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UNIVERSITY PHYSICS IN TODAY'S WORLD

Inaugural Lecture
delivered at the College
on 21st November, 1967

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UP to about thirty years ago it would not, I suppose, have been necessary for an Inaugral Lecture of this sort by a new Professor of Physics to include reference to more than the first two words of my title. Up to about that time there was little realisation that the affairs of Physics were of much relevance to the practical every-day life of the world outside the walls of academic institutions. Indeed, the late Norman Clarke, who was Secretary of the Institute of Physics for many years, quoted[1] Professor J. A. Crowther as commenting at a conference of leading employers of scientists and engineers in 1936, that "it appears that the title physicist is still not understood by a large section of the general public (including many members of Industrial Boards of Directors) . . . it is evident that scope exists for a more intensive effort to educate the general public as to the meaning and content of physics and the kind of work which can most properly be entrusted to the trained physicist".

That was in 1936; I wonder if the position is very different to-day? Of course, no-one can fail to be aware of the technological revolution that has occurred in the past thirty years and there is too, I am sure, an awareness that in some general way Physics is related to this revolution. Just how much of the change in our every-day life has been brought about directly as a result of the rapid advance of Physics itself is, however, difficult for any but its practitioners to appreciate, because the same developments which have led to the technological revolution have made Physics itself more difficult to understand. This increase in difficulty of comprehension results from an extension of Physics which, I believe, is a continuation of, and not different in kind from, the train of events set in motion by that great upheaval in human thought, the transition from Greek philosophy to experimental physics, so that a study of the development of Physics from that time throws valuable light on the present situation.

Physics is, of course, concerned with understanding the behaviour of the physical universe, and rests on the

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[1] *Physics as a Career*, N. Clarke (The Institute of Physics, London).

belief that underlying general laws can be formulated by which a wide range of often apparently unrelated observable natural phenomena can be correlated. Of the essence of the discipline is that we are dealing with observable phenomena, and it is no accident that the oldest branch of Physics is Astronomy, because here were a set of observable spatial relationships—the stars, presented to the normal senses—the eyes, in a way which could not but arouse man's curiosity. Moreover, the observations were amenable to systematisation by geometry which was the mathematical equipment of the time. This, however, was not Physics as we now understand it, because it remained at the stage of a systematisation of a collection of data, which are only the first stages in the modern physical approach to a problem. That the ancients did not progress beyond this stage was due, to a great extent, to the profound influence of the Aristotelian philosophy. Whether this philosophy was one based on the belief that knowledge gained by reasoned argument was superior to that gained by observation, as is generally believed, or as has been suggested, a systematisation of "common sense" observations of direct observables such as 'motion', I leave others better qualified than I to judge. Certainly, the dominance of this philosophy, brilliant as in many ways it was, together with the theological climate of the Middle Ages, stultified the growth of Physics for about 1700 years.

The next stage, which transformed the subject and set it on the road to becoming the powerful scientific discipline that it now is, started in the middle of the Sixteenth Century with Galileo, who may be regarded as the father of modern physics. His achievement lay in developing the scientific method, not only by subjecting hypotheses to experimental test, which as an incidental involved the development of measuring instruments to supplement the senses, but also by introducing a degree of abstraction into the subject. First, by considering not just direct observables such as 'motion', but the components of those observables such as distance and time, and second, by introducing the concept of ideal systems to which the real systems being studied in the experiments, could only be approximations. These ideas were carried much further by Newton, who made the final break with the dominance of the earlier Greek philosophical ideas of the perfection of geometrical motions.

Newton, by means of the Universal Theory of Gravitation and the laws of motion, together with the appropriate form of mathematics which he initiated, was able to generalise the theory of the motion of both terrestial and heavenly bodies. In this, and in many other ways, Newton laid the foundation for the Physics of the next 150 years, during which time the mathematical basis was extended and perfected by mathematicians such as Euler, Laplace and Legrange, other forces, such as those arising in electricity, magnetism and electro-magnetism, were investigated on a macroscopic scale, and the theory was extended to the atomic scale with its application to atoms, treated as small hard elastic spheres, in the kinetic theory of gases developed by Maxwell and Boltzmann. All this enormous body of knowledge sprang from the application of the new scientific method.

It is worth noting here, I think, that although the scale of physical observation had changed from that of the solar system to the terrestial, it was not the change of scale which induced the change in fundamental outlook. Rather, it was the viewpoint itself that underwent the fundamental change; the change of scale was incidental, and arose because the experimental verification of hypotheses, which was one of the touch-stones of the new viewpoint, required experimentation—and it is not too easy to push the sun and the planets around! The theories themselves, however, were adequate to account both for the observable facts on the astronomical scale and the results of the terrestial experiments. The ideas involved in the new approach were, as it were, one degree removed from "common sense" experience, and special instruments were needed in electricity, for example, for their observation. The experiments and their results, however, could still be related to every-day experience, e.g. in the kinetic theory of gases there is an exact analogy between the collisions of atoms and of perfectly elastic billiard balls—and everyone knows what a billiard ball is and how it behaves in collisions! For this reason, the ideas, although more abstract than previously, bore close enough relation to sense experience to be readily understandable by an intelligent lay-man, even if the details of the mathematical arguments were only fully understood by specialists. In any case, with certain notable exceptions such as Faraday's experiments on electro-magnetic induction, the scientific results themselves were of interest primarily only to a relatively few devotees of natural philosophy. Although, of course, the Newtonian ideas had profound repercussions outside the purely scientific sphere as, for example, in the philosophy of Locke who, according to Voltaire, "reduced metaphysics to being the experimental physics of the soul".

Thus, towards the end of the 19th Century, the whole edifice of classical physics built on the foundations laid by Newton had been built up; and an impressive structure it was, dealing successfully, as it did, with most observable natural phenomena over a range of distances for example, of at least 21 orders of magnitude, from that of atomic dimensions, involving lengths of about 1 hundred millionth of a centimetre, to that of the solar system, in which the distances involved were ten million million centimetres or greater.

Then at the end of the last century the range of experimentation was carried downwards in scale, in order to investigate manifestations of phenomena occurring at the sub-atomic level, a phase which was initiated by J. J. Thomson's discovery of the electron just 70 years ago, and which has proceeded with ever-increasing momentum to this day. This extension faced physicists, almost straight

away, with experimental results, such as the observed radiation from a black body, for example, which could not be explained in terms of the classical concepts. In this situation, physicists such as Planck, Einstein and De Broglie made progress during the first quarter of this century, in a way which amply justified Max Born's statement that "faith, imagination and intuition are decisive factors in the progress of science, as in any other human activity". These were exciting years, as indicated by George Gamow's little book giving the history of the period, pithily entitled "20 Years That Shook Physics", and from them emerged quantum mechanics—the mathematical theory by which phenomena at the sub-atomic level must be handled. In the process the scientific method, originating with Galileo and Newton, had not been altered, but the degree of sophistication had been increased by one stage further removal from the 'common sense' observables of Aristotle; the Aristotelian view, preserved in the deterministic Newtonian mechanics, that in any change there was always something that changed, was no longer valid at the sub-atomic level. The result is that, although one can still describe atomic events in terms of atoms, thought of pictorially in analogy with a solar system with a central positive nucleus and electrons whirling around it at relatively large distance, the behaviour of this system and its interaction with other similar systems, which give rise to the properties of materials in bulk, cannot be described in terms of the deterministic classical mechanics which over the past three centuries had come to be absorbed as, for lack of a better phrase, 'modern common sense'. Moreover, the behaviour of such sub-atomic systems can only be studied indirectly by complicated apparatus, so that atomic phenomena can never become part of general experience as macroscopic phenomena can, and can only be fully understood in terms of the sophisticated mathematics of the quantum theory itself. This is even more the case with events on the even smaller scale of the atomic nucleus and of elementary particles, the investigation of which forms one of the present advanced fields of pure physics research, and where, incidentally, Physics appears to be becoming dominated by mathematical ideas of number and symmetry, more sophisticated, but not entirely unlike the ideas of the Greeks of the Pythagorean school.

This increase in the complexity and degree of sophistication of the ideas of physics has occurred at the same time as the methods of experimentation which gave rise to them, and the consequences of the application of these methods have led to the revolution in all the other sciences and technology to which we referred at the beginning.

To illustrate this, I have shown on the first slide (see Table 1) some present day applications which have resulted directly from original investigations in pure physics. First on this list is electronic circuitry, which is the basis of all modern communications such as radio and television, and which became possible as the result of the knowledge gained from physical investigations, first of the behaviour of electrons in gases and *in vacuo*, and more recently, of electrons in solids. Second, there is the mass spectrometer, developed originally by Aston from earlier experiments by J. J. Thomson to determine the ratio of charge to mass for positive rays in gas discharges, and now widely used in Chemistry, in the natural sciences and in many industrial concerns. Then there are the high energy radiations, X-Rays, α, β and γ rays and neutrons, the fundamental properties of which were first studied by the physicists indicated in the table, and which now find such wide use in diagnostic and therapeutic medicine, in non-destructive testing and radio-carbon dating. Further investigations of X-Rays by Von Laue showed that in their interaction with matter they gave intricate patterns, which W. L. Bragg showed gave information about the atomic arrangement within the matter. From these studies grew the techniques which have recently given such an impetus to the life sciences by the establishment of the structure of elements of the genetic code. As a fifth example, I have listed the electron microscope, developed from the crucial experiments of G. P. Thomson in this country and of Davisson and Germer in the United States to establish the wave properties of electrons, and now so widely used for the study of specimens in Metallurgy and in the life sciences. Finally, not to give too long a catalogue, there is the fission of the nucleus, resulting in the release of enormous energy (which was first accomplished by Hahn and Strassman in experiments in which they were trying to transform uranium to an element of higher atomic number) and which formed the basis on which the nuclear power industry, and other more sinister developments grew. Such a list as this, chosen almost at random and which could be multiplied almost indefinitely, shows clearly how the ideas and methods of modern physics have penetrated into all other scientific disciplines both pure and applied, and into modern industrial practice.

This situation means that in the last fifty years there has been a change in the role of Physics, taking it from being a discipline mainly of academic interest to one in the very centre of the scientific stage. In fact, a subject as essential to the education of a scientist, and therefore because this is a scientific age, to a general education, as was Latin to a mediaeval scholar or to general education, in a classical era. This change of emphasis and the increasing depth required for understanding Physics itself, poses many problems. These are accentuated by the fact, realised for some years, and confirmed quantitatively by the recent interim report of the Dainton committee, that although physical science is a virile, rapidly developing discipline, full of intellectual challenge and practical import, it is attracting a decreasing proportion of our ablest students—the Dainton figures show a decrease in science specialists at A–Level as a percentage of the whole from 58·4 to 56·7% in the years from 1960 to 1963. There is evidence that in the physical sciences the attraction is waning even more rapidly than for science as a whole and that, more recently, the absolute number of students in these disciplines is beginning to fall. Moreover, this is not a phenomenon peculiar to the United Kingdom; recent figures given by the American Institute of Physics show that in the United States, too, not only the percentage of students taking Physics declined from 1962 to 1967, but so did the absolute numbers.

Why should this be the case, and granted that it is so, does it really matter, or could it be that we were over supplied with physicists previously? I think that it does matter if only because there is ample evidence, judged by national need, that we are producing not too many but too few physicists; as the 1965 Technical Manpower Survey puts it "the existence of a large continuing demand" (for scientific manpower) "is incontrovertible". Filling this demand is vitally important to a country such as ours, not rich in natural resources, and therefore, utterly dependent for its future development on its industrial well-being. It may perhaps be felt that the guardianship of intellectual standards and the pursuit of academic excellence through teaching and research is the only function of a University. That these functions are indeed paramount in relation to the procedures the University adopts within its own walls, no-one would question; but, in present circumstances, I am sure that the wider obligations of the University to society must also be considered. If so, the national need for scientifically qualified manpower must be a relevant concern of the University Department, as the only source of education at the required level.

What then are the causes for the decline in the number of students opting to take science in general and Physics in particular? The reasons are undoubtedly many and complex, and that the same effects should appear in education systems as different as those of Britain and of the United States leads one to think that an international

enquiry into the reasons could do nothing but good—at least we might in this way, by determining the lowest common denominator, be able to eliminate some of the suggested reasons as being of minor importance. Be that as it may, I personally believe that major aspects of the problem are of an educational and sociological nature. We are, after all, concerned with the choices of boys and girls who have been brought up in an age which has been in the shadow of Hiroshima and the hydrogen bomb and at an age when idealism is at its strongest. Small wonder then, that to many, Physics and Mathematics, without which it is common knowledge 'the bomb' could never have come about, should be regarded with suspicion as suitable disciplines within which to spend a lifetime's work. There are far more reasons, it seems, to go into other spheres such as sociology where one can be of help to one's fellow man. To counteract this, is, I think, part of a wider educational problem which arises not from this alone, but is inherent in the situation which now exists, that a general education is incomplete without a knowledge of the methods and philosophy of the physical sciences.

One of the main concerns of educationalists in recent years has been, what seems to me the far too negative one, of avoiding too early specialisation. What I believe should be the aim is the far earlier generalisation of our education. By which I mean that the cultural implications of the development of the physical sciences since Newton must be recognised, to the extent of bringing these subjects into balance with other subjects, from at least the beginning of secondary education. I would plead at least for the equivalence of physical science with, say, a modern language throughout the early grammar school, a status which it is far from attaining in many schools today. In fact, I think more than this is required, by carrying to a much earlier stage in our educational system a tendency, which has been evident in University education in recent years, of a much more intimate relationship between disciplines both within faculties and across faculty boundaries. This is, incidentally, a tendency to which the structure of the degree courses of the University of Wales, with its requirement for three subjects in the first year and the possibilities of General and Joint Honours degrees, is well able to respond, and one which I hope we shall see spreading further. In this way, by bringing the physical sciences in closer contact with history, sociology and philosophy, as well as with the other sciences, both pure and applied, the unity of human knowledge and experience can be stressed instead of its division into water-tight compartments. Under the impetus of the demands of war and defence, we know the power of physical science for destructive purposes, but is it not possible that the enormous potential for good—as evidenced, for example, in the widespread applications of physics in medicine and as recognised by Conferences such as the 1963 United Nations Conference on 'Techniques for Tomorrow's World', which was concerned with the application of science and technology for the benefit of the less developed areas—is it not possible that this potential can be released by acting on the latent idealism of the young through our educational system?

To bring this about requires, among other things, first-rate teaching in the schools and universities, and here we come to one of the roots of the problem, because although university work has proved attractive to a sufficient proportion of graduates in Physics, school teaching has not; with the result that even to hold the present situation, let alone to make the sort of transformation I believe to be necessary, requires urgent action to make school teaching attractive *vis-a-vis* the other employment open to graduates in Physics. Here I think the universities can be of help, because it seems to me that one of the main differences between teaching and other types of work which physicists enter, is that the teacher finds himself, to a much greater extent, cut off from the main stream of developments in his subject, and one way of reducing his isolation is for the University Departments to have much closer links with teachers in its area. A scheme to bring this about, under the auspices of the Institute of Physics and the Physical Society, and the Royal Society, is already under way with the recent establishment of Physics Centres in various parts of the country. The object of these centres is to provide a place for informal meetings of teachers at all levels to discuss common problems, with the additional possibility of the provision of workshop facilities and laboratory space, where manufacturers' apparatus, as well as apparatus designed and constructed by teachers themselves, can be tried out. There exist distinct possibilities for this sort of development at local level, together with the other much wider contacts with the local area implicit in the recent appointment of the first tutor in physical sciences in the Extra-Mural Department of the University.

In short, the unique position of Physics demands, in present circumstances, that it be outward looking and that its practitioners be prepared to explain its mores and method to all willing to listen.

So far, what I have said has been concerned with the nature of Physics and its development to its unique relationship with to-day's world. It is legitimate for you to ask, does this throw any light on my views on the approach to Physics in the University, to elucidate which, must surely be one of the purposes of an inaugural lecture. Implicity, I think it does, because throughout I have tried to emphasise the basic conceptual structure of the subject, and this, I think, must be the key-stone to the teaching of the subject at University level. Through the absolute welter of specialised techniques, both theoretical and experimental, which must be mastered to come to grips with modern Physics and despite pressures from all sides for 'useful' Physics, we must not lose sight of the underlying unifying structure. It is for this reason that the traditional divisions of the subject into light, heat, sound, and so on, which because they are linked with direct experience through sense perception, are useful in introductory treatments of the subject, soon have to be abandoned at University level—for, to take a simple example, it is of far more fundamental importance that X-Rays, light and radio-waves are all electro-magnetic radiations and that their properties can thus be understood in terms of electro-magnetic theory than that for their detection they need, say, a photographic plate, an eye and an electronic circuit, respectively; even though to understand the characteristic interplay between theory and experiment which leads to the establishment of the fundamental conclusion, both the experimental arrangements, including the details of the detectors, must be understood, and the mathematical techniques required to handle the equations involved, achieved. Thus, within the subject, just as between subjects, there is a need to break down the superficial barriers, to establish fundamental unities, and to keep before us the method by which our understanding, incomplete as it is, is established.

An essential requirement for achieving these objectives in the teaching of Physics is, I believe, that the teacher himself shall be actively engaged in research. This performs a two-fold function. In the performance of research, the teacher himself is continually brought up against the central ideas of his subject and is continually reminded of its mode of operation, so that the research activity becomes a perpetual stimulant to his teaching, as well as to his own interest and enthusiasm for his subject. Secondly, it enables him to bring the ablest of his students to the boundaries of the subject where the student can experience for himself, under expert guidance, the intellectual power of the scientific method as applied to an original problem. Surely, there can be no doubt that this is the level to which we wish to bring our ablest students, whatever is to be their subsequent career. Only after such training can they see the implications of new ideas and developments for their particular interests, and if their work requires, contribute to the ideas or adapted them to their needs. In short, the centre of gravity of a university physics department should be its honours school, and a department without a strong research school cannot fulfil its function. This may well seem self-evident, but it seems necessary to state and re-state this basic requirement for education in Physics at a University, because from time to time, suggestions are made which, in effect, would alter the balance. In particular, at the present time, there is growing up a tendency to evaluate the immediate usefulness of graduates. This arises from the fact that two recent government reports on scientific manpower have established that only a very small percentage (somewhere between 10 and 20%) of Ph.D.'s in Physics enter British Industry. Admitting that, on a national level, this is a serious situation which requires careful consideration and positive action, I must, however, say that I am much concerned with the negative methods which seem to be beginning to be used in an attempt to solve it. There is no doubt, for example, that this year, for the first time since the war, we had students with very good degrees who, in numbers not out of proportion to previous years nor to our Departmental requirements and facilities, were prevented from returning to the Department to carry out research, as they wished, because they were unable to obtain financial assistance. If this trend towards what is effectively a reduction in research support continues, it will strike at the root of University education in the physical sciences and may well set off a chain reaction which instead of improving recruitment to industry, could accentuate another major manpower problem—the 'brain drain' of both students and staff. In my view, there should, without doubt, be University consultation at national level on this problem before the present trends gain momentum and end in catastrophe.

To return to my main theme, from which I seem to have digressed too far, and in which I was setting out my views on the approach to my subject in a University, may I hasten to add that these views are not new here in

Swansea. They are merely a re-statement and re-emphasis of the lines on which the Physics Department has been developed from its inception. And here, I am sure, you will allow me to digress just once more to pay tribute to the three previous holders of Chairs of Physics, who in the forty-odd years since its establishment, have brought the Physics Department here to be one of world-standing. First, Professor E. J. Evans, who after important experimental spectroscopic work related to the early foundations of the quantum theory in Rutherford's laboratory at Manchester, came to Swansea to get the new department off to a flying start. A few years later he was joined by Dr. P. M. Davidson; then a young lecturer, who in O. W. Richardson's department in London, had already solved a major problem by being the first to apply quantum mechanics successfully to the hydrogen molecule; now the distinguished head of this Department, of the theoretical Physics in which he has been the mainstay for so long. Characteristically, he is retiring later this year not to a well earned rest, but to grapple with a profound problem associated with the interaction of high intensity coherent radiation with matter, which will again bring him back to considerations of the fundamentals of the quantum theory. The Department will not be the same without him! The third member of this distinguished group is, of course, our present Principal, who also came first to Swansea as a young lecturer, after having carried out distinguished experimental work on gas discharges at the Clarendon, with Sir John Townsend, who, with Rutherford, was one of J. J. Thomson's first research students. It was Professor Llewellyn Jones who took over the Department, after the untimely death of Professor E. J. Evans, and steered it unerringly through the difficult post-war years. Anyone who has experienced his drive and enthusiasm will not be surprised to know that during this period, in addition to building up the Department from one with four Honours students immediately post-war, to one with over 40, he also established within the

Department, not one but two research schools, both of which made significant contributions in their own areas, and both with world-wide reputations. It is also due, in a very large measure, to his vision and foresight, that the Physics Department is now housed in this magnificent new building which we are in tonight. With his dynamic teaching, his enthusiasm and his demandingly high standards for research, he has indeed had a deep and abiding influence on Swansea Physics. Consequently, it gave us very great pleasure in the Department to learn, when he moved on to higher places, that the College Council had recognised these services by granting him an Honorary Professorship in the Department, which allows us still, when occasion demands, to draw on his wide ranging knowledge and experience in Physics.

I am deeply sensible of the honour of following in the footsteps of giants such as these three men, and very conscious of the responsibility involved in maintaining the traditions they established.

In addition to the debt which the Department owes to Professor Llewellyn Jones, I have an even greater, and very special, personal indebtedness to him for introducing me to the fascinating world of the physics of ionized gases, in which he first fired my enthusiasm as a research student, and in which we subsequently worked closely together for many years. I should like, in this last portion of my lecture, to sketch the highlights of this field of study, in order to point my earlier general remarks and to indicate the way in which it satisfies my previous criteria for University research. Since my justification for such research at all is based on the fact that it should bring its practitioners in contact with the conceptual basis of the subject, it goes without saying that the research must be concerned with significant questions at the frontiers of the subject. The frontiers of physics are, however, long and continually changing, so it behoves us to be a little more specific. To do so, it helps to introduce an idea used by Professor Weisskopf in a recent discussion of nuclear structure research. This is the question of "intensiveness" or "extensiveness" in physical research. There are, at any given time, research fields in Physics which are of no concern to anything but Physics itself. At the present time, high energy particle or mesonic physics would be in this category, and this is what we designate as "intensive" physics; at the other extreme, there are branches of the subject which are so complete, as far as the physical content is concerned, that they are primarily concerned with the interaction of Physics with other disciplines, such fields have a strong element of "extensiveness". Most research in Physics, of course, lies somewhere in between the extremes, having varying degrees of "intensiveness" and "extensiveness". We can envisage the situation as shown on the next slide, due to Professor Weisskopf. Here the diagonal line represents the advancing boundaries of the subject. In the early 1900's, the line would have been back near the origin with atomic physics as the intensive topic for research, but as the basic ideas became established, research in this field became more extensive in character and nuclear research became the intensive field and so on. The whole situation is a dynamic one of course, and within an extensive field the various subjects jostle each other at the boundary as various developments occur, and new sub-disciplines arise. Thus the topics included here, and their position, are open to discussion, and change will occur as time goes on. This was merely the position as Professor Weisskopf saw it at the present.

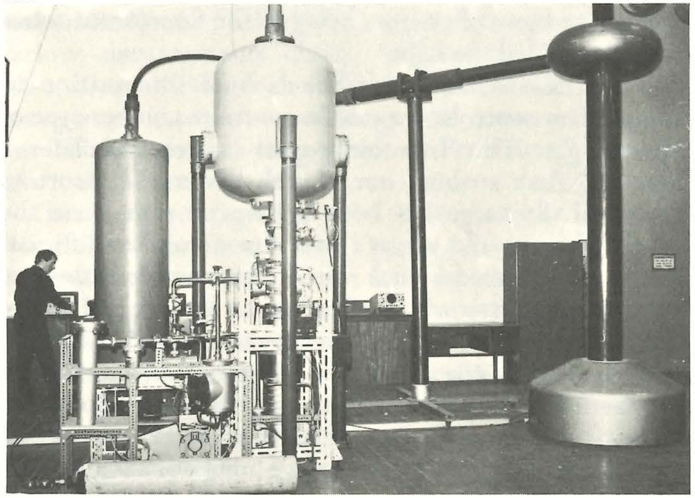
There are protagonists who champion the cause of "intensive" or "extensive" types of research to the exclusion of the other, but at a fundamental level either type is a legitimate concern of a University Department of Physics. There are, however, I believe, practical advantages for a University in the "extensive" type. Firstly, the student after he has completed his postgraduate work will, in general, have a wider range of employment open to him and, perhaps, just as important in the present national situation, to which his research experience is relevant. Secondly, at least in experimental physics, the expense of the present "intensive" type of research, which requires high energy particle accelerators, means that it has to be carried out at international centres where such machines are available. The need for both staff and research students to spend frequent, long periods away from the Department to which they belong in order to carry out their work clearly presents major difficulties.

Thus, in my view, suitable fields for university research in physics are ideally those with some degree of "extensiveness" and near the advancing boundary of the subject. This, as we see from the slide, is, I am glad to say, exactly where Professor Weisskopf puts Plasma Physics, which is part of the more general field of ionized gases, with which I am here concerned. Had he not done so, I should have felt bound to argue the case that it should be there, and since *ex-cathedra* statements are the antithesis of the scientific method, perhaps I should, in any case, pursue this argument at least in a general way.

To show the extensive nature of the subject on the terrestial scale is relatively easy, because if I remove all the ionized gas in this room, the effect is immediately obvious. The ionized gas, of course, being in the fluorescent tubes which provided the light.

If we take advantage of the lack of illumination to adjust a few controls, we can demonstrate another type of ionized gas. This is a long spark which simulates a lightning flash striking our church tower. This sort of electrical discharge has been known to man since the dawn of history and it may (even if in somewhat different form), have played a vital role in the transformations of primordial matter which gave rise to life itself. Despite its antiquity, the physics of lightning is still not completely understood, and the solution of this problem remains one of the long-term aims of our Department. However, when we started on this particular aspect of our investigation of ionized gases, the lightning discharge which, in practice, occurs with potential differences of millions of volts over distances of several miles seemed a long way off, because the mechanism of 30,000 volt spark over a distance of half-an-inch, was still the subject of much dispute. In fact, we were presented with the classical situation for the application of the scientific method; two theories had been put forward and very careful experimentation of a sort not previously attempted was required to decide between them. These experiments, which were started in our old Physics building, are now being continued and extended in the specially designed High Voltage Ionization Laboratory which adjoins the rear of this building. The laboratory will, we hope, soon be joined to this lecture theatre by closed-circuit television, but since that is not yet installed, I thought it would be as well to show you one or two slides in order to give you some idea of the sort of apparatus required in a modern physics investigation of this sort. The next slide shows a half million volt d.c. generator, the special feature of which is that the voltage varies by less than 1 part in ten thousand, which is an essential requirement for our experiments. (Figure I). These generators are, incidentally, only obtainable from a French firm in Grenoble and we had the first one of this type in Britain—it was known during construction as the 'Wales generator'. The half-a-million volts from this generator has, for our experiments, to be measured to 1 part in a thousand, and shown on the slide is part of the arrangement for doing this, by comparing the half-a-million volts through a potential divider with a standard cell. The voltage is applied through a high voltage bushing in the ionization chamber to 6 inch diameter electrodes inside, like those shown in the next slide in which we see a quarter-million volt spark passing between the central portion of the electrodes. Our main concern however, is with the very small currents, less than a thousand millionth of an amp from which the sparks develop, and by investigating these with this apparatus and with that shown in the next slide, which shows a d.c. generator of the more conventional Cockroft-Walton type, (Figure II) we have been able to establish the

Figure I. Highly stablised electrostatic 0·6 MV d.c. generator and associated equipment in the High Voltage Ionization Laboratory of the Physics Department at Swansea.



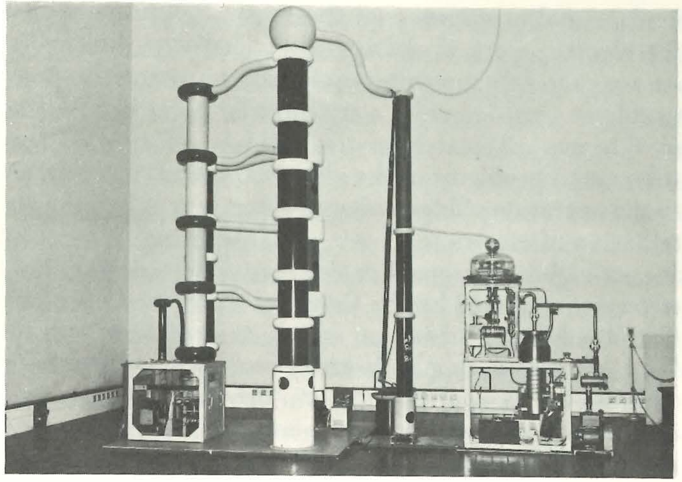


Figure II. Half million volt Cockroft-Walton d.c. generator and associated ionization chamber in the High Voltage Ionization Laboratory of the Physics Department at Swansea.

fundamental processes contributing to the mechanism of the electric spark at voltages up to half-a-million volts; we are currently designing equipment to extend this work to at least 2 million volts, a region so far never investigated in this way. Research in this field is, of course, very relevant to problems in the electrical industry in relation to the operation of high voltage switch-gear and to the distribution of electrical power, which is being transmitted at ever higher voltages. For this reason the work has been strongly supported by the Central Electricity Generating Board and forms a basis on which co-operation with the local electrical supply industry can be developed. In addition to its applied interest, the research also gives information about the cross-sections of fundamental atomic collision processes between electrons and atoms which it has not, at present, been possible to obtain in any other way in this region.

These, then, are some, although by no means all, of the terrestial reasons for a physicist's interest in ionized gases, but to appreciate the full ramifications of this branch of the subject one must proceed outward from the earth, as there is every likelihood, of course, that shortly one of our species will literally do. On passing through the atmosphere, we come, at some 100 km, to our first extra-terrestial ionized gas, the ionosphere, which plays such an important role in radio communication. Then a little further away again, we come, as the next slide shows, to belts of charged particles, consisting of high energy electrons and protons, girdling the earth at distances shown on the axis marked L values of about 1·5 and 2·5 earth radii. These particles are trapped by and undergo a complicated motion,[2] in the earth's magnetic field and that is what the rest of the information on the slide is concerned with. The presence of these radiation belts was quite unsuspected until revealed by Geiger counters, themselves ionized gas devices, on early satellites. They are known as the Van Allen belts, after their discoverer. Then, if we proceed further past the sun, which is itself

a huge blob of plasma, which sprays plasma in the form of the solar wind into much of inter-planetary space, and then on again past the other stars into the depths of space, we eventually come to the other galaxies, some of which appear as shown on the next slide. This is actually the nearest galaxy M31, which is almost a twin of our own, as seen through a 48 in. telescope; this galaxy is situated about 2 million light years, i.e. about 9 million, million, million miles away, and contains some hundred thousand million stars. Each of these stars, like our own sun, consists of high density, high temperature plasma. In fact, everywhere we look we find more and more plasma, and it has been estimated that more than 90% of all matter in the universe is in the plasma state. The enormous energy released by the sun and other stars is produced by fusion reactions which we have been trying so hard to produce in a controlled way in ionized gases on earth in recent years. In fact, one of the major recent advances in the study of stellar evolution has been the establishment of the actual nuclear reactions responsible for the heating of stars at various stages of their development, by using information concerning nuclear reactions gained from terrestial experiments. This is why Professor Weisskopf, you may have noticed, included astrophysics near the advancing boundary of nuclear physics. There are clearly close cross-links, too, between plasma physics and astrophysics. These links were recognised a few years ago in the United States by the establishment of the Joint Institute for Laboratory Astrophysics, where I had the privilege to spend last year, and in which groups of theoretical astrophysicists and experimental atomic physicists have been brought together, so that the results of terrestial experiments on atomic collisions and plasmas can be used to help solve the problems of the development of the universe. The wheel has thus come full circle, for you will remember that in discussing the transition from the Aristolelian philosophy to Galileo's scientific method, I mentioned the change of scale which occurred because it was not feasible to push the sun and planets around. From recent work, it now appears that results of experiments on the much smaller sub-atomic scale have profound significance for the understanding of the universe on the galactic scale.

This, together with all the other activity in plasma physics I have mentioned, is the very stuff of physics, which is, to me, a source of intellectual stimulation and excitement. Our job as educators is, I believe, through the use of our whole educational system, to persuade the young that this is so, because in the full development of their intellect lies tomorrow's world.

	ORIGINAL PHYSICAL INVESTIGA	ES OF PRESENT APPLICATIONS
1.	Electron motion in gases (Townsend 190 (J. J. Thomson 1899). Emission of electrons from heated meta 1902). Electron motion in metals and semi-conductors (Drude, Lorentz, Sommerfeld, Bloch).	cuitry for modern *communications* (radio, *computers*.
2.	Measurement of (charge)/(mass) for positive rays (J. J. Thompson 1913) and isotope separation (Aston 1919).	Identification of substances by mass spectrometers in *chemistry*, in *natural sciences* and in *industry*.
3.	Fundamental properties of high energy radiations, X-Rays (Rontgen 1895). α, β, γ rays (Becquerel 1896, P. & M. Curie 1898, Rutherford 1902). Neutrons (Chadwick 1932).	Diagnostic and therapeutic *medicine*. Non-destructive testing in *industry*. Radio-carbon dating in *geology*, *archaelogy*.
4.	Interaction of X-Rays with matter (von Laue 1912 W. L. Bragg 1913).	Structure studies of *genetic* code.
5.	Experiments to establish wave properties of the electron. (G. P. Thomson 1917, Davisson and Germer 1927).	Electron microscope for study of specimens in *metallurgy*, *life sciences*.
6.	Nuclear fission (Hahn and Strassman 1936).	Nuclear *power industry*.