupric compounds. Consequently there are many laboratory and industrial processes in which copper species are oxidising agents (electron acceptors) or reducing agents (electrons donors), or function as catalysts by going through an oxidation/reduction cycle.

An early example of oxidising capacity in organic chemistry was the introduction by Fehling (1849) of his copper salt solution, well-known to students, for the analysis of sugars. Earlier in the day I warmed some of this glucose with Fehling's solution, and you will see that a chemical reaction has occurred; the soluble blue cupric salt has been replaced by a brown precipitate of cuprous oxide. The process which I have demonstrated happens to have had a predecessor in older times.<sup>13</sup> Copper metal in contact with vinegar forms verdigris (cupric acetate), and this, when mixed with honey, which contains sugars, gave a brown paste (cuprous oxide). This was sold by alchemists, several centuries ago, as a cosmetic or medicine under the name of Egyptian ointment.

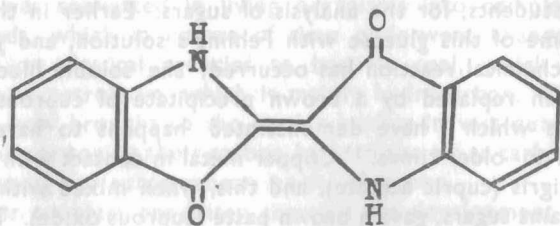
For a third theme I turn to the dyeing of cloth with indigo, an art which was practised in Egypt around 1500 B.C. and later in many parts of the world. In Nigeria, particularly among Yorubas and in the North, indigo dyeing still flourishes for production of the traditional dark blue patterns of adire cloth.<sup>14</sup> Synthetic indigo contributes to Western culture as the essential dye for blue jeans.

If an organic chemist were standing by the dye pots of Ibadan or the dye pits of Kano, how might he view the process? He would know that the precursor of indigo is the compound indican (IV), which is present, in the leaves of tropical plants of the genus *Indigofera*.<sup>15</sup> It consists of a colourless compound, indoxyl, combined with glucose. When the leaves are crushed the glucose is hydrolysed away and the liberated indoxyl undergoes oxidative coupling in air



(IV)

to give the deep blue indigo (V). The plant's essential metabolism leads to indican as a by-product. Nature is prodigal in furnishing an endless variety of such secondary metabolites. They may have no obvious biological function, but many are useful to man, and



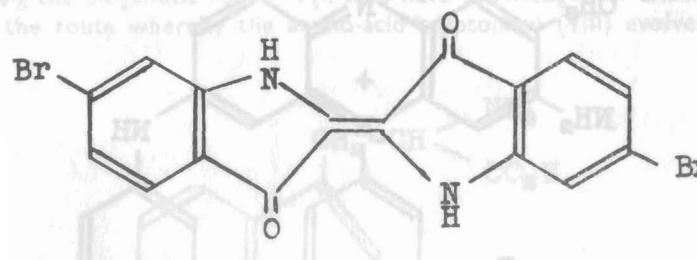
(V)

investigation of them, over the last two centuries, has given tremendous impetus to the development of organic chemistry.

The system of alternating single and double linkages shown in the structural formula is indicative of a mobile pool of electrons, a chromophore, capable of excitation by light waves, to which the colour is due. The carbon-oxygen sequence shown in the middle of the structure will readily take hydrogen from a suitable donor, and the compound thereby becomes colourless, soluble in alkali, and capable of penetrating into the fibres of the cloth. This is what the traditional dyer is achieving when he adds a fermenting mass of

carbohydrate material to the vat. And when he later exposes the cloth to air, or applies a chemical oxidant, the hydrogen is removed, regenerating the blue dye within the fibre.

Nature has provided a close relation of indigo in the form of Tyrian purple, another dye of antiquity, exclusive at one time to the robes of Roman emperors. Its source was the glands of a shellfish, *Murex brandaris*, plentiful at one time off the coast of present-day Lebanon. Its structure was not ascertained until 1909, when a German chemist obtained about 1 gram of the dye from 12000 of the molluscs and found it to be 6, 6'-dibromoindigo (VI), which was already



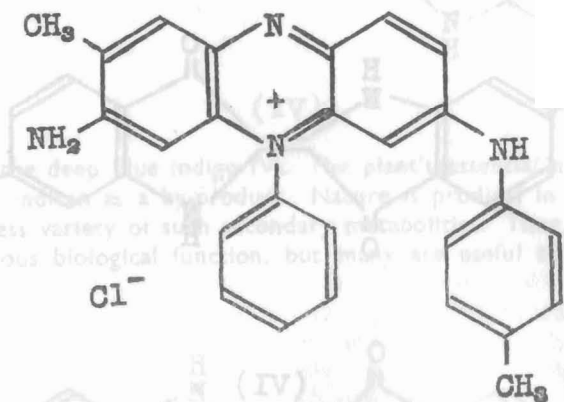
(VI)

known as a synthetic product.<sup>16</sup> The structure of this compound illustrates the fact that the colour of a dye may often be modified (here from blue to purple) by the presence of a substituent (here bromine). The incorporation of an element of the halogen family into a natural product is not common. Moreover, the selectivity of nature is here displayed; the source of halogen selected on the enzyme surface in the mollusc was bromide ion and not the related chloride ion, although the latter is 300 times more abundant than the former in sea water.

The elucidation of the structure of indigo, and then its synthesis, was the work of Baeyer, a German chemist, in the 1870's, just 100 years after the time of Lavoisier's discoveries. So far as the history of organic chemistry is concerned, Baeyer's choice of indigo as a subject for study is perhaps incidental. It was his success in what was at that time a difficult problem in natural-product investigation which made his work a landmark, and it served as a model for later investigators.

By the 1870's it was becoming clear that a virtually unlimited variety of organic compounds could be produced by appropriate reactions in the laboratory. Some of these synthetic products proved

to be dyestuffs of types unknown in nature. The first of these discoveries occurred accidentally in 1856, when Perkin, an 18-year old assistant to Professor Hofmann in London, set out to synthesise quinine, the constituent of the South American *Cinchona* bark which was prized as a cure for malaria. His proposed route, which we now know to have been quite impossible, was to oxidise toluidine (methylaniline), a coal-tar product. Instead of quinine he obtained a dirty-brown precipitate, but when he tried the same reaction on aniline itself he was delighted to have prepared a purple dye. Its structure (VII), elucidated about 30 years later,<sup>17</sup> shows it to have resulted



(VII)

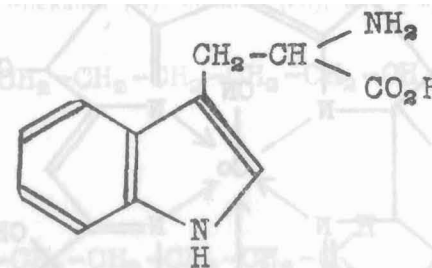
from oxidative fusion between aniline molecules and molecules of toluidine which happened to be present as contaminants.

From this and other small beginnings the manufacture of synthetic dyestuffs emerged as an important branch of the chemical industry. Until about 60 years ago it was almost a German monopoly, largely because of the 19th century pre-eminence of the organic chemical research schools of the German Universities. An important commercial target was a practicable synthesis of indigo, but this was not achieved until around 1900. Today the chemical industries produce a very great variety of dyestuffs<sup>18</sup> including many which belong to the indigoid and thioindigoid category of compounds.

During this account of the history of indigo I have touched upon some general themes which have major importance in organic chemistry: biosynthesis; the elucidation of molecular structure; synthesis in the laboratory; the industrial exploitation of chemical discoveries. We should look briefly at these matters in present

context, two hundred years after Lavoisier, one hundred years after Baeyer.

We mean, by biosynthesis, the elaborate sequence of chemical reactions whereby complex organic molecules are built up or degraded, rapidly and at ambient temperatures, on the surface of enzymes in living cells. The mapping of these complicated routes is one of the great achievements of the last 30 years and it has been made possible by the production of radioactive isotopes, such as <sup>14</sup>C (carbon-14), which was discovered in 1941 in the Berkeley laboratories in California.<sup>19</sup> Such isotopes are used to label particular atoms in participating molecules and so to track their course along the biogenetic route. We thus have knowledge, for example, of the route whereby the amino-acid tryptophan (VIII) evolves in



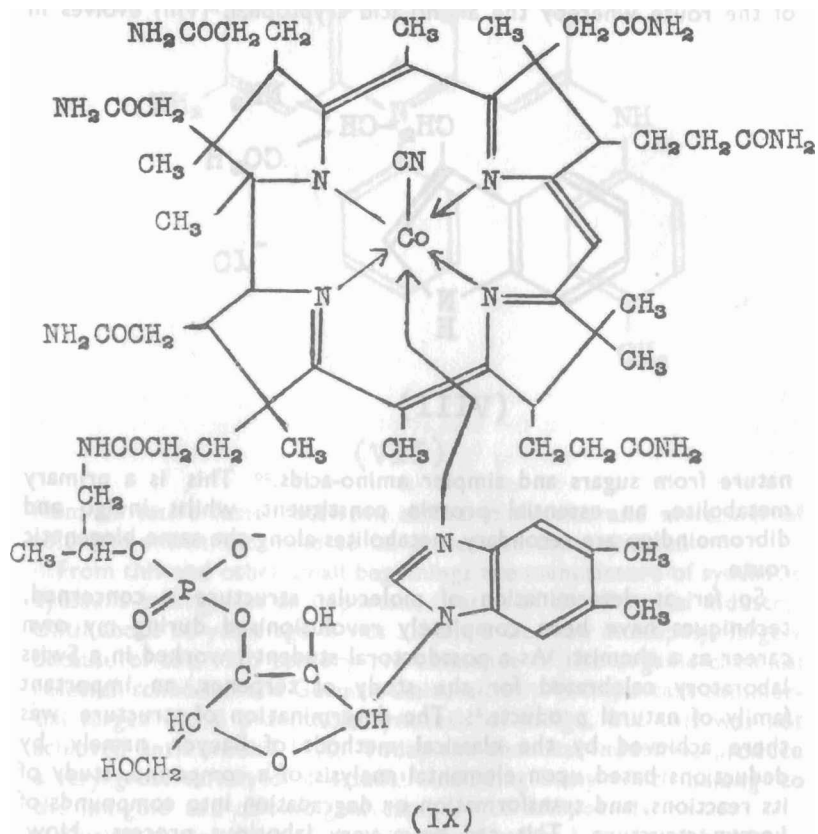
(VIII)

nature from sugars and simpler amino-acids.<sup>20</sup> This is a primary metabolite, an essential protein constituent, whilst indigo and dibromoindigo are secondary metabolites along the same biogenetic route.

So far as determination of molecular structure is concerned, techniques have been completely revolutionised during my own career as a chemist. As a postdoctoral student I worked in a Swiss laboratory celebrated for the study of terpenes, an important family of natural products.<sup>21</sup> The determination of structure was there achieved by the classical methods of Baeyer, namely, by deductions based upon elemental analysis of a compound, study of its reactions, and transformation or degradation into compounds of known structure. This can be a very laborious process. Now, in a well-equipped and well-staffed laboratory, a few days or weeks may suffice to determine structures which formerly might have required months or years of study, or might indeed have proved too complex to tackle by classical methods.



Three technical developments have made this advance possible. One is the introduction of a succession of spectroscopic techniques which give a vast amount of information about constituent parts of molecules.<sup>22</sup> Secondly, the full three-dimensional molecular geometry of complex molecules can be obtained with the aid of improved techniques in X-ray crystallography. An outstanding achievement of this kind<sup>23</sup> was the indispensable contribution of Dorothy Hodgkin and her fellow crystallographers at Oxford, in 1955, in the elucidation of the structure of the biologically important vitamin B<sub>12</sub> molecule (IX). Thirdly, chromatographic techniques, particularly gas-liquid chromatography, have greatly aided the separation

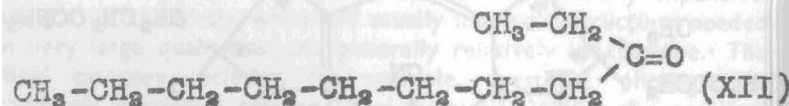
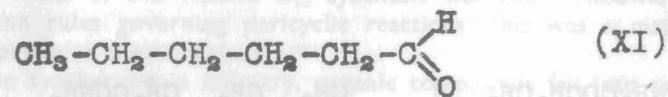
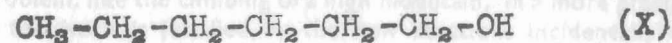


and identification of components of complex mixtures, often available only in small amounts.<sup>23</sup>

Gas-liquid chromatography has wide practical applications — for example, in the laboratories of an oil refinery — but I have been

tempted at this point to digress with a different case of its application, which has local biological interest. This concerns pheromones, which are chemicals employed in nature, particularly among insects, for intercommunication in essential activities such as mating and defence of territory. This subject is today being intensively studied<sup>24</sup> partly because, in the field of sex-attractants, it may offer means of controlling insect populations.

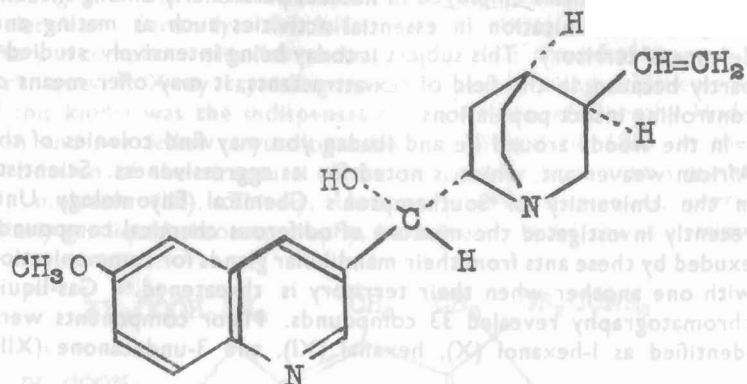
In the woods around Ife and Ibadan you may find colonies of the African weaver ant, which is noted for its aggressiveness. Scientists in the University of Southampton's Chemical Entomology Unit recently investigated the mixture of odiferous chemical compounds exuded by these ants from their mandibular glands for communication with one another when their territory is threatened.<sup>25</sup> Gas-liquid chromatography revealed 33 compounds. Major components were identified as 1-hexanol (X), hexanal (XI), and 3-undecanone (XII).



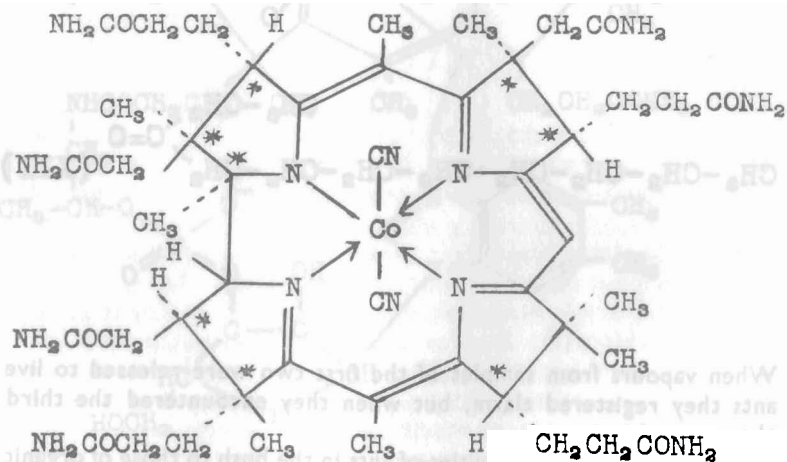
When vapours from samples of the first two were released to live ants they registered alarm, but when they encountered the third they started biting.

Returning from the activities of ants in the bush to those of organic chemists in their laboratories, we may observe that the major research schools, being relieved of a good deal of the labour of structure determination, can concentrate with increasing success on problems of reaction mechanisms and of synthesis. Pre-eminent in this field is R. B. Woodward, of Harvard University. One of his

earliest successes was the 20-stage synthesis of quinine (XIII), in 1945,



(XIII)



(XIV)

nearly a century after Perkin's abortive attempt.<sup>26</sup> His greatest achievement, in 1972, after some years of research in collaboration with Eschenmoser in Zurich, was the synthesis of cobyrinic acid (XIV), which is convertible into vitamin B<sub>12</sub>; this work involved 17 post-doctoral fellows in America and 7 in Switzerland.<sup>27</sup>

One of the major difficulties in such syntheses is the presence in the target molecule of several centres (indicated by asterisks and by firm and dotted lines in the cobyrinic acid formula XIV) at which a different structure results if a particular bond lies in a right-handed or a left-handed direction. In nature these directions are precisely determined at the surface of the enzyme on which biosynthesis is occurring, but in the laboratory much ingenuity must be exercised to obtain the correct result at each centre.

You may ask what is the value of these multi-stage syntheses, since they are far too difficult and expensive to reproduce in a factory. In part, the endeavour is justified by the very difficulty of the problem, like the climbing of a high mountain. In a more practical sense the work is justified by the new reactions incidentally discovered and the new reagents and techniques introduced; they often have useful applications in more mundane areas of chemistry. Occasionally an important new chemical concept emerges. Thus, a by-product of the vitamin B<sub>12</sub> synthesis was the Woodward/Hoffmann rules governing pericyclic reactions; this was a major development in chemical theory.<sup>28</sup>

When synthesised in industry, organic compounds fall into two categories; 'fine' chemicals, often complex in structure, which are needed in relatively small quantities, and are generally expensive, and 'heavy' chemicals, which are usually simpler in structure, needed in very large quantities, and generally relatively inexpensive. The 'fine' category includes, for example, dyestuffs, photographic chemicals, pesticides, and medicinal chemicals. Within the medicinal group<sup>29</sup> are purely synthetic drugs like the sulphonamides and antimalarials; the antibiotics, like penicillin, produced by micro-organisms; and products like cortisone and oral contraceptives, obtained by chemical transformation of naturally occurring steroids. The 'heavy' category<sup>30</sup> includes solvents, detergents, and a great variety of synthetic polymers in the form of plastics, fibres, and rubbers; the hydrocarbons required as the basis of their manufacture come from the petroleum refineries.

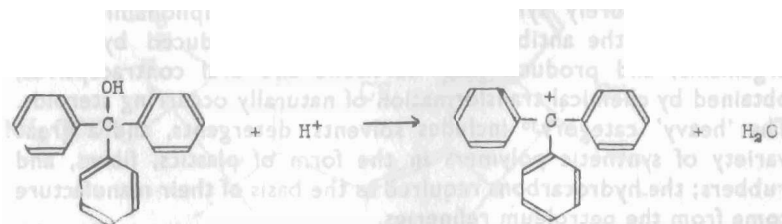
A large proportion of the industrial products which I have listed—and I think you will agree that they have been essentially beneficial to humanity—have been developed during the course of my own career as a chemist; they lie along that steeply rising portion of the exponential growth curve which I displayed earlier. In view of their

present dependence on oil, their production will be affected by the impending energy crisis, which has been foreseen for the end of this country, when demand for oil may exceed supply.<sup>31</sup> To this impending crisis in the supply of its raw materials the chemical industry is giving much attention<sup>12</sup>.

In quantitative terms the organic chemical industry is dominated by the synthetic polymers which are so much in evidence everywhere.<sup>32</sup> In life markets plastic bowls and buckets outnumber the traditional calabashes and pots of fired clay; bread is wrapped in plastic film; the textiles on the stalls are likely to be made from synthetic fibres; the motor tyres may contain synthetic rubber. A similar situation is encountered in the souks of Baghdad, in the bazaars of Bombay, and of course in every High Street department store.

Scientific understanding of polymers and polymerisation processes began in the 1920's. In the developments of the succeeding 50 years in Europe and America there has been a remarkable intermingling of academic and industrial research interests. Discoveries in academic laboratories have sometimes had important industrial consequences; discoveries in industrial laboratories have sometimes enlarged the horizons of academic chemists. The industries producing or utilising polymers have become major employers of chemists. For example, a few years ago it was estimated that 60% of all Ph.D. chemists in the U.S.A. were finding employment in that sector of industry.<sup>33</sup>

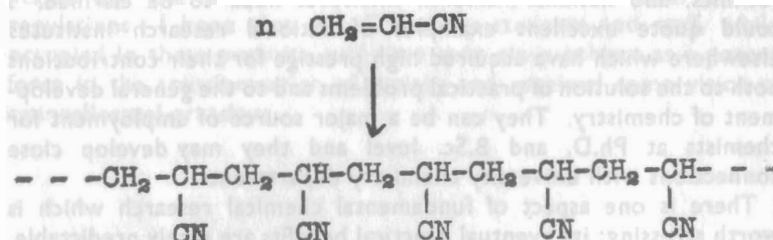
There is a great variety of synthetic routes to polymers. A common method is to employ conditions whereby small molecules containing olefinic bonds are joined together in long chains constituted of thousands of linked carbon atoms, as demonstrated in this model. The initiators, which make such polymerisations possible, may be highly reactive positively or negatively charged species, or radicals (species with unpaired electrons), or they may be the organo-



(XV)

metallic complexes which gained the Nobel Prize for their discoverers, Ziegler in Germany and Natta in Italy.

To make a positively charged species visible to you (though the one I am demonstrating happens not to be very effective in polymerisation), I shall generate the deep yellow triphenylmethyl carbonium ion (XV) by adding these colourless crystals to sulphuric acid. In a second demonstration, I shall generate radicals by mixing these two solutions, one an oxidant and the other a reductant. The radicals are invisible, but when I next add this polymerisable liquid, acrylonitrile, you should see their effect in converting it into a solid white polymer (XVI). If this polymer were separated, dissolved



(XVI)

in a suitable solvent, spun into fibre, and woven, it would make nice dress material. This experiment happens to be a repetition of one which I carried out several years ago as an industrial chemist.<sup>34</sup> The principle involved found wide application in industry because it enabled polymers to be produced much faster, or at lower temperatures, than had previously been possible. The observation also benefited our university associates who at that time were trying to understand the chemistry of radical reactions in solution. You will notice, incidentally, that no equipment was needed for this experiment beyond a balance, a few flasks, some chemicals, and water.

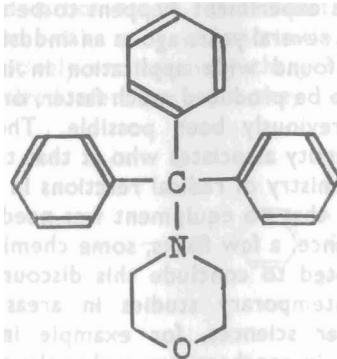
I had been tempted to conclude this discourse by referring to some exciting contemporary studies in areas where chemistry overlaps with other sciences, for example in biochemistry, in prebiotic chemistry, in geochemistry, and in the chemistry of planets and stars,<sup>35</sup> but I decided to avoid celestial space and geological time and finish in the Chemistry Department at Ife.

Here, as you know, we do a good deal of service work, but our main job is to train chemistry specialists. By the end of this session we shall have produced about 150 Honours B.Sc. Chemistry

graduates since our foundation. The output to date from all Nigerian Universities put together may therefore be approaching 1000. A good many of these graduates are now in university appointments. I doubt whether many have discovered opportunities for employment as industrial chemists.

The provision of courses at Ife in selected aspects of applied chemistry is under discussion. These need a firm foundation in pure chemistry and so must either be incorporated in a 5-year B.Sc. programme or introduced as M.Sc. courses. At postgraduate level in chemistry it is important to achieve a sensible balance in universities between fundamental and applied research. I think too that in applied research the respective functions of universities, polytechnics, and national research institutes need to be clarified. I could quote excellent examples of national research institutes elsewhere which have acquired high prestige for their contributions both to the solution of practical problems and to the general development of chemistry. They can be a major source of employment for chemists at Ph.D. and B.Sc. level and they may develop close connections with university chemistry departments.

There is one aspect of fundamental chemical research which is worth stressing: its eventual practical benefits are rarely predictable. For example, through four decades this century F. S. Kipping in the University of Nottingham was a pioneer in the study of organosilicon chemistry, on which he published 57 papers.<sup>36</sup> His contemporaries probably viewed his choice of subject as unfashionable and rather eccentric. Today there is a major industry based on these compounds;



(XVII)

their special properties give them value as oils, lubricants, rubbers, and water-repellant finishes.<sup>37</sup> By way of an example from personal experience, I exhibit this commercial brochure<sup>38</sup> which describes the most effective chemical yet discovered to eradicate the snails which infest African waters and act as carriers for the worm species which cause bilharzia. This compound, known commercially as 'Frescon' and chemically as N-triphenylmethylmorpholine (XVII), was first prepared by one of my students in 1965.<sup>39</sup> We were not seeking a cure for bilharzia; we were making a thoroughly academic study in a branch of organosulphur chemistry.

We live in a situation of congestion and stress, rather like the weaver ants. Academic studies tend to centre on quests for certificates and the fabrication of elaborate systems of courses and regulations. I hope that our Chemistry students and staff, while occupied in these pursuits, will have seen their subject as a potent force in the transformation of society and received some vision of its intellectual grandeur.

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