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ATTITUDES AND INNOVATION IN RESEARCH

Inaugural Lecture of the Royal Society Research Professor, Department of Chemistry, delivered at the University College of Swansea on January 20, 1976

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An inaugural lecture offers a variety of opportunities. To the members of the University and to the public it is an opportunity to "look the new boy over" and to form an opinion of what he has to offer. To the new professor it presents a captive audience and the opportunity of speaking at length on a subject of his choosing. I believe myself to be the first holder of a Royal Society research chair in the University of Wales and this has determined my choice of subject. Before moving to my main theme and thence to a short account of my own general area of research perhaps it would be appropriate to give you some background information on this Chair. There are currently twelve Royal Society research professors and a grant-in-aid is made by the Government to the Royal Society to provide for their salaries and support. Each appointment is renewable every five years provided that the President and Council of the Royal Society are satisfied that the holder is competently discharging his duties. Upon appointment, the new professor is allowed to choose the University of which he would like to be a member and I am indeed fortunate that Swansea agreed to accept me. Some of you may know that Swansea is my *alma mater* and that I read physics here between 1940 and 1943. The College has always been prominent in my own area of research, mass spectrometry, about which you shall hear more later; it already uses advanced mass spectrometric equipment both in its organo— and physico-chemical research. I am proud to have been associated with the College since 1968 when I was appointed one of its very first Honorary Professorial Fellows and I have made short, regular visits to the Chemistry Department since that time. I am now looking forward to complementing the chemical research on a full-time basis so that I do not become the first Royal Society Research Professor to be dismissed for incompetence!

My inaugural lecture gives me an opportunity of explaining the scope and purpose of my research work to my colleagues and of taking an important step towards becoming a member of the University community. It is, of course, of vital importance to maintain a dialogue between different disciplines and for this to happen there are two requirements. The first of these is that both sides must be prepared to try to explain to one another what they are doing without the use of jargon. I shall be talking tonight about my own work and I shall be trying my hardest to do so in terms that you can all understand. I must admit to having found the preparation of my lecture a salutary experience, but despite (or perhaps because of) the difficulties, its preparation has proved valuable to me. The second necessity for a fruitful dialogue is that people in the various disciplines should mutually respect and appreciate the different aims and objectives of their colleagues in other fields. This is most difficult in the present situation of diminishing financial support for the Universities and the consequently increased competition for the available resources. We must all try the harder to understand the relevance of what the other person is doing and how it fits into the overall scheme of things that make up a University.

All too often, I know that the scientist feels that people who have not, perhaps, tried very hard to understand what *he* is doing make a harsh and superficial judgement. Samuel Johnson comments[1] upon an acquaintance whose

> "... daily amusement is chemistry. He has a small furnace, which he employs in distillation, and which has long been the solace of his life. He draws oils and waters, and essences and spirits, which he knows to be of no use; sits and counts the drops as they come from his retort, and forgets that, while a drop is falling a moment flies away".

It is all too easy to criticise what someone else is doing and all too easy to ignore one's own ignorance concerning the total facts of the situation; it is easy to make suggestions for improvements when one carries none of the responsibilities for seeing the changes through. Thomas Malthus, an 18th century English clergyman made this point strongly[2].

> "The speculative philosopher equally offends against the truth. With eyes fixed on a happier state of society, the blessings of which he paints in the most captivating colours, he allows himself to indulge in the most bitter invectives against every present establishment, without applying his talents to consider the best and safest means of removing abuses, and without seeming to be aware of the tremendous obstacles that threaten, even in theory, to oppose the progress of man toward perfection".

So how shall I begin? Perhaps by stating my opinion of the importance of some training in science and the acquisition of an appreciation of the scientific method for all educated persons. I believe that no-one can claim to have received a liberal education until he has acquired some understanding of the principles and practice of science. The training that ends in literary culture without any knowledge of the achievements of science is just as incomplete as one that ends in scientific knowledge without an appreciation of the arts.

References 1-13 are on page 20.

The work of Faraday and Newton and Einstein is every bit as important and deserving of recognition and study as that of Shakespeare and Picasso and Chopin. After all, the long-term value of their ideas has been incalculably great. The development of science by such people has led to a huge increase in the numbers of the human race; it has fashioned every aspect of our everyday lives; it has fed and clothed us, removed the drudgery from our work, given us ample leisure time and shown us new ways of enjoying our lives. Surely the basis of science is deserving of study by all. During my lecture I shall be giving some specific examples of how scientific research has led to an enrichment of the quality of our lives and to lead up to this I must first discuss the scientific method. Professor Ziman[3] gives us a good introduction when he comments

> "To the layman scientific knowledge seems esoteric and strange: it has almost the power of magic. It is difficult to believe that it is not inspired from some hidden source, only to be acquired by mysterious rites based upon transcendental doctrines. This is not at all the case. Even a sophisticated, highly theoretical subject such as quantum physics really depends on vast quantities of very direct material observation and experience. The scientific world is merely an extension of the everyday world".

One can compare the way a scientist learns with the way a child learns.

> "One finds that in the way a child acquires concepts of number, size, space, time, etc., two factors are at work: (a) personal experience and manipulation of objects and (b) social contact by means of language with older people who have already learned to give meaning to such experience. The result is a gradual growth of the ability mentally to structure the world about us, both in geometrical patterns and in abstract words. The reality of the child's home extends, by experience, to the town in which he lives, to the country to which he belongs and, eventually, to the world at large.
>
> Scientific knowledge, for each individual, is essentially an extension of this making of maps. The physics student, for example, starts with magnets and iron filings, and learns to think in terms of *fields of force* ... He acquires this new way of thinking both by personal experience and manipulation and by discourse with those familiar with the subject. When you have lived in it for a while, the world of science seems just a matter of fact and real as your own kitchen".

Most of the advances in science come from research that adds minute particulars to what we know, but every now and again there is a large step forward when a scientist suddenly arrives at an entirely new theory which unifies a great amount of factual data and extends our understanding of it, as happened, for example, with Darwin. But these great unifying concepts are the exception rather than the rule.

> "In science we do not leap from hilltop to hilltop, from triumph to triumph or from discovery to discovery; we proceed by a process of *exploration* from which we learn to do better (and that is also what we ought to do in social affairs)"[4].

Learning to do better produces a feature that distinguishes scientists, namely that they are anxious to publish their findings in the expectation of corporate constructive criticism. It has been claimed that it is not the experiment nor the observation which is a scientific act, but the making of it into 'public knowledge'. So no man can be a scientist on his own. To have science there must be two men, one to do and one to criticise. On St. David's Day, 1664, the Council of the Royal Society made a decision far more momentous than it realised. It authorised Henry Oldenburg to publish a scientific periodical, which, though his private venture, was under its patronage. The next year, the *Philosophical Transactions* commenced publication. The year 1665 ended an era during which the scattered scientific intellectuals had been formed into a community mainly by private letters, with all the loss of time and irregularity that correspondence then involved. The scientists had intented their own method of communication. Monks had previously written metaphysical tomes, religious dissenters had published endless pamphlets and sermons, but the new international community of scientists created its own distinctive literary form—the scientific journal, printed periodically, with a variety of contributing authors and administered by editors. Between 1665 and 1730 more than 300 journals were established, of which 30 were devoted to the natural sciences. The tradition that all worthwhile scientific work should be published continues to the present day and the volume of published work is now so large that it is difficult to read more than a small part that relates to one's own special interests. The majority of prestigious journals are produced and edited by scientific societies and almost all matter submitted for publication is subject to critical refereeing before acceptance. To merit publication, material must be novel and not just a trivial extension of previous work. Scientists may also be invited to present their results at regular meetings of the various societies. The general atmosphere of critical appraisal means that scientists set high standards for themselves and their colleagues and it sometimes seems that the layman, too, sets higher standards for scientists than for others engaged in the pursuit of learning for its own sake. Only in the case of science is the inherent selfishness of this pursuit stressed and the view put forward that knowledge should be a means to life and not an end in itself. But as will be stressed again later, even if one accepts this criterion for judging the relevance of scientific work, one must take a very long view indeed in assessing the potential practical value.

Research may conveniently be divided into two kinds, one in which the only motive is to extend the boundaries of knowledge, the other where the purpose is to solve problems of common concern. The two fields are, respectively, pure and applied research and I shall refer to the people working in these fields as scientists or "pure scientists" and inventors or "applied scientists" respectively. Both these classes of pioneers play a vital part in the progress of our civilisation but they need very different environments. The scientist must have the freedom to follow wherever his work may lead: the inventor can be directed towards definite problems whose solution would be of direct benefit to mankind. The standard of value in one case is that of knowledge only; in the other it is that of profit, benefit or use. But either kind of research can sometimes be used to give the same result. This can be illustrated by an actual example—the invention of the miner's safety lamp. Sir Humphrey Davy researched into the nature of explosive gases and flame and was quickly able to announce his discovery—

> "... that explosive mixtures of mine-damp will not pass through apertures or tubes; and that if a lamp or lanthorn be made air-tight at the sides, and furnished with apertures to admit the air, it will not communicate flame to the outward atmosphere".

Davy played the part of the pure scientist in discovering a principle and the part of the inventor in constructing a lamp based upon this principle, having a wire gauze surrounding the flame. At the same time, completely independently, and with no access to scientific work nor any communication with scientists, George Stephenson made a lamp in the form of a long chimney with a tube at the bottom to admit air. The flame was unsteady and by experiment he improved it by substituting several small tubes for the single tube that supplied the air. This gave a steadier flame and so the lamp was further modified by replacing the tubes by small holes in a plate. He had thus arrived at a similar design of lamp to Davy. Stephenson was an inventor and not a scientist but he used the scientific method to test and perfect his design.

Pure and applied research have one major feature in common. Both kinds of research must be carried on with an open mind, uninfluenced by preconceived ideas, critical of its own experimental observations, cautious in making deductions and ready to revise any conclusions which do not stand up to further experiment or reasoning. Michael Faraday, one of the greatest experimental scientists of all time said that

> "The philosopher should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biassed by appearances; have no favourite hypothesis; be of no school; and in doctrine have no master. He should not be a respecter of persons but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of Nature".

The scientist believes that he spends his time in the pursuit of truth. He sees the motive of all scientific work as seeking to arrive at the truth. But in scientific truth there is no finality and so there can be no dogmatism. Science works to uncover broad, basic principles from which predictions are possible but advances are made by the study of instances that cannot be embraced by these principles and from predictions based on them that are later proved wrong. A successful researcher must have the ability to detect the exceptions and an eagerness to examine them instead of putting them aside because they are not in accord with preconceived ideas. Many discoveries have been made by chance observations in the course of experimental work, but it has been said that such accidents only happen to people who deserve them. Having noted the unexpected, the researcher needs an originality of mind to devise experiments that enable the exceptions to his principle to be investigated critically but there is often a vast difference between the result he expects to find and the one he actually obtains. Exceptions to rules and deviations of experimental results from those he expected are welcomed by a scientist, because they show him that there is still further knowledge to be gained. In this respect, I suggest that the scientist differs from most other people who tend to cherish convictions based on their experience and tend not to seek out and even to avoid evidence that is not in harmony with what they believe. They cannot understand the habit of mind that looks upon all truth as relative or temporary and that is delighted when a new fact emerges that cannot be fitted within the limits of an accepted principle.

Of course, one cannot put forward a principle and make a prediction from it unless the research has been performed and the experimental facts ascertained. One can certainly guess at what might happen and the guess might be

a good one, but it is still not a prediction and it has no value in furthering our understanding.

> "Unfortunately, we seem to be plagued by guessers who have not done their homework and by that even more dangerous breed of ideologists whose motto seems to be: *My mind is made up, don't confuse me with the facts.* They would do well to heed the advice of one of the greatest of all experimental scientists, Louis Pasteur, who warned his students—*the greatest derangement of the mind is to believe in something because one wishes it to be so*"[5].

It is true to say that research is essential to the acquisition of knowledge and that knowledge and understanding are essential for formulating new principles and making predictions in any area. Of course, scientists make mistakes and give wrong predictions, but devising critical experiments to test the predictions ensures that the scientific method is continuously self-correcting and that a closer and closer approach to the truth is being made as the experiments progress. It has been said[6] that the scientific mind is a

> "mind which appreciates the imperfections of the human reason, and is thus careful to guard against them. It values the truth as it should be valued and ignores all personal feelings in its pursuit".

Surely, the development of minds with these qualities is important in our society and this can be achieved by a training in the use of the scientific method.

Of particular concern to the Universities is research carried out which leads to the award of an advanced degree. An aim of this research is to give students a training which makes them capable of performing independent research without the necessity of guidance from more experienced people. Given the time to acquire the necessary background, the training will enable students to work in a field different from that to which their experience has accustomed them. From the student's point of view, the actual topic researched during his training is less important than that he should work in an atmosphere where new ideas flourish and proliferate and where he will be encouraged to develop originality of thought. Of course, the general education and training of a scientist, like that of any other person, involves two quite different tasks. The first is the development of his individual gifts and talents so as to increase and bring to full fruition his quality of originality. The second is to make him sensitively and sympathetically aware of what is going on in the rest of the world so that he can appreciate the aims, achievements and problems of other people. Universities are widely recognized as institutions both for advanced teaching and for research. If scholarship is to survive and intellectual pursuits to flourish, sufficient able, young people must be attracted to the Universities. Educated young people are the product of the University "factory" and their quality as well as their numbers must be maintained. It is no accident or matter of convenience that there is a close association between teaching and research. Without the new knowledge generated by research and the new insights and ideas resulting from this, teaching would become stagnant and uninspired.

The advantages of taking a research degree were fully appreciated by Sir J. J. Thomson, one of the giants of the scientific scene at the turn of the century and the man who discovered the electron[7] and who also laid the foundations of mass spectrometry, the research area in which my own interests lie. In his biography of Thomson,[8] Lord Rayleigh writes

> "The special value which he attached to research as a means of education was that it necessarily took the learner away from that reliance on teachers to which all set teaching was subject. A man who was attempting even the most modest piece of research had to find out what others had done on the same lines and he had to find it out for himself in the largely uncharted country of original literature instead of having it presented to him in cut and dried form by a lecturer . . . . . . But this was far from being all. J.J. maintained that he always saw the minds of those attempting research strengthen and mature under the process. It gave independence of view, self-reliance, initiative and training in judgement: and the very disheartening phases through which a research worker goes before light begins to emerge was in itself a valuable training for the battle of life".

The qualities being developed in this advanced scientific training are just those involved in large scale planning where operative complexity often brings failure and frustration. Hinshelwood felt[9] that there was a need for a whole new specialised area of science, a kind of biological and psychological statistical mechanics to clarify these matters but he warned that

> " . . . we may be told that the organisation of affairs must be placed in the hands of specially trained humanists, and that the scientific man should be confined to the rôle of an advisory expert. Such a tradition has of course tended to grow up in some of the public services. But one can say with conviction that its persistence will be unfortunate and its extension disastrous. It is like a separation of the heart from the brain and of the mind from the body. The man of science must handle human problems, and, in scientific affairs, nobody but the man of science can do it. On the whole, the universities and the great chemical industries are aware of this, and the excellent relations that have been growing up between them will exert a powerful influence for good, and are of happy augury. But eternal vigilance is the price of these things. At every level in every organisation where men are engaged in scientific pursuits, those in charge must continue to wrestle with the problems of combining liberty with order to the end of finding that cause which is humanly as well as technically the most effective".

It is an ironical comment upon modern civilisation that the social reaction to the gifts of plenty made possible by science is not an improvement of human welfare but distress and unemployment. In so far as science has brought about increased productive powers it must accept responsibility for these conditions. It insists, however, that these consequences are not essential, but are due to the neglect of the application of scientific methods to the solution of social problems,[10] and unfortunately many of our statesmen and administrators are unfamiliar with the significance of the factors involved. I do not want to suggest that the scientific method applied to the fields of politics, human biology, sociology, economics and psychology are competent by themselves to solve modern problems. What I do suggest is that the method will enable facts to be ascertained and organised by minds free from prejudice and passion and with a clear appreciation of what constitutes scientific truth.

A problem currently giving rise to passionate argument on both sides is whether fluoridation of our reservoirs should be undertaken. The facts have all been displayed—the likely benefits in terms of reduced dental caries, the effects of fluoride in areas where the natural level is even higher than the proposed dosage rate, the likelihood of side-effects have all been given, together with an interpretation of these facts by the representatives of the medical profession. But one is left with the impression that many of those who speak passionately for or against this measure are quite unaware of the facts. In this problem as in every other similar case, having arrived at sound conclusions, to construct practicable policies based upon them will also of course require a knowledge of history and an insight into human nature. But a consideration of the facts is the first essential.

I should now like to turn to a consideration of another subject that is assuming great importance in these days of financial stress. Science has now become a public concern and a lively debate centres on the amount of money to be devoted to research both in the Universities and in industry. Most interest is expressed in applied science, because Government, Industry and in his turn the ordinary man are all anxious to enjoy the economic advantages resulting from technology. But it would indeed be foolish to decree that all scientific work must be devoted to demonstrably practical ends. The applications that will develop out of a new and deeper understanding of some area of science can never be predicted in advance. No-one foresaw the applications of Faraday's magneto-electric effect; the development of the transistor and the consequent revolution in the field of electronics arose from a fundamental study of the mechanism of conduction of electricity in solids; no-one wanting to endow surgical developments in 1895 would have thought of giving research money to Röntgen, but the discovery of X-rays resulted from his work on electric discharges in gases. Ultimately, all technological advances must stem from an understanding of the laws of nature. Without a continuous extension of this understanding, applied science must eventually stagnate. The report last year of the study group on postgraduate education of the Committee of Vice-Chancellors and Principals reminded us that the entire research expenditure of our Universities represents only a small fraction of the national research and development budget. Much the largest proportion is spent by government research establishments, by research associations and by industrial laboratories all three of which concentrate, in the main, on applied research. If a balance is to be achieved between pure and applied research, the Universities' resources must be devoted to providing the fundamental research effort without regard to its immediate application. Only thus will there be provided the foundation for future applied studies but in ways that, in general, cannot be foreseen. It is daunting to read a statement by the Minister of State for Higher Education that "*relevance must be the guiding principle in all our discussions about the country's higher education system*" but reassuring to see the contrary view expressed by the Vice-Chancellor of the University of Oxford that "*No one in the Universities would argue for irrelevance. But there are many different views among individual scholars as well as among different institutions as to what constitutes relevance.*"[11] At the time of discovery of new knowledge its value is often hard to determine. When Faraday first showed that movement of a magnet near a coil of wire produced a small, transient current in the wire, the experiment did not seem very impressive. Faraday's memorable reply to the question as to the use of the effect was—"*Will you tell me the use of a new-born child?*". But from Faraday's discovery of the principle of magneto-electricity has developed the whole of the electrical engineering industry of the world. This is an example of the way in which science is

concerned with general principles out of which may come the mastery of nature in the service of man through inventions based directly upon the new-found knowledge. I suggest that it is not only relevant, but vitally necessary that some research in pure science should be encouraged, and that the Universities, whose concern is with the pursuit of learning and of knowledge for its own sake, give the natural environment for this research.

Sir Cyril Hinshelwood dealt[9] with the matter of the balance between pure and applied research and generalised it to cover the whole field of human affairs. He introduced an

> " . . . . analogy between human affairs and certain scientific laws. The particles composing matter are endowed with individual motions which would lead to complete chaos but for the attractive forces constraining them at times into orderly configurations. The two conflicting tendencies are, of course, what men of science know as the entropy factor and the energy factor. It is the balance of the two which governs all the rich complexity of chemistry and physics, and determines that measure of effective action called free energy. Were there maximum entropy and complete chaos, the world of phenomena would be much the poorer, but were there rigid constraint which the energy factor alone would impose, things would be as bad or worse. Nobody who has thought about science can fail to admire the art with which Nature interweaves her two great themes. When molecular chaos is set in order, it is only at a price, but price and value are astutely bargained. So must it be in human affairs. Complete individualism means chaos which is only given form by something analogous to an energy factor, by State compulsion, or by powerful emotional forces. If any of these controls are applied too rigorously the result is order indeed, but the order of utter stagnation. Just as Nature strikes her subtle balance, so it must be here. Nothing is less fruitful than doctrinaire argument about freedom and planning . . . . The problem is not to propound facile doctrines, but by hard and detailed thinking in every possible sphere to find those mechanisms and those techniques which in combination lead to the greatest measure of effective action".

In the final part of my lecture I want to say a little about my own research field which was the one used to test an extremely important and well known hypothesis put forward by Einstein in 1905 concerning the equivalence of mass and energy. The mass spectrometer had by then already been invented and used by Thomson.[12] This is an instrument in which a low pressure of the vapour from the sample it is desired to examine is ionised, that is to say is made positively charged. If more than one ion species is present, the ions can be separated into a "spectrum" according to their masses (more strictly according to the ratio of their masses to the number of charges carried) and the abundance of each species present can be measured. A plot of mass against abundance is called the mass spectrum. The instrument was improved by Aston[13] so that it was capable of measuring mass to a precision of better than one part in ten thousand. Aston found that ions formed from elements near the middle of the Periodic Table were not as heavy as would have been expected if they were made up of a simple collection of hydrogen nuclei.

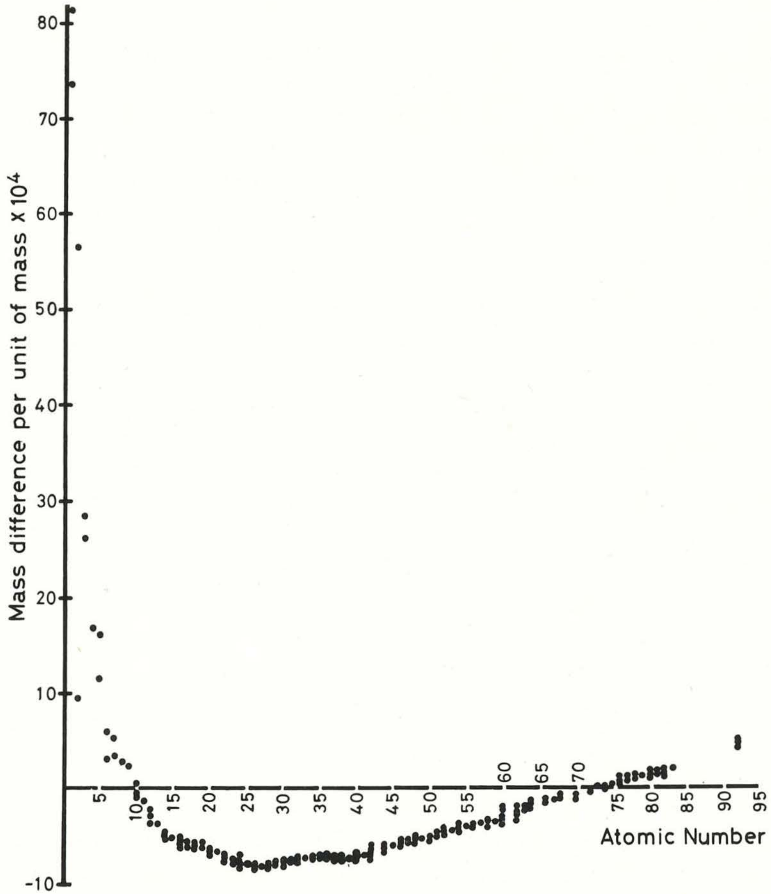

Fig. 1—A "packing-fraction" curve. This shows the deviations of the masses of the isotopes of the elements from whole numbers.

The missing mass was only about a thousandth part of the total mass but from Aston's measurements one could be sure that this amount of mass really was missing. A "packing fraction" curve of the elements based on Aston's measurements is shown in Figure 1. It led Eddington to argue:

> "Aston has, further, shown conclusively that the mass of the helium atom is less than the sum of the four hydrogen atoms which enter into it . . . . Now, mass cannot be annihilated, and the deficit can only represent the mass of the electrical energy set free in the transmutation . . . . If, indeed, the sub-atomic energy in the stars is being freely used to maintain their great furnaces, it seems to bring a little nearer to fulfilment our dream of controlling this latent power for the well-being of the human race—or for its suicide".

We now all know that hydrogen-fusion and the hydrogen bomb are a practical reality.

When complicated organic compounds are examined in the mass spectrometer, the ionised molecule is likely to break, making it probable that a variety of charged fragments is formed. The resulting mass spectrum is complicated, as shown in Figure 2 and may even contain hundreds of lines

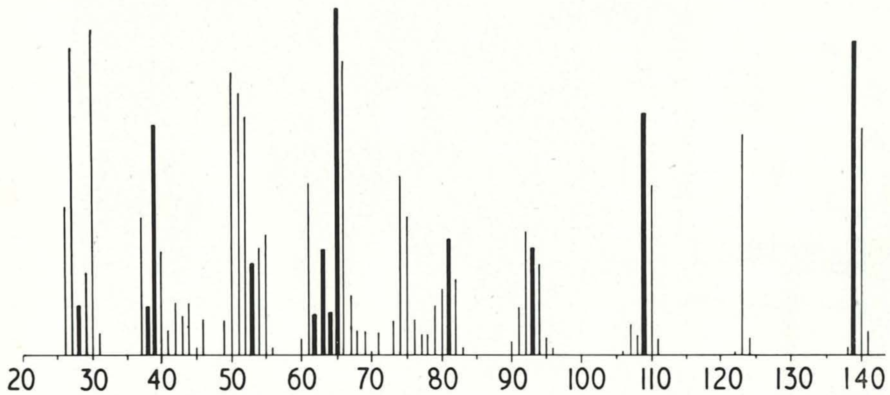

Fig. 2—A simple mass spectrum of an organic compound. The abscissa shows the mass-to-charge ratio of the ions. The ordinate shows the relative abundances of the different ions; the heavy lines should be ten times longer than they are drawn.

but, given the mass spectrum, it is often possible to solve the puzzle of fitting the parts back together again to give the structural formula. This is most easily accomplished if the actual formula of each fragment can be determined, and now that the precision of mass measurement has been further increased

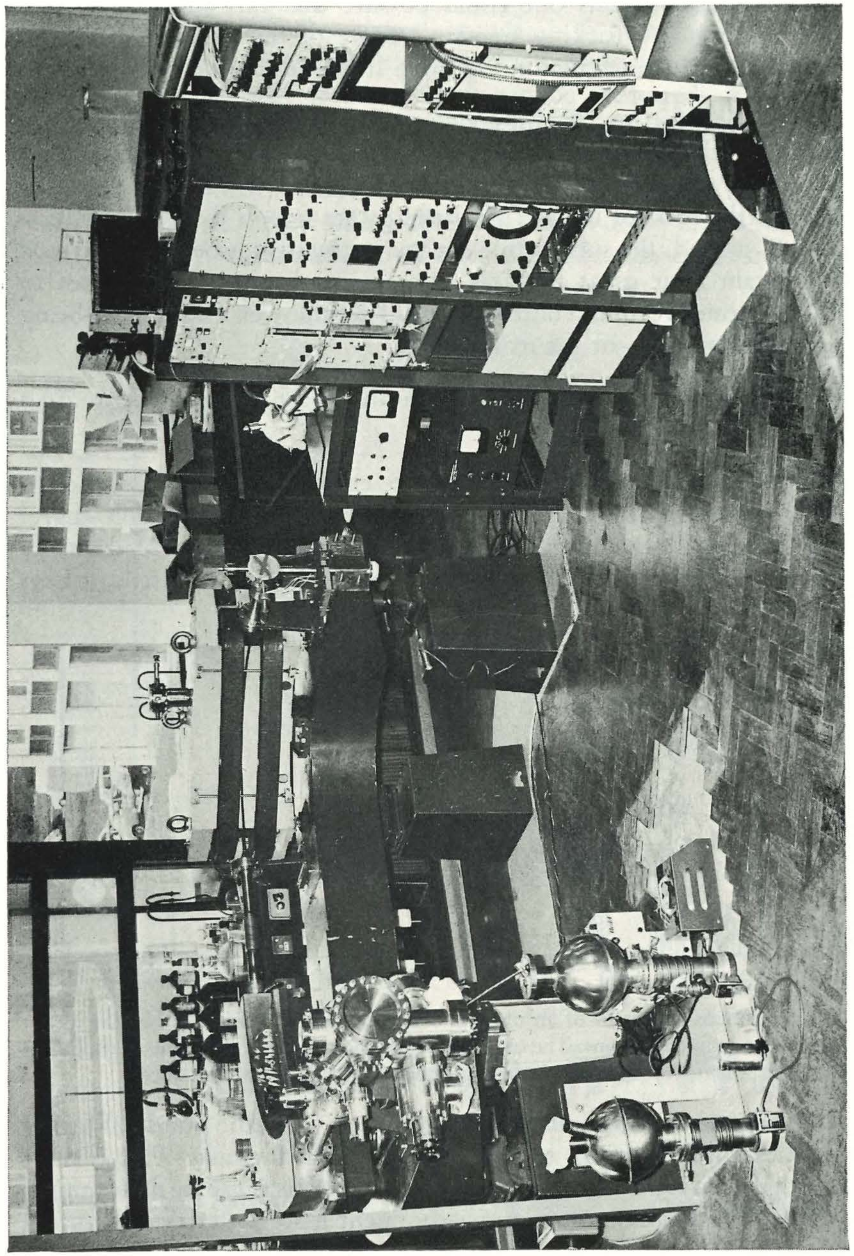

Fig. 3—The photograph shows the parts of the Varian MAT System-S mass spectrometer in course of assembly in the Department of Chemistry, University College of Swansea.

so that masses can be determined with an uncertainty of only one part in several million, this is generally possible. Let us take a simple example. Suppose that we limit ourselves to consideration of a compound containing only the atoms carbon, hydrogen, nitrogen and oxygen and suppose that in its mass spectrum this compound gives a peak at a nominal mass of 400. There are 206 plausible formulae that would correspond to the mass of 400, but only one, $C_{22}H_{32}N_4O_3$ that has the mass 400.247426 and there are no alternative formulae that have an accurate mass as close as within one part in three million of this. The closest matches are, in fact $C_{24}H_{34}NO_4$ of mass 400.248769 and $C_{19}H_{34}N_3O_6$ of mass 400.244744. Thus a sufficiently accurate mass measurement gives the exact formula directly. It is now not unusual for masses to be measured to within a part in a million at a rate of 100 masses per second, or to an even greater accuracy if the speed of measurement is reduced. And although the arithmetic involved may seem daunting, it requires only a modest computer. The power of the analytical technique is such that there is now an average of about two mass spectrometers per chemistry department in the Universities of this country. There is an equal number in industrial laboratories and these are mainly used to examine natural products and other complex organic compounds and to obtain their structural formulae. Other analyses, requiring very high sensitivity can also be performed by mass spectrometry and the entire transistor industry, for example, rests upon mass spectrometric analysis. Who would have supposed that the ability to measure mass would lead to the development of a revolutionary new method of identifying complex chemicals?

The above research is the kind with which I have been associated for more than twenty years. The equipment needed is large and expensive and I can best illustrate this by a photograph (Figure 3) showing the first of my research instruments now being installed in the Chemistry Department of the College. My present interests are concerned with modifying the standard, commercially available instruments so as to extend their applications in chemistry and physics. The way in which some of the new applications were discovered illustrates well the effectiveness of the scientific method and the details could form the basis of a new lecture. It all began when it was noticed that the baseline of the spectrum in between the mass peaks was not flat. A photograph of part of an actual spectrum, taken at high sensitivity to illustrate my point is shown in Figure 4 and, at first glance, the "interference" hardly seems worth bothering about. The phenomenon was identified as being due to ions fragmenting during their passage through the analyser; the diffuse nature of the peaks was shown to be due to release of translational

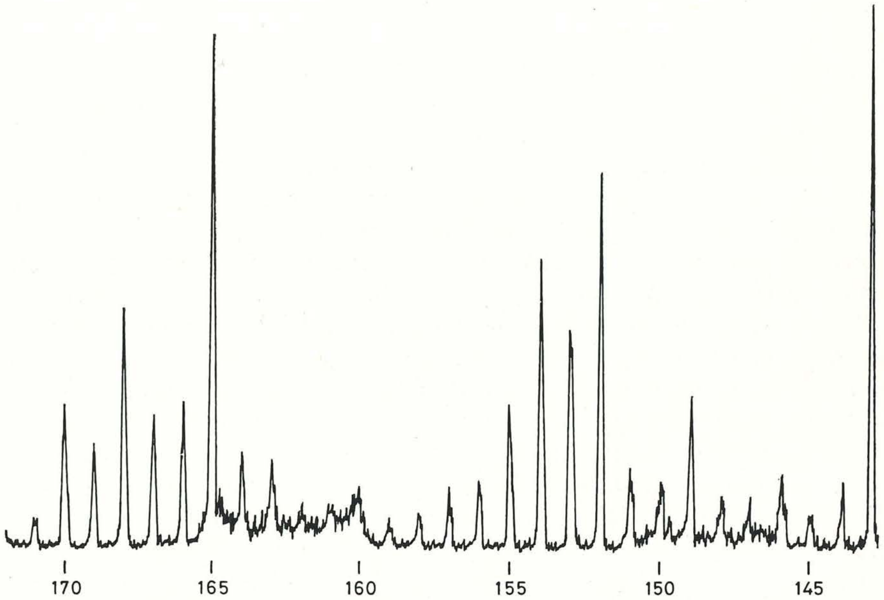

Fig. 4—Part of the mass spectrum of an organic compound showing small diffuse peaks along the base-line.

energy at the moment of fragmentation. Some of the ions were found to fragment spontaneously, others were caused to fragment when they passed near to a molecule of the very small amount of background gas remaining in the instrument. The background pressure in a mass spectrometer is only about 10^{-7} torr, or about one part in ten thousand million of the atmospheric

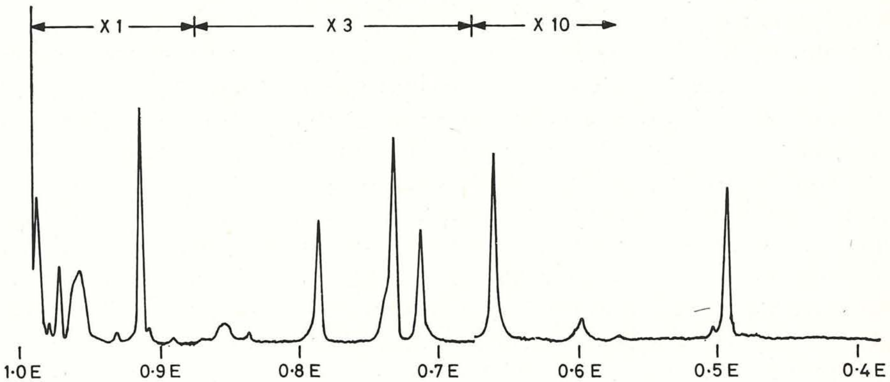

Fig. 5—The complete ion kinetic energy spectrum of an organic compound.

pressure and an ion would be likely to travel about a mile in such a vacuum before it collided with a gas molecule. Nevertheless, even this small amount of gas is sufficient to give rise to many kinds of fragmentation and produce small, diffuse peaks. It is already clear that the importance of these diffuse peaks is so great that research was carried out to find a way of suppressing all the normal mass peaks, so that this background could be studied at high sensitivity and without interference. This research was successful. The instrument is also being modified so that background gas can deliberately be introduced at the most appropriate point along the ion's path to enhance these fragmentation reactions. The kind of spectrum then obtained is much simpler than a mass spectrum as can be seen from Figure 5; it contains far fewer peaks, but each peak contains much more information concerning the actual fragmentation reaction. The masses of the parent and daughter ions can be found, the rate of the reaction as a function of the internal energy of the ion becomes accessible, the partitioning of the excess energy between internal and translational energy may be investigated and several fundamental thermodynamic quantities such as double ionisation potentials and reverse activation energies can be measured. The new method, which has been given the name *Ion Kinetic Energy Spectrometry* also shows advantages for determining the structures of unknown organic compounds and a second instrument, the prototype of a new range of commercial machines, will be installed at the College later in 1976. With it, and the companion instrument that is now being assembled, we can hope for a fuller understanding of ion reactions in the gas phase and through this, help to maintain the high level of research at this University College.

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