Address of the President, Sir Ernest Rutherford, O.M., at the Anniversary Meeting, November 30, 1929.

At our Annual Meeting, our thoughts naturally turn to the losses by death to our Society. These include fourteen Fellows, among them some of our most distinguished figures, and one Fellow elected under Statute XII, Lord Rosebery, prominent in the political and social life of this country.

In James Whitbread Lee Glaisher, the Society has lost one of its senior Fellows. Elected in 1875, at the early age of 27, for his contributions to pure mathematics, his interest in this subject was soon equalled, and afterwards eclipsed, by his interest in astronomy. He was an active member of the Royal Astronomical Society for almost 60 years, having served continuously for the last 54 years on its Council, and having twice been President.

His striking figure, which changed but little even in advanced age, was well known to many generations of Trinity men. Those to whom he acted as College tutor or as mathematical lecturer learnt to regard him as their sincere friend.

He was a man of many interests, and in later years devoted himself to the collection of pottery, on which he became an outstanding authority. No reference to him would be complete which omitted to mention his fluency, charm and wit as a speaker, and the spirit of geniality which he introduced into any social gathering at which he was present.

Mr. M. J. M. Hill, Fourth Wrangler and Smith’s Prizeman in Cambridge, 1879, was professor of Mathematics at University College, London, for forty years, and Professor Emeritus at his death. He was mainly a pure mathematician, especially interested in the theory of differential equations and in the logic of his subject generally. At one time he took an excursion into hydrodynamics, and made an interesting discovery, now known as Hill’s Spherical Vortex. He observed a high standard of rigour in his teaching, which was a reflection of his own singularly conscientious and upright character. He took an active part in the politics of the University of London, always in the progressive spirit. These efforts were recognised by his appointment as Chairman of the Academic Council and later as Vice-Chancellor.
The death of Sir William Boyd Dawkins at the age of 92 years closed a long career of varied scientific activities. He had been Fellow of the Society for no less than 62 years, having been elected in 1867. After studying Geology in the University of Oxford, he joined the staff of the Geological Survey of Great Britain and gained wide experience as a field geologist. For many years Professor of Geology in the University of Manchester, he was one of the creators of the Manchester Museum. Apart from his professorial duties, he gained an extensive practice as a consultant geologist in connection with problems of mining and civil engineering.

Boyd Dawkins' exploration of caves in different parts of England, and of deposits in river valleys, resulted in his classical monograph on the British Pleistocene Mammalia. In his book on "Cave Hunting," published in 1874, he described another outcome of these explorations in the discovery of human relics of the Stone Age, and dealt with the similar discoveries in other countries. He was one of the group of pioneer investigators who raised the study of prehistoric archaeology to the dignity of a science.

Henry John Horstmann Fenton died on January 13th last at the age of 74; he was closely associated with the teaching of chemistry in the University of Cambridge for nearly 50 years. His contributions to new knowledge, although not numerous, were important, and were all characterised by the elegance and completeness with which the particular problems were solved; his discovery and study of dihydroxymaleic acid, a peculiar oxidation product of tartaric acid, furnish a striking example of his high qualities as an investigator. He was elected a Fellow in 1899 and served on the Council in 1913-16.

By the death of Sir Bertram Windle the Society has lost a Fellow whose main activities were devoted to administrative work as Principal of University College, Cork, and in his later years as a Professor of Archaeology in Toronto. In his earlier days as Professor of Anatomy in Birmingham he carried out important researches in comparative myology, and wrote interesting popular books on prehistoric Britain.

Michael Rogers Oldfield Thomas was for many years on the staff of the British Museum, where the recognition of his distinguished abilities as a naturalist led to his early transfer from the clerical to the scientific staff. He occupied a position of high authority in systematic zoology, especially in that of the mammals, of which he described more than 2,000 species and defined more than 200 genera.

Samuel Burnett Schryver, elected only last year to the Fellowship of the Society, was a chemist who had worked in a number of different fields.
of investigation. During the latter part of his scientific career, in which he occupied a Chair of Bio-Chemistry in the Imperial College of Science and Technology, his attention was chiefly given to the biochemistry of plants. With his pupils he published an important series of papers, many of which appeared in our own ‘Proceedings,’ on the pectins and on the amino-acid constituents of the vegetable proteins.

By the death of Sir Baldwin Spencer the Society has lost a biologist who accomplished valuable pioneer work in research and teaching in the University of Melbourne, and during the last 35 years attained a wider fame by his writings on Australian Ethnology. In collaboration with the late Mr. F. J. Gillen, he rescued much of the fast disappearing lore relating to the natives of Central and Northern Australia.

As a student recently arrived in Oxford from the Owens College in Manchester, his curiosity was aroused in a lecture by Professor Moseley’s reference to a white spot in the head of the archaic reptile which the Maoris of New Zealand call the Tuatara. As a result he discovered and described the most complete survival of a pineal eye found in any living creature.

Thomas John I’Anson Bromwich, who died aged 54, was Senior Wrangler in 1895. For a short period Professor of Mathematics in Galway, he returned to Cambridge as Lecturer in St. John’s College, where his learning and industry in teaching and research were proverbial. Interested at first in algebraic forms, he later turned his attention to applied mathematics, and his well-known investigation of Heaviside’s Calculus in his classical memoir on “Normal Co-ordinates in a Dynamical System” has given fresh life to the study of this most valuable method. His tragic ill-health for ten years or more robbed mathematical science of an original and penetrating mind.

Mr. Walter Heape was one of the group of students who drew their inspiration from the school created by Francis Balfour in Cambridge. He introduced precision into the study of the embryology of mammals, and was one of the first to investigate seriously the oestrous cycle, and to promote scientific study of breeding and sexual physiology. During the War his inventive genius found expression in devising cinematographic apparatus capable of recording the flight of a rifle bullet. A man of private fortune and business interests, for the greater part of his active career he belonged to the class of scientific amateurs to whom science in this country has been so indebted in the past.

Edwin Ray Lankester, Copley and Royal Medallist and Fellow since 1875, was an acknowledged master in the science of Zoology.
scarcely a group of animals he did not study, scarcely a problem he did not help to elucidate, more especially in the morphology of the Invertebrata.

As a mere schoolboy, in 1862, he published his first contribution on Pteraspis, one of a remarkable group of armoured fossil fish, of which he later wrote a now classical monograph. A year later appeared a note on the Gregarinidse, the prelude to a series of works on parasitic Protozoa, the study of which in relation to disease he did much to promote both in England and abroad. His researches on the structure and development of Annelids and Molluscs helped to make clear the distinction between the cœlomic body-cavity of animals and their blood-vascular system, thereby leading to important advances in our knowledge of the morphology and phylogeny of the Invertebrates.

The early memoir on Embryology and Classification contained many new and fruitful conclusions, and introduced new and more precise nomenclature. His proof that the King Crab, Limulus, is not a Crustacean, but the lonely survivor of a group of palæozoic Arachnids closely allied to the Scorpion, shed a flood of light on an obscure problem. We may mention also his work on Amphioxus, his pioneer researches on the pigments of animals, and his later interest in prehistoric flint implements. These and many other contributions, including his masterly articles in the 'Encyclopædia Britannica,' and other more general works, and his long and successful editorship of the 'Quarterly Journal of Microscopical Science,' furthered the progress of that zoological science so dear to his heart.

Among his signal services should be mentioned his invaluable help in the foundation of the Marine Biological Association and the erection of its now famous laboratory at Plymouth. A man of exceptional intellectual power, of deep insight and sound judgment, he was a great teacher, and for long the recognised leader among British zoologists.

A picture of Lankester would be incomplete without reference to his vivid and impulsive personality. He was restrained, prudent and temperate in scientific statement, but in other contacts with the world, and especially with the official world, he was apt to be not only fortiter in re but violenter in modo. But these exuberances welled up from a generous heart, and were displayed only in what Lankester believed to be a just cause. He will be remembered not only as a great zoologist, but as a lover of all natural knowledge, a respecter of all serious workers in science, and a very strong help to his friends and pupils.

William Henry Perkin, Davy and Royal Medallist of our Society, who
died on September 17th last in his 70th year, had long been an outstanding figure in the world of synthetic organic chemistry. The eldest son of the late Sir William Henry Perkin, F.R.S., he was a student at the Royal College of Science and worked for several years in Germany, first with Wislicenus and later with Adolph von Baeyer. Appointed Professor of Chemistry in the Heriot Watt College in 1887, he succeeded in 1892 Carl Schorlemmer as Professor of Organic Chemistry at Manchester. In 1912 he became Waynflete Professor of Chemistry in the University of Oxford, and retained this position till his death.

Perkin's first great contribution to synthetic organic chemistry consisted in the discovery in 1883 of derivatives of the closed-ring analogues of the paraffin hydrocarbons; this led rapidly to a vast extension of synthetic methods, to the discovery of the so-called bridged-ring systems, and to the elaboration of modern methods for building up many types of complex naturally occurring products. In this latter work Perkin was not only a pioneer but remained a leader throughout his life. His experience in connection with the cycloparaffins enabled him to synthesise many of the more important degradation products of camphor, such as camphoronic and the campholytic acids, and so to lead up to the proof of the constitution of, and to the synthesis of, camphor; it led him later to a series of masterly studies of the terpene hydrocarbons, which culminated in the synthesis of the terpineols and the limonenes.

All these achievements, remarkable as they seemed at the time, were surpassed by his work on alkaloids. Perkin early conceived the ambitious project of determining the constitution and effecting the synthesis of certain of the more complex vegetable alkaloids; his memoirs on this subject, by their insight into intricacies of molecular constitution, their grasp of experimental methods, and their attention to minute detail, opened a new epoch in organic chemistry. His ingenuity and pertinacity were rewarded by the synthesis of many of the naturally occurring alkaloids.

Throughout his life work Perkin was well served by his instinct for talent among his students, and by his faculty for inspiring and sustaining enthusiasm in his co-workers, many of whom have attained high rank as investigators. To every subject which aroused his curiosity he brought the same qualities of concentration and pertinacity which had raised him to the head of his profession; he was an enthusiastic horticulturist and also an accomplished musician. The intensity of his devotion to organic chemistry, to gardening and to music, left little leisure for other interests, even to one of his over-
flowing energy and vitality. Of a genial personality, his unexpected end will be mourned by a wide circle of friends.

Thomas Barlow Wood was appointed to the Drapers’ Professorship of Agriculture in 1907, and under his influence the Cambridge School of Agriculture has attained to eminence and high efficiency. In 1912 he became also Director of the Animal Nutrition Institute established at Cambridge by the Development Commissioners.

Wood had exceptional qualifications for the responsible position he occupied. He was a highly trained chemist, and the scientific point of view was natural to him. At the same time he was a practical agriculturalist, who for many years managed a Norfolk farm with economic success. He disliked empiricism even in the most practical affairs, yet his main interest always centred in the practical application of his scientific knowledge. That knowledge was wide, embracing most departments of agricultural theory and practice.

These qualities obtained for Wood the confidence, not of his students alone, but of the Government officials with whom his duties brought him in frequent contact. He gained the farmer’s respect, and was often able to tempt him to apply new scientific knowledge in the teeth of conservative instincts.

During the War Wood’s influence was widely felt. His intimate knowledge of the feeding of farm stock made his advice on this question invaluable, at a time when the country was faced with grave problems of shortage.

Wood’s exacting administrative duties left him little leisure for experimental research, but he inspired a large amount of such work in the Cambridge Laboratories. The experimental studies which he himself undertook were, as might have been expected, on the borderline between science and practice, for example the effect of crossing in sheep, and the evaluation of the maintenance diet for farm animals.

His influence was much increased by his fine personal qualities, and his geniality and readiness to help and sympathise when difficulties arose. His early death is a great loss to Science, to his University, and to the Nation.

As recently as November 17th the death occurred of Dr. Harold W. T. Wager, who combined for many years the position of H.M. Inspector of Secondary Schools and Honorary Professor of Botany in the University of Leeds. Notwithstanding this division of his energies, he made important contributions to botany, particularly in the region of cytology and reproduction of the lower organisms. Dr. Wager, indeed, was one of the first to introduce cytological methods into mycology.
I shall now say a few words on events of interest to our Society in the past year. To-day, the Society loses the services of two distinguished officers, Sir David Prain, Treasurer for ten years, and Sir James Jeans, Secretary for an equal period. During their tenure of office, the Society has greatly increased its responsibilities, mainly owing to the large bequests received by the Society, which have resulted in the foundation of Foulerton and Yarrow Professorships. In the same time, the Government Grant for Scientific Investigation has been increased from £4,000 to £6,000 and the Publication Grant from £1,000 to £2,500 a year. These changes have involved increased responsibilities and work for the officers and staff.

Sir David Prain has devoted himself wholeheartedly to the welfare of the Society; his wide experience of administration and breadth of scientific knowledge have been of much service on innumerable occasions. He has been ever ready to subordinate his own convenience, if he could thereby more effectively help the Society.

Sir James Jeans has been largely responsible for the great growth of the Society’s publications during the last decade. When he took office in 1919 the number of pages annually in the ‘Proceedings’ was 700, and is this year 3,661. I referred in my address two years ago to the large amount of labour involved in arranging for the selection and publication of such a large number of scientific papers. In addition to this important work, he has carried out the other duties of his office with great energy and ability, and the Society owes much to his clearness of vision and sound judgment.

We shall deeply miss the presence of these two officers in our counsels, but we may feel assured that they will still retain a lively interest in the welfare of our Society.

Sir Henry Lyons, appointed last year Foreign Secretary, has agreed to fill the post of Treasurer. I referred last year to the value of his services to the Society in connection with the International Research Council, of which he is now Secretary.

We welcome to-day Lord Rayleigh as our new Foreign Secretary, not only for his own scientific eminence but as a link with the past; for his father, the late Lord Rayleigh, served the Society both as Secretary and President.

Dr. F. E. Smith, who succeeds as Secretary, is well known for his accurate work on Electrical Standards at the National Physical Laboratory. As Director of Scientific Research and Experiment at the Admiralty and in other capacities, he has gained a wide experience as a scientific administrator. He
has recently been appointed to the important post of Secretary to the Department of Scientific and Industrial Research. The Council feel that it is an advantage, rather than a disadvantage, that Dr. Smith should hold these two posts concurrently; for, although the main spheres of work of the two bodies are distinct, they have many interests in common in fostering the research activities of the nation.

In the report of Council attention has been drawn to the foundation of a new Research Fellowship, tenable at Cambridge, financed from the bequest left to the Society by the late Mr. E. W. Smithson. The Society had already, in the Sorby Research Fellowship and the Foulerton Research Studentship, created two research appointments of a type designed to give opportunity for continuous research, over a period of some years, to investigators of proved ability, but of less established eminence than the holders of our Royal Society Research Professorships. In founding the new Smithson Fellowship, with an emolument on a scale appropriate to present needs, the Council have welcomed the opportunity of adding another to this important intermediate group of their research appointments. In the case of the Sorby Fellowship, the existing regulations require the holder to devote his time entirely to research and not to do any teaching work. The Council feel that this complete divorce between research and teaching is not in the best interests of the Society or the University concerned. After consultation with the representatives of the University of Cambridge, it is proposed that the Smithson Research Fellow, when appointed, should be permitted to do that minimum amount of University instruction necessary to obtain, or retain, an official post as teacher in the University. Such an arrangement should be of advantage to the University, and should make it easier for a holder of the Fellowship to obtain a suitable academic appointment on the completion of his tenure.

I am personally of opinion that it is in most cases advantageous for the holder of a Research Fellowship or Professorship to be permitted, and even encouraged, to give a limited course of advanced lectures or other suitable form of University instruction. This has the advantage of bringing the holder into touch with the younger workers and tends to prevent too exclusive a specialisation in his own work. The regulations made with regard to all the major research appointments, created in recent years by the Royal Society, make provision for such a possibility, and this is in most cases in effective use. I consider that a combination of research with a limited amount of instruction of the University type, rather than research alone, is in the long run likely to result in a greater advantage to science and to the community.
In my Address last year, I referred to the researches carried out by the Foulerton and Yarrow Professors of the Royal Society. We note with gratification that three Fellows of our Society have this year received the award of Nobel Prizes, namely, Prof. A. Harden, Sir Frederick Hopkins and Prof. O. W. Richardson (Yarrow Research Professor). It will be remembered that Prof. A. V. Hill has been similarly honoured; so that two of our Research Professors have now received this high international recognition of the importance and distinction of their researches.

I would like to take this opportunity to refer briefly to the admirable work that has been done by the holder of the Sorby Research Fellowship, Mr. N. K. Adam, and of the holder of the Armourers and Brasiers Research Fellowship, Dr. C. F. Elam, whose appointments now cease.

Mr. N. K. Adam worked in the University of Sheffield on problems connected with the formation and properties of mono-molecular films on liquids. Studies of this kind have not only given us valuable information on the dimensions of the molecules and their arrangement on the surface film, but also have thrown much light on the properties of mono-molecular layers in general. The results of his researches, which have been published in numerous papers in our Proceedings, have added greatly to our knowledge in this interesting field.

Dr. Elam, who held her Fellowship for five years, devoted herself mainly to investigations on the mode of preparation and on the properties of single crystals of the metals. In conjunction with Prof. G. I. Taylor, one of our Yarrow Professors, experiments were carried out to test the distortion of a large single crystal of aluminium under tensile stress. An account of this pioneer investigation was given in the Bakerian Lecture by Prof. G. I. Taylor and Dr. Elam in 1923. Similar methods were then applied to produce single crystals of certain metals, such as gold, silver and copper. Single crystals of iron, prepared by Edwards and Pfeil, were subjected to tensile tests and their peculiar distortion investigated. In addition, single crystals of certain alloys were prepared and tested under tension, while experiments were begun on the diffusion of one metal into another and especially into a single crystal. The results of these researches have proved of much interest and importance and have thrown much new light on the way in which the crystal planes slip on each other. Such investigations help us also to understand the effects of tensile stress on ordinary metals, which consist of an assemblage of small distinct crystals. The excellent work done by Dr. Elam affords a justification, if justification were needed, of the foundation of this Fellowship, due to the
generosity of the Armourers and Brasiers Company, for the promotion of research in metallurgy and kindred sciences.

In watching the advance of Science, and particularly of the Physical Sciences to-day, one cannot fail to be struck by the very close connection between theory and experiment—a relation which is probably more intimate than at any other period of scientific history. Every new experimental observation is at once seized upon to test whether it can be explained by existing theories, and if not, to find the modifications necessary to include it in the general theoretical scheme of natural processes. The mathematical analysis often suggests the possibility of unexpected relations which can be made the subject of fruitful experimentation. These two, in a sense, complementary branches of Physics profoundly react and interact with each other, and their united efforts lead to a greatly accelerated rate of advance in knowledge and understanding of the essential principles involved. The rapidity of advance in Physics, which has been so marked a feature in the last decade, is mainly due to this close combination of theory with experiment.

It will be seen that this interaction is clearly manifest in the subjects which I have selected to speak of to-day. I wish to refer briefly to certain recent discoveries which have excited much interest among physicists and chemists, and have thrown much new light on problems which have long been the subject of close investigation.

All of you are familiar with the scattering of light by small particles and the "Tyndall blue" of the scattered light, when white light from the carbon arc or the sun falls on a solution filled with a multitude of small particles. The late Lord Rayleigh in 1871 first gave the mathematical theory of the scattering of light by such particles, and was able to account in a general way not only for the colour of the reflected light but also for its state of polarisation. He suggested that light should be scattered, not only by particles containing many millions of molecules, but also by the individual molecules themselves, and that the blue of the sky was probably due mainly to the scattering of sunlight by the molecules of the atmosphere in its path.

This suggestion of molecular scattering was strikingly confirmed by the experiments of his son, the present Lord Rayleigh, who showed that scattering of light could be observed in gases freed from all dust nuclei, and that the light scattered perpendicularly to the direction of the incident beam was mainly plane-polarised.

In recent years there have been a large number of investigations on the scattering of light, not only by gases but by liquids and solids, with especial
attention to the amount of scattered light and the degree of its polarisation. I shall not refer here to these results and the interesting deductions that have been made from them, but concentrate attention on a more recent development. Sir Venkata Raman, of the University of Calcutta, who had for many years experimented on this subject, made an important observation which has thrown much new light on this question. For simplicity, suppose that monochromatic light of a definite frequency passes through an organic liquid, say benzene or toluene, which has been carefully purified. It was observed that the colour of the scattered light was distinctly different from the incident beam, showing that the light had in some way been altered by scattering by the molecules in the liquid. To examine this change more accurately, the scattered light was passed through a spectroscope. A striking result was observed. The strongest line was equal in frequency to the incident light, as was to be expected on the classical theory, but in addition a number of new lines were observed on the low-frequency side of the main line, and a few fainter ones on the high-frequency side. By the process of scattering, a set of new discrete frequencies had thus made their appearance.

An excellent account of these beautiful experiments was given this year by Raman and Krishnan in our 'Proceedings.' Similar effects were observed by Landsberg and Mandelstamm by examining the light scattered by certain crystals. Such experiments are not easy, for the scattered light is very feeble, and long exposures with intense sources of light are necessary to bring out the relatively faint new lines. An examination of the results showed that the changes of frequency depend on characteristic frequencies of the molecule, connected with its vibrational states.

The interpretation of these results is most clearly seen by consideration of the similar effects in gases, and we shall consider these first. For example, if $v$ be the frequency of the incident light, the frequencies of the new lines are $v - v_1$, or $v + v_1$, where $v_1$ is always found to be a difference between two fundamental frequencies of the molecule. This is completely in accord with the quantum theory of scattering, which was given formally by Kramers and Heisenberg in 1925. It is to be presumed that the light scattered by liquids is of the same nature, and the frequency shifts are due equally to differences of molecular frequencies; although in molecules, which absorb strongly in the infra-red, these differences may themselves appear as actual molecular frequencies.

It is of interest to note that the possibility of a process of this kind, involving the appearance of new frequencies, had been predicted by Smekal as well as...
by Kramers and Heisenberg. While theory and experiment agree admirably for gases, the theory could not have been legitimately extended to the case of molecules of a liquid, and here the Raman effect provides a new and effective tool for determining frequencies which are naturally present in a liquid or a solid.

It is clear that this new effect may be of great importance in determining the slow characteristic frequencies of molecules in the infra-red, which may be difficult to measure by other methods. This new discovery, of great interest in itself, thus promises to open up a new field of experimental enquiry and throw valuable light on the modes of vibration and constitution of the chemical molecule. This discovery has attracted much attention, and a number of papers dealing with it have been published in all parts of the scientific world.

It is naturally of great interest to consider the processes occurring in the molecule that give rise to these scattered radiations. The action of a train of waves in its passage through the complex electrical system of a molecule, which may be set in vibration in a variety of ways, is naturally very complicated and difficult to explain briefly in simple language. If, however, we content ourselves with a consideration of the energy changes only in the radiation, and disregard the detailed mechanism involved in the radiation processes, a simple explanation can be offered on the ideas of the light quantum.

We start by observing that it is a general consequence of wave mechanics that if a system possesses a number of states of equal energy, there is usually a finite probability of a transition from one of the number to any of the others. Consider a quantum of light, of frequency $\nu$ and energy $h\nu$, falling on a molecule in a given direction. The quantum and the molecule are to be regarded as a single system. This system has a number of other states of the same energy.

Firstly, those in which the molecule is unchanged and the original quantum is scattered in a new direction without change of frequency; transitions to these states correspond to Rayleigh scattering. Secondly, other states in which the state of the molecule is changed, its energy being altered by $\pm h\nu_1$, while a quantum of light of energy $h\nu \mp h\nu_1$ is scattered in some new direction. Changes to these states correspond to the Raman effect, where frequencies $\nu - \nu_1$ and $\nu + \nu_1$ are observed. The actual changes occurring in the molecule to give rise to these new frequencies can only be inferred from a detailed consideration of the possible modes of vibration of the molecule itself.

I shall now consider a very interesting discovery which has been made in the past year. It has been found that, in a sense, hydrogen consists of two
different kinds of molecules, which under ordinary conditions of temperature and pressure behave in a distinctive way. For example, the specific heat and conductivity of the two kinds of hydrogen are very different. I will first state the general conclusions to be drawn from the experimental observations and later discuss the intimate connection of theory with experiment that led to this discovery.

The hydrogen molecule in the normal state consists of two nuclei and two electrons. On the ordinary views of the gas-kinetic theory, it is to be expected that the molecules, in addition to their ordinary velocity of agitation, may rotate on an axis, perpendicular to the line joining the nuclei. On the quantum theory, it has a series of states of rotation which are specified in terms of a quantum number which has the values 0, 1, 2, 3, etc. Experiments on the band spectrum indicate that in ordinary hydrogen gas at atmospheric temperature, the molecules which have rotation numbers 1, 3, 5, are about three times as numerous as those with even rotation numbers, 0, 2, 4, . . . For convenience, the molecules of even rotation number will be termed \( \alpha \)-hydrogen, and those with odd rotation numbers \( \beta \)-hydrogen. When in equilibrium the relative number of hydrogen molecules in the different rotation states at any temperature is governed by the well-known Boltzmann law of distribution and can be calculated approximately. If, however, ordinary hydrogen gas is reduced to a low temperature, say, that of liquid hydrogen, on the ordinary kinetic theory it is to be expected that the rotation of the molecules should practically vanish, i.e., the majority of the molecules should have a rotation number 0 and only a small fraction, depending on the temperature, remain in the higher rotational states.

Actually, however, it is found that while \( \alpha \)-hydrogen is mainly in the rotation state 0, the \( \beta \)-hydrogen does not change into the state 0, at any rate for a long time, but retains its individuality, although, of course, the ratio of the number of molecules in each odd rotation state is governed by the Boltzmann law. The surprising fact emerges that the \( \beta \)-hydrogen under the influence of ordinary gas-kinetic collisions is only with great difficulty changed into \( \alpha \)-hydrogen. The time required for true equilibrium, after lowering the temperature, may be measured in months, or even in years under some conditions. This interval depends, as we should expect, on the pressure and temperature of the gas, since these govern the number and magnitude of the molecular collisions. This means that a molecule with odd rotation number finds a very great difficulty in passing to the even state of rotation.

A general explanation of this can be given on wave mechanics and it appears
to be intimately connected with the very weak coupling between a rotation state of the molecule with the spin of the minute individual nuclei (protons) which make up the molecule.

While under normal conditions, the passage of $\beta$-hydrogen into $\alpha$-hydrogen and *vice versa* is excessively slow compared with the duration of an ordinary experiment, yet the transitions can be greatly accelerated by appropriate treatment of the gas. For example, if hydrogen cooled to a low temperature is subjected to an electric discharge, there is a rapid transformation.

The passage of the cooled gas through charcoal immersed in liquid air or liquid hydrogen acts in a similar way. When the hydrogen is rapidly cooled to the temperature of liquid air, the odd rotation states are much in excess over the equilibrium value. The passage through the charcoal causes a rapid transformation of the $\beta$-hydrogen and the emerging gas, at the temperature of liquid air, consists mainly of $\alpha$-hydrogen.

It is of great interest to note that if the gas is warmed to ordinary temperature after passage through the charcoal, it remains mainly $\alpha$-hydrogen, while hydrogen gas in equilibrium consists only of about one-quarter of $\alpha$-hydrogen. It has been found that the specific heat of the gas and its heat conductivity at the temperature of liquid air before passage through charcoal is markedly different from the values for the gas at the same temperature issuing from the charcoal. In a sense we may say that $\alpha$-hydrogen has been obtained by this process in an approximately pure state. The effect in charcoal cooled to the temperature of liquid helium would be even more complete.

It seems probable that the rapid transformation brought about by passage through charcoal is catalytic in nature, and may quite likely be due to the dissociation of the molecules into atoms and their subsequent recombination to form new molecules. This striking and unexpected behaviour of hydrogen—the simplest molecule known to us—is of great theoretical as well as experimental interest.

I shall now attempt to describe briefly the various observations and theoretical suggestions which have ultimately led to the experimental proof of the existence of these two kinds of hydrogen molecules. It had been known for some time that no satisfactory theoretical explanation could be given of the change of specific heat of hydrogen with temperature, either on the kinetic theory or with the modifications of the theory based on the older form of the quantum theory.

A new orientation of our ideas was given by the development of the wave-mechanical theory. One of the first triumphs of this theory was the explanation by Heisenberg of the complex spectrum of helium. The two types of spectra
which appeared were shown to be connected with the different directions of spin of the electrons themselves. In one case, the orbital wave functions were symmetrical and in the other case antisymmetrical. From analogy with the behaviour of the helium atom, Hund showed that it was to be expected that the hydrogen molecules should consist of two kinds; in one, which we have called \( \alpha \)-hydrogen, the wave functions were symmetrical in the rotational wave function and in the other called \( \beta \)-hydrogen antisymmetrical. It was recognised that on the wave theory, there must be a very weak coupling between the symmetrical and antisymmetrical states, so that the transition from one state to the other must be fairly slow.

Dennison, in a paper published in our 'Proceedings' in 1927, calculated the specific heat of hydrogen at different temperatures on the bold assumption that the time of transition from one state to the other was very slow—of the order of one year—compared with the time required for a determination of the specific heat experimentally. Under these conditions, ordinary hydrogen could be considered to be a mixture of two gases, which have not only different specific heats but a different variation with temperature.

By assuming that the ratio of \( \alpha \)- to \( \beta \)-hydrogen was 1 to 3, he found that the calculated and observed specific heats agreed over the whole range of temperature. This ratio between the two states of hydrogen was in accord with the observations of T. Hori on the band spectrum of hydrogen.

Experimental proof of the accuracy of this deduction was soon forthcoming by a variety of experimental methods. Prof. J. C. McLennan examined the Raman effect in liquid hydrogen and found that the changes of frequency observed in the spectrum of the scattered light indicated that hydrogen at this temperature consisted of a mixture of molecules having even and odd rotational states. The relative intensity of the lines was in accord with the relative distribution assumed by Dennison.

About the same time experiments were undertaken by Eucken and Hiller and by Bonhoffer and Harteck in Berlin. Eucken and Hiller determined the specific heat of hydrogen under different conditions. Hydrogen at high pressure was kept for some days at the temperature of liquid air, the specific heat was measured at intervals and at different temperatures, and was found to show marked variations with time. The fraction of \( \alpha \)-hydrogen was found to vary from 25 per cent. at the beginning to 95 per cent. after a long interval. It was found that the rate of transition from \( \beta \)- to \( \alpha \)-hydrogen at liquid air temperature depended on the pressure of the gas and was approximately proportional to the number of molecular collisions.
Bonhöffer and Harteck used a simpler and more rapid method for following the change of state of the hydrogen under different conditions. By measuring the change of resistance of a heated wire in the presence of the gas, the changes in the heat conductivity of the gas, which varies with the specific heat, were easily followed.

We have already referred to their experiments of passing hydrogen through charcoal at low temperature and of the effect of the electric discharge. The results of the beautiful experiments of Bonhöffer and Eucken afford a complete and striking proof that hydrogen under ordinary conditions is composed of two sets of molecules which are transformed into each other so slowly that they may be regarded in a sense as two distinct gases differing in specific heat and conductivity. The specific heat of \( \alpha \)-hydrogen at low temperature is greater than that of \( \beta \)-hydrogen. A large quantity of heat is given out in the passage of \( \beta \)- into \( \alpha \)-hydrogen. At very low temperatures, the heat evolved in this transformation is greater than the heat of volatilisation of liquid hydrogen.

It may be of interest to note that the peculiar behaviour of hydrogen might have been discovered long ago, for no new experimental knowledge or technique is involved. Attention, however, was only directed to this subject by the failure of existing theories to account for the variation of specific heat of hydrogen with temperature. The development of wave-mechanics threw new light on this problem and a happy suggestion, based on this theory, was found to fit in well with the observations on the specific heat. Following this clue, the question was attacked experimentally by several different methods, with results in complete accord with the predictions of theory.

We must now pass to the presentation of the medals.

The Copley Medal is awarded to Prof. Max Planck, For.Mem.R.S.

In the realm of Physics the name of Planck is intimately connected with the bold and fertile concept of the quantum of action, which has exercised such a profound influence on theoretical and experimental physics in the last twenty years.

In the first instance, he applied the concept to derive a formula giving quantitatively the distribution of energy in the spectrum of a complete radiator at any temperature, and it was basing upon this that Einstein developed a formula for the atomic heats of solids as a function of the temperature which laid the foundation for all progress that has been made on this subject in the last twenty years. The concept of quanta of action as applied by Bohr to
atomic processes in 1913 has proved of fundamental importance in elucidating the meaning of the complicated spectral series, and it has given an insight into the constitution of the atoms and been able to account for their various properties from first principles. In its most recent developments Heisenberg has shown that Planck’s quanta of action are bound up with an essential indeterminacy of physical measurements, which has the most far-reaching metaphysical consequences. Though his name is not immediately associated with any of these theories, Planck has taken an important part in formulating, clarifying and criticising these developments of his original idea.

It is no exaggeration to say that the development of the idea of the quantum of action, first formulated by Planck nearly thirty years ago, has effected not only a veritable revolution in physics, but profoundly changed our methods of thought and concepts of philosophy.

Quite apart from his work on quanta, Planck’s papers and books on other subjects are sufficient to place him in the front rank of physicists. His contributions to thermodynamics and his applications of Boltzmann’s definition of entropy to complicated systems have proved eminently fruitful, whilst his book on mechanics is a model of clarity and succinctness. In his papers he has never allowed the physical ideas underlying his work to be overwhelmed by the mathematical apparatus, and this faculty has enabled him to treat of the philosophical aspects of the modern views of physics in a manner both fascinating and profound.

A Royal Medal is awarded to Prof. John Edensor Littlewood, F.R.S.

Prof. J. E. Littlewood is a mathematical analyst of great distinction, whose work, done partly independently and partly in conjunction with Prof. G. H. Hardy, is widely appreciated by mathematicians of all countries. The various problems which he has successfully attacked are characterised by their extreme difficulty. Into certain properties of primes, in which the Riemann zeta-function is employed, he has penetrated further than any other mathematician. Among the results he has obtained in this domain may be mentioned his proof that a conjectural expression given by Gauss for the number of primes less than a prescribed number is false, although its correctness is supported by all empirical evidence for numbers up to a thousand million. He has also obtained the best known result giving the number of primes less than a prescribed number. In the general theory of series he has obtained various important results, the most celebrated of which is his Tauberian theorem for power-series. This has given rise to many later results. He has done much work on
the general theory of functions, the earliest of which relates to integral functions of finite or zero order. His theorem that (roughly) a function of sufficiently low order has associated with it circles on which its minimum is of the same order as its maximum, has led the way to many developments by other mathematicians. Another striking piece of work is his extension to real sub-harmonic functions of the theorem due to Fatou, that an analytic function, bonded in the unit circle, tends to a limiting value almost everywhere on the unit circle. Besides all this independent work, the importance and width of the results which have been published by the partnership of Prof. Hardy and Prof. Littlewood must be referred to. Among the subjects which they have treated are additive number theory, especially Waring and Goldbach problems, the theory of the zeta-function, Diophantine approximation, general theory of series, and Fourier's series.

A Royal Medal is awarded to Prof. Robert Muir, F.R.S.

Prof. Robert Muir has for over a quarter of a century taken a leading part in the development of pathological and bacteriological research in this country. He is particularly distinguished for his pioneer work in the study of immunity reactions and mechanisms at a time when the foundations of the science of immunology were being laid, and the combining properties of normal and immune sera with antigen were being submitted to analysis by test tube methods. The schools of Ehrlich and of Bordet, which were then particularly active in this new branch of science, had their worthy counterpart in this country in that founded by Robert Muir in Glasgow, and during the first decade of the century there emanated from that school a most important series of contributions devoted to the elucidation of the interactions between complements and immune bodies on the one hand, and antigen on the other. Hæmolytic systems were chiefly studied and problems concerned with the specificity, constitution and dissociation of immune bodies and with the combining properties of complements were attacked by accurate quantitative methods. These studies by Muir and his collaborators are of fundamental importance in the history of the development of the science. They are embodied in Muir's "Studies on Immunity," published in 1909, which contains a full discussion of their bearing on current theory. The pursuit of serological problems by many pupils working under his direction has been ever since successfully continued.

Muir's interests, however, have not been confined to immunology. In the field of general and experimental pathology he has made important contributions to knowledge, and his researches on experimental anaemia produced by the
injection of haemolytic serum, and on the regenerative changes in the bone marrow in response to infection, are widely known. In many other directions the work of Muir and his school has influenced the advance of pathology.

The Davy Medal is awarded to Prof. Gilbert Newton Lewis.

Prof. Gilbert Newton Lewis, of the University of California, is justly regarded as one of the leaders of modern physical chemistry, mainly on account of his remarkable contributions to chemical thermodynamics. Carrying on the work associated with such names as those of Horstmann, Willard Gibbs, van't Hoff and Nernst, Lewis has been responsible for the development of fresh and original methods in attacking the problem of chemical affinity. By the skilful utilisation of appropriate experimental measurements, Lewis and his collaborators have shown how the free energy of a great variety of elements and compounds can be ascertained, and how this quantity is related to the thermal and electro-chemical characteristics of chemical reactions in which these elements and compounds are involved.

It is to Lewis that we owe the concepts of "activity" and "activity coefficient," and recent advances, more especially in our knowledge of the thermodynamic properties of solutions, are the direct outcome of the introduction and development of these ideas. Further, in the closely-related field of electrode potentials, Lewis's work, both on the theoretical and practical sides, has been outstanding.

Apart from his contributions to chemical thermodynamics, Lewis has rendered great service to chemistry by his theoretical work on electron configuration, and the bearing of this on polarity, valency and cognate matters. His conceptions in this field and his recognition of the fundamental importance of the electron duplet have greatly influenced the development of modern chemical theory.

The Hughes Medal is awarded to Prof. Hans Geiger, of Tübingen University.

Prof. Geiger has made many important contributions to our knowledge of radioactivity. He was the first to examine in detail the scattering of alpha particles by matter. His classical investigation, in collaboration with E. Marsden, on the large-angle scattering of alpha particles in their passage through matter, not only gave a definite experimental foundation to the nuclear theory of the atom, but led to the suggestion that the properties of an atom are defined by its atomic or ordinal number—a suggestion soon to be so strikingly verified by the investigations of Moseley. Among many notable
researches in radioactivity, we may specially refer to his determination of the ranges of the \( \alpha \)-particles from all the radioactive elements with the greatest possible precision. From these measurements we are enabled to deduce the velocity of expulsion of the \( \alpha \)-particles from many radioactive bodies. He discovered with Nuttall a remarkable relation between the life of a radioactive element and the velocity of the alpha particle ejected from it. This relation, known as the Geiger-Nuttall law, has an intimate bearing on the new theories of the constitution of atomic nuclei.

With Sir Ernest Rutherford, Geiger devised an electric method of counting alpha particles and determined the number of alpha particles emitted by a gram of radium. Later Geiger devised a point detector of great sensibility, which could be used for counting both alpha particles and beta particles. Within the last few years he has succeeded in making a new type of detector, by which the liberation of any electron throughout a comparatively large volume is detected. This beautiful device, which has been applied by Geiger himself and by others to the study of the penetrating radiation in the atmosphere, promises to provide a method of great power for extending our knowledge of this radiation.

Geiger’s work has been characterised throughout by great thoroughness and accuracy, and has had a marked influence on the development of our knowledge of the radioactive bodies and of the radiations emitted by them.

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