Address of the President, Sir Ernest Rutherford, O.M., at the Anniversary Meeting, November 30, 1928.

During the past year the losses to our Society by death have been unusually heavy, including three Foreign Members, thirteen Fellows, and two Fellows elected under Statute 12, the Earl of Oxford and Asquith and Viscount Haldane. While the main work of Lord Haldane lay in legal and administrative fields, he always had a deep interest in science and its philosophy, and gave much valuable help to the cause of University Education.

The death of Prof. P. H. von Groth, Foreign Member of our Society, at the age of 84, removes a notable figure from the Science of Mineralogy. Distinguished as investigator and writer and editor for 39 years of the 'Zeitschrift für Krystallographie und Mineralogie,' he widely influenced the development of his science, and by his own researches and through his students made notable contributions to our knowledge.

The death of Hendrik Antoon Lorentz, Foreign Member of the Royal Society and Nobel Laureate, has deprived physical science of one of the greatest figures of our time. He will be remembered mainly by his extension of Maxwell's electromagnetic theory. He introduced a new precision into this theory, and brought it into line with current experimental physics, by breaking up Maxwell's electric charges into crowds of electrons. Especially noteworthy was his explanation of the newly-discovered Zeeman Effect, in terms of electronic motion inside the atom. Contemporaneously with Larmor, he examined and discussed the effects produced by the motion of an electric system through "the ether." This part of his work culminated in a proof that the effect of this motion could be exactly reproduced by a modification of the measures of time and space in the system. The equations which embody this result, universally known as "Lorentz's transformation," ultimately formed the foundation stone of the Theory of Relativity.

In his latter years, he naturally and by general consent took the leading place in every Continental congress of physicists. Those who have seen him...
presiding over such functions can never forget his unfailing tact and courtesy, his geniality and kindness to all, his ready wit, his command both of language and languages, and the vast store of scientific knowledge which was ever held in reserve, to be brought into service when needed.

At the request of the Society, I attended the funeral of Lorentz at Haarlem, which was national in scope and testified to the high place he held in the esteem of all sections of his countrymen. Eulogiums on the work and personality of Lorentz were spoken at the graveside by Prof. Ehrenfest, Langevin, Einstein and myself.

By the death of W. H. Dines, at the age of 73, Meteorology has lost an outstanding pioneer in the study of the upper atmosphere. By means of kites and balloons and measuring apparatus of entirely his own design, he was one of the first to make a systematic study of the meteorological state of the upper air. For 20 years Director of Experiments in the Upper Air for the Meteorological Office, he rendered great services to the Science he loved.

Sir Aubrey Strahan, who died on March 4th, was till 1920 Director of the Geological Survey of Great Britain and a leading authority on the stratigraphical Geology of this country, and especially on that of the coalfields. He had been President of the Geological Society of London, and a member of the Royal Commission on Coal Supplies. Elected to our Fellowship in 1903, he gave valued service on the Council and Committees of the Society, acting in the last months of his life as Chairman of a Committee appointed to draft a report on Museums and Public Galleries.

In Sir David Ferrier, who has died in his 87th year, we have lost a pioneer investigator of the physiology of the brain, whose work laid the experimental foundation of all modern knowledge of the localised functions of the cerebral cortex, and thereby opened a new epoch in the medical diagnosis of disease or injury of the brain, and in their relief by surgical operation. Ferrier was one of the founders of the Physiological and of the Neurological Society, and one of the small group who, in 1878, started the Journal 'Brain,' to deal with neurology in its widest experimental and clinical aspects. For many years an honoured and successful physician, he preserved to an advanced age an enthusiastic interest in the advance of neurology by the experimental method. In 1906–1908 he was a Vice-President of the Society, of which he had been a Fellow for 52 years at the time of his death.

Science has suffered a severe loss by the early death of Theodore W. Richards, Director of the Gibbs Memorial Laboratory, Harvard University,
Nobel Laureate in Chemistry, Foreign Member of our Society and Davy Medallist. He early devoted himself to the accurate determination of the atomic weights of the elements and introduced many new methods leading to much increased precision in the measurement of these fundamental constants. The value of his work has been universally recognised, and his laboratory at Harvard attracted many research students from all parts of the world. He was much interested in the compressibility of atoms and molecules and made many accurate measurements in this field. A man of wide interests and sympathies, he had many friends in this country.

Hans Friedrich Gadow, of German birth, but of British nationality since 1884, was for many years lecturer and reader in the advanced morphology of vertebrates in the University of Cambridge. His researches and writings on vertebrate anatomy, and especially on that of birds, reptiles, and amphibia, have had a great and stimulating influence on zoological thought. A naturalist as well as an anatomist, he sought every opportunity of seeing the forms which he studied under natural conditions, keeping many alive in his garden and wandering as far afield as the caves and mountains of Northern Spain and of Mexico. A man of robust and enthusiastic temperament he is held in grateful memory by many Cambridge men as a popular and influential teacher.

John Horne, a former Assistant Director of the Geological Survey of Great Britain, was in charge of the Geological Survey of Scotland from 1901 until 1911. In association with different colleagues he was responsible for important memoirs on the structure of the North-West Scottish Highlands and on the Silurian rocks of Scotland. At the time of his death, at the age of 80 years, he was still engaged in the completion of a work on the Geology of Scotland, begun in collaboration with the late B. N. Peach.

Sir John Thornycroft, who died in his 85th year, became a Fellow of the Society in 1893. A pupil at Glasgow of Kelvin and Rankine, he began the construction of small high-speed craft on the Thames almost simultaneously with Sir Alfred Yarrow. In 1877 he built for the Admiralty his first torpedo boat, followed in rapid succession by other craft, including, in 1907, the ocean-going destroyer "The Tartar," driven by Parsons turbines at 35·6 knots. In time his yard was moved to Southampton, and from it during the War was launched a stream of destroyers and flotilla leaders. During his later years he devoted himself to some of the problems which troubled the builder of high-speed vessels, utilising for the purpose a small tank constructed in his grounds.

Charles Chree, after graduating in the University of Aberdeen, came to
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Cambridge, and was 6th Wrangler in 1883, gaining a Fellowship in King's College in 1885. In 1893 he was appointed Superintendent of the Kew Observatory, and filled this post with much distinction until his retirement in 1925. He published many original papers on subjects connected with terrestrial magnetism and atmospheric electricity and elasticity. Of international reputation, the value of his work was recognised by the award to him of the Hughes Medal of the Society.

Sir Horace Darwin, son of Charles Darwin, was educated as an engineer. He will long be remembered as the man who, by the application of engineering principles, transformed the industry of scientific instrument making in this country. Soon after Michael Foster went to Cambridge as teacher in physiology, Darwin began, in partnership with Dew Smith, to make instruments for the new laboratory. The work grew, and in time developed into the Cambridge Scientific Instrument Company, with Darwin as its chairman and inspiring genius. Many of the instruments were of his own design, and practically all bore the impress of his supervision. He was one of the first to apply the principles of geometrical design laid down by Kelvin and Maxwell. The changes in instrument making during the past fifty years have been far reaching. Darwin was a leader in this advance, a friend ever ready to help those who came to him for advice.

Diarmid Noël Paton, for 22 years Regius Professor of Physiology in the University of Glasgow, was an eminent and successful teacher and an enthusiastic investigator of problems drawn from a wide range of his subject. He was among the earliest of British physiologists to investigate metabolic problems and in more recent years had devoted, with his pupils, many years of experimental study to the function of the parathyroid glands. In an age of increasing specialisation he remained conspicuous for the width of his knowledge and interest in physiology and in its practical application to sociology and medicine.

G. H. Bryan was an applied mathematician of distinction. His early work lay in the fields of hydrodynamics, thermodynamics and the kinetic theory of gases. Later he turned his attention to the problem of aviation; he was the first to investigate stability of flight by treating the moving aeroplane as a system undergoing small oscillations about a state of steady motion, thus laying the foundations of the theory of stability in aviation.

By the death of Sir Charles Tomes, in his 83rd year, the Society has lost from its Fellowship a great pioneer in dental anatomy. In his continuation of the work of his father, also one of our Fellows, he may be said to have founded the science of comparative dental histology. As a member and Treasurer
of the General Medical Council, he was largely responsible for raising the standard of scientific training for the practice of dental surgery.

Sir ALEXANDER KENNEDY, who has recently passed from us, had been for over forty years a Fellow of our Society. In 1874 he became Professor of Engineering in University College, Gower Street, and established there the first Engineering Laboratory in this country, devising a method of education which has been followed widely both at home and abroad. He was one of the first to realise the need for placing structural engineering on a sound mechanical basis and was largely responsible for the introduction of testing machines. On resigning his professorship in 1889, he commenced practice as a consulting engineer and in that capacity designed electrical works for power and lighting in many parts of the Empire. He was a man of many interests and, of late years, by his photographic records of the ruins of Petra made known to the world some of the wonders of the civilisation of which it was the centre.

Sir HUGH KERR ANDERSON, Master of Caius College, Cambridge, since 1912, and a Fellow of our Society since 1907, was a member of our Council at the time of his recent death, at the early age of 63. Returning to Cambridge in 1891, on the completion of his medical course in London, he devoted himself during the next 14 years, with self-sacrificing zeal and conspicuous success, to research and teaching in his chosen subject of physiology. He was one of the investigators who were then unravelling the intricacies of the autonomic system and shaping the conceptions of its function now everywhere accepted. The series of classical papers in which he was associated with the late Prof. Langley, and his later and independent work on the complex reactions of the pupil of the eye, had shown him to the world of science as a coming master in his subject; while to every Cambridge man who in that period entered upon research or higher study in physiology, Anderson had been lavish in his gift of interest, encouragement and personal help. From 1905 onwards the recognition of his aptitude for business drew him, always diffident and reluctant, away from research into the wider affairs of his College and of his University. As a member of the Royal and Statutory Commissions, and in many other capacities, he did inestimable service to Cambridge, to science, and to education, and earned the honour and affection of a wide circle beyond his University and our Society.

Turning to other matters, I shall say a few words on events of interest to our Society during the year. After the normal period of office, Sir Richard Glazebrook retires to-day from the position of Foreign Secretary, and I
am glad to take this opportunity to convey to him the gratitude of the Society for his valuable services. In a difficult time, he has very efficiently represented our Society at the meetings of the International Research Council and has been indefatigable in his correspondence on international questions. We are fortunate to secure as his successor Sir Henry Lyons, who, in association with Sir Richard Glazebrook, has represented the Society at International meetings. His wide experience in this direction had led to his appointment as Secretary of the International Research Council in succession to Sir Arthur Schuster, who has recently retired from this important office. Since its foundation, he has been General Secretary of the Union for Geophysics.

Before the meeting on June 21, I had the pleasing task of accepting on behalf of the Society a portrait by Mr. R. G. Eves of our former President, Sir Charles Sherrington, which was presented by Sir John Rose Bradford on behalf of the subscribers. The Society is proud to possess this portrait, which is now hanging on our walls, and I think all will agree that it is an excellent likeness of my distinguished predecessor. It will serve as a permanent memento of one whose great and still continued services to Science and our Society we all gratefully recognise.

I have already referred to the loss of that veteran investigator Sir David Ferrier. His friends and admirers have collected a fund of £1,000 which they have presented to the Society for the foundation of a Lecture in his memory. The Society has gratefully accepted this offer, so that in future on the biological side in addition to the well-known Croonian Lecture, there will also be a "David Ferrier Lecture" to be given at intervals and on subjects to be determined later.

It will be remembered that in the year 1922 our Society made a new departure by instituting Royal Society Professorships. With the aid of the Foulerton Fund, bequeathed to the Society, and the munificent gift of Sir Alfred Yarrow, we have been able in the last few years to appoint five professors, two Foulerton Professors in the medical sciences and three Yarrow Professors in the physical sciences. The main object of our Society is the "Improvement of Natural Knowledge" by discovery, and the main line of discovery must depend upon research. The Society has endeavoured to attain this object in two ways, first through its Studentships or Fellowships, six in number, including the Sorby, Foulerton, Mackinnon, Moseley, Tyndall and Armourers' and Brasiers', awarded to younger men who have shown marked promise as investigators, and secondly, through its Professorships, which are awarded to those who have shown over a longer period an unusual original capacity for advancing know-
ledge by experiment. The holders of these Professorships are expected to devote their whole attention to research and are freed from all duties of routine teaching and administration.

As the Royal Society has no laboratory of its own these Professorships may be held in any scientific institution which is in a position to offer suitable research facilities. A satisfactory feature of this scheme of administration lies in the fact that the Royal Society does not compete with existing institutions, but co-operates with and reinforces them. In all cases so far arrangements have been made for our Professors to continue their work in the same laboratories as before, and we are grateful to the Universities and Institutions concerned for the cordial and generous way in which they have co-operated with the Royal Society for this purpose.

The creation of Research Professorships by the Society was in the nature of an experiment, but I think all will agree that the experiment has proved an unqualified success. We have been fortunate in being able to attract some of our ablest and most original workers, who have devoted themselves to their investigations with zeal and enthusiasm, as evidenced by the high quality of their accomplished work. As it is now six years since the institution of the first professorship it has been thought desirable that I should give a brief review of some of the work carried out by our Professors. This is a difficult task in a limited time, but I hope I shall be forgiven for any shortcomings.

Prof. A. Fowler, who was appointed Yarrow Professor on December 1, 1923, has continued his researches in the Astrophysics Laboratory of the Imperial College of Science and Technology. Everywhere recognised as one of the most skilful of our experimenters in spectroscopy, he has during his tenure of office contributed to our 'Proceedings' a number of important papers, which have widely extended our knowledge of the modes of vibration of atoms under different conditions of excitation, when they have been deprived of one or more of their normal number of electrons.

His attention has been directed mainly to the production and analysis of the spectra of some of the lighter elements at successive stages of ionisation, including carbon, nitrogen, oxygen and silicon. These spectra are not only of importance from the theoretical standpoint, but also in their application to the interpretation of the spectra of the hotter stars. He has obtained data of precision over a wide range of experimental conditions, and covering a range of spectrum from the extreme ultra-violet to the infra-red. The investigation of these spectra has presented considerable experimental difficulty, especially in connection with the elimination of impurities. The results obtained for
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Nitrogen and oxygen have already found an application of special interest, in the use which has been made of them by Bowen in his important interpretation of previously unidentified lines in the spectra of gaseous nebulae.

During the tenure of his professorship Prof. Fowler has also been charged with the direction of the work of a number of research students and assistants at the Imperial College, some of whom have published valuable papers on spectroscopic subjects.

Prof. G. I. Taylor, who was appointed Yarrow Professor on December 1, 1923, continued his investigations in the Cavendish Laboratory, Cambridge. Prof. Taylor possesses that unusual combination of power of detailed mathematical analysis coupled with an ability to design and carry out difficult experiments. He has been specially interested in studying the modes of deformation of single crystals when subjected to uniform strain. The ordinary engineering tests applied to a specimen of metal merely give the average stress over a large number of crystal grains. The discovery of methods of producing single crystals of metals has made it possible for the first time to know the direction and magnitude of the stress throughout the crystal. Prof. Taylor and his co-workers have now determined the relationship between stress, strain and crystal axes for aluminium, iron and some other metals, with most interesting and important results. This work has been extended by other investigators at home and abroad, and to include cases where the stress is alternating.

I can only refer in passing to his continued interest in problems of hydrodynamics, where he has made calculations leading to predictions concerning fluid motion and the behaviour of bodies immersed in fluids. These have been verified by simple experiments shown before our Society. Recently he has turned his attention to the effect of compressibility on the flow of air past bodies moving at high speeds. This problem is now acquiring great importance in aeronautics owing to the rapidly increasing speed of aircraft, but difficulties of mathematical analysis have so far prevented more than very limited advances towards a dynamical theory. Prof. Taylor has now invented a machine, a kind of mechanical mathematician, by means of which problems of flow can be solved, which have so far defeated ordinary human mathematicians. He is now applying this machine to problems of practical importance in aeronautics.

Prof. O. W. Richardson, who was appointed third Yarrow Professor on August 1, 1924, continued to work in the laboratory of King’s College, London. Like Prof. G. I. Taylor, he is equally at home in the theoretical and experimental side of physics. His main work in the last few years has been connected
with the elucidation of the complicated spectrum of the hydrogen molecule. While the types of vibration of the hydrogen atom are comparatively simple and well understood, very little progress had been made in deciphering the spectrum of the molecule, which shows several thousand bands. The interpretation of this spectrum, which is obviously of great importance to the study of molecular structure, presents peculiar difficulties. These have been largely overcome, and Prof. Richardson has taken a large part in this successful work. The results have been interpreted in terms of the wave-mechanics, and the values obtained for the moment of inertia of the molecule, its ionisation potential and heat of dissociation, fit in well with other observational data. The peculiar alternating intensity of the band spectra appears to show that the hydrogen nucleus has a moment of momentum, like the electron.

In addition to a number of papers on this subject Prof. Richardson, in collaboration with his research students, has continued his important investigations in thermionics, ionisation potentials and X-rays; nor must I omit mention of his excursions into the field of theoretical physics, where he has considered the application of the new mechanics to the theory of the extraction of electrons from a cold conductor by an electric field, and, in conjunction with Mr. Flint, to other problems of theoretical interest.

The first Foulerton Professor, the late Prof. E. H. Starling, was appointed in 1922, and I had occasion last year, in recording his death, to refer to his distinguished record of research during his tenure of the chair. The second Foulerton Professor, Dr. Archibald Vivian Hill, was appointed less than three years ago, in January, 1926. Since then he has carried out an important series of investigations on the energy changes and physico-chemical processes involved in the measurable vital activities of muscle and nerve. He has measured, for instance, with specially devised apparatus of extreme delicacy, the minute quantity of heat liberated in the passage of a wave of excitation along a nerve, and also the different factors concerned in the efficient muscular activity of man, as exhibited in the running of trained athletes. It is significant of the wide interest in these researches, to which his Foulerton Professorship has enabled Dr. Hill to devote his whole time, that they have been published, largely in our own 'Proceedings,' under the names of some sixteen investigators, who have come to work with him from seven different countries.

The Council have recently decided to fill the other Foulerton chair, vacant since the death of Prof. Starling, and I am able to make this first announcement of the appointment thereto of Dr. Edgar Douglas Adrian, a Fellow of our
Society and of Trinity College, Cambridge, and hitherto Lecturer in Physiology in that University. Dr. Adrian has already a distinguished record as an investigator, especially in the physiology of the nervous system. In recent years, with the aid of apparatus using the modern means of electrical amplification, he has been engaged in recording and analysing the minute changes transmitted, from an excited peripheral sense-organ, along the conducting system of the nerves—changes which, on arrival at a nerve-centre in the brain of a conscious being, would result in one or another form of sensation. In this, or in other important fields of investigation, we may wish Dr. Adrian a long and fruitful use of that greater freedom for research which our Royal Society Professorships afford. Dr. Adrian will for the present continue his researches in the Physiology Laboratory, Cambridge.

In my address last year, I referred to recent advances in the production of very high voltages for technical purposes, and the application of these voltages to highly exhausted tubes in order to obtain a copious supply of high-speed electrons and atoms and high-frequency radiation. It is of interest to note how rapidly in recent years our ideas have widened as to the possibilities of production of very high-frequency radiation of the X-ray type, both by artificial and natural processes.

In my address this afternoon, I shall briefly consider the present state of our experimental knowledge on this subject, and the various directions of attack by which we may hope to get further information. On the quantum theory, the energy associated with a quantum of radiation of frequency $\nu$ is given by $h\nu$, where $h$ is the well-known constant of Planck. When swift electrons impinge on matter, radiation of an X-ray type is generated over a wide range of frequencies, and it has been verified experimentally that the maximum frequency of the radiation obtainable in this way is limited by the relation $E = hv$, where $E$ is the energy of motion of the electron, a result in accordance with energy considerations.

For purposes of discussion, it is very convenient to express the energy of a quantum not in ergs but in terms of a potential difference in volts, through which an electron must fall to acquire an equal energy. Expressed in this way, the energy of a quantum of green light corresponds to 2 electron-volts, or 2 volts for brevity. Before the advent of X-rays, the highest frequencies examined were confined to the ultra-violet part of the light spectrum, corresponding to less than 10 volts. Following the discovery of X-rays and the application of methods for determining their frequency, we have been enabled
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to study radiations over a wide range of individual energy, varying from a few hundred volts to 300,000 volts or more. By the use of special gratings and other methods, the gap in frequency between ordinary ultra-violet light and soft X-rays has been bridged in the last few years. There appears to be no limit to the maximum frequency that can be obtained by the bombardment of matter with electrons, except the practical difficulty of obtaining streams of the requisite high-velocity electrons. In some recent experiments in the Institute of Technology, Pasadena, about 1 million volts has been successfully applied for a short time to a suitably designed X-ray tube. It is stated that the X-rays obtained were of such intensity and penetrating power that they could easily be observed by the luminosity on a phosphorescent screen 100 feet away.

So far our experiments in this direction have been limited to about 1 million volts, and we have not yet been able to produce X-rays in the laboratory of penetrating power equal to that shown by the gamma-rays spontaneously emitted by radioactive bodies. The highest frequency observed in their transformations corresponds to between 3 and 4 million volts. Some recent experiments indicate that the gamma-rays which accompany the weak radioactivity of potassium are of still greater penetrating power than the rays from radium, but no definite estimate of the maximum frequency has so far been made.

There is, in addition, another general method of estimating the frequency of radiation that may arise in certain fundamental atomic processes of a simple type. According to modern views energy and mass are closely connected, and the relation between the energy \( E \) resident in a mass \( m \) is given by the well-known equation of Einstein \( E = mc^2 \), where \( c \) is the velocity of light. According to this view, if any system decreases in mass by internal rearrangement, the total energy lost in the process is given by the product of the change of mass multiplied by \( c^2 \). If this energy is emitted in the form of a radiation of one definite frequency \( \nu \), then \( h\nu = c^2 dm \), where \( dm \) is the accompanying change of mass of the system. On account of the very small change of mass even for a large emission of energy, it is difficult to give a direct experimental proof of this relation, but there seems to be little doubt of its general validity. Even for the radioactive bodies, which in their successive transformations spontaneously emit a very large amount of energy per atom, in the form of alpha-, beta- and gamma-rays, the effect to be expected is small and difficult to measure. The atom of uranium, of mass about 238, after successive transformations involving the loss of eight alpha-particles changes into an isotope of lead, of mass about 206.
It is to be anticipated, that, if the methods of positive ray analysis could be applied to these elements, the difference between the atomic masses of uranium and the resulting lead would include not only the mass of 8 helium nuclei in the free state, but also about 0.05 unit of atomic mass, corresponding to the total emission of energy of about 46 million electron-volts per disintegrating atom of uranium. This difference—about 1 in 4,000—should be just detectable by the methods employed by Aston in his study of isotopes. Similarly the change of mass in each transformation can be deduced if the energy released during the process is known experimentally.

We shall now consider the application of these ideas to certain nuclear processes. It is now generally accepted that the nuclei of all the elements are composed of protons (hydrogen nuclei) and electrons. While it is, of course, difficult to give a definite proof of this hypothesis, we know that it is strongly supported by the work of Aston on the atomic masses of the isotopes of the elements, and by the experiments on the liberation of protons from certain light elements when bombarded by swift alpha-particles. It is generally supposed that the helium nucleus is composed of a close combination of four protons and two electrons. The mass of the helium atom is $4 \cdot 00216$ ($O = 16$), while the mass of four hydrogen atoms in the free state is $4 \times 1 \cdot 0078$. There is in consequence a loss of mass of 0.029 units in the formation of the helium atom. This indicates a loss of energy of 27 million electron-volts in the process of building a helium nucleus from free protons and electrons. If it be possible to imagine that in some way this energy is emitted catastrophically, in a single quantum of radiation, the energy of the quantum would correspond to 27 million volts. The energy emitted per atom is thus very large, and it has been suggested by Eddington and others that the formation of helium from hydrogen nuclei and electrons may be one of the sources of the energy radiated from the stars.

In a similar way the total energy emitted during the formation of any atom of known mass from free protons and electrons may be estimated. Since the proton in a free state has a mass 1.0073, and a mass about 1.000 in the average nuclear combination, the energy released per proton is about 7 million volts. For example the atomic weight of the most abundant isotope of mercury (atomic number 80) is 200.016, and this presumably contains 200 protons, of mass nearly unity, and 120 electrons. Disregarding the small mass due to the electrons, we may conclude that the total energy emitted during the formation of a mercury atom from free protons and electrons is about 1400 million electron-volts.
When we consider the extreme complication of such a heavy nucleus and the number of its component parts, it is difficult to believe that this emission of energy can take place in one single catastrophic act. It is so much more likely that the energy is emitted in a step by step process during the organisation of the nucleus. Except for light atoms, where the nuclear structure is simple, it is to be expected that the radiation of energy from all complex nuclei would occur in successive stages.

On the other hand, there is one possibility to consider, which was first put forward by Jeans to account for the long lives of the hot stars. He supposes that even the protons and electrons are not indestructible, but may under unknown conditions be transformed into radiation. The total internal energy of the electron is about 500,000 volts, but of the proton 1,840 times greater, or about 940 million volts. If we suppose the proton and electron to disappear together in the form of radiation, there must be an enormous liberation of energy. If this energy be emitted in a single quantum, we should expect to obtain a gamma-radiation corresponding to about 940 million volts. Such an hypothesis is admittedly of a very speculative nature and may be very difficult of direct proof or disproof.

Apart from the radioactive bodies, we have no definite experimental evidence of the emission of penetrating radiations, either in the formation of atoms or destruction of protons, and it may be that the processes considered do not take place under the conditions of our experiments on the earth. On the other hand, the long life of the hot stars indicated by general astronomical evidence does seem to demand some such process or processes, in which the liberation of energy is enormous compared with the mass involved.

It is thus of very great interest to examine whether any direct experimental evidence can be obtained of the existence of such extraordinarily energetic gamma-rays. This interest is heightened by the experiments in recent years which have shown the existence of an extremely penetrating type of radiation, sometimes called the "cosmic" rays, in our atmosphere—a radiation much more penetrating than the gamma-rays from the radioactive bodies. This radiation has been detected and measured by the small ionisation produced in a closed electroscope. The initial observations were made by Hess and by Kolhörster, and we owe much to the admirable experiments of Millikan and Cameron, who have carefully examined the absorption of this radiation by the water of mountain lakes, which are practically devoid of ordinary radioactive matter.

It is clear from these experiments that the radiation is complex in character,
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and that there are present radiations which are able to pass through 17 metres of water for a reduction of intensity to one-half value. It is natural to suppose that this radiation is of a gamma-ray type, but it should be borne in mind that the effects so far observed would be equally explicable if the radiations consisted not of high-frequency gamma-rays, but of high-energy electrons entering our atmosphere.

Assuming, however, that the radiation is of the gamma-ray type, it is necessary to consider the factors that determine the absorption of such a radiation by matter. During the past 20 years, the problem of the nature on the absorption of X-rays and gamma-rays by matter has been the subject of detailed investigations, and there is now a general consensus of opinion on the main features of the processes involved. In the case of the heavier elements, the absorption of ordinary X-rays is mainly due to the interaction between the radiation and the electrons in the atom, whereby the energy of the quantum of radiation is transferred to the electron. This is generally known as the "photoelectric" effect. In addition there is a relatively small loss of energy due to the scattering of the incident radiation by the electrons; but in general, except for very high-frequency X-rays and light elements, the absorption due to the photoelectric effect predominates. The case is quite different when we deal with penetrating gamma-rays, where the loss of energy due to the process of scattering becomes relatively much more important, and for radiation of energy of the order of 100 million volts almost completely governs the absorption.

The main features of this scattering, known as the Compton effect, are now well understood. There is an occasional interaction between the quantum of radiation and the electron in an atom, whereby the radiation is scattered and the electron set in motion. The scattered radiation is always of lower frequency than the incident radiation, the difference depending on the angle of scattering. In this type of encounter between radiation and an electron, both momentum and energy are conserved, and consequently the energy given to the electron depends on the nature of the encounter, and thus on the angle of scattering of the radiation. The essential correctness of this theory has been verified by several distinct methods.

When a pure radiation of definite frequency is passed through matter, there always remains some transmitted radiation which has not been transformed, but mixed with it are degraded radiations of much lower frequency and swift electrons set in motion by the process of scattering. The ionisation observed in a closed vessel is probably mainly due to the electrons liberated by scattering in the medium and the walls of the containing vessel.
Assuming that the laws of the Compton process of scattering are valid for high-frequency radiation, there still remains the difficulty of estimating the probability of such scattering encounters, for on this probability depends the actual magnitude of the absorption coefficient. Different methods of calculating this probability have been given by A. H. Compton, Dirac, and recently by Klein and Nishina. The theory of Compton is based mainly on classical analogies, and that of Dirac on the earlier quantum mechanics. Recently the problem has been attacked again by Klein and Nishina (‘Nature,’ Sept. 15, 1928), using the later relativistic form of wave-mechanics formulated by Dirac. The calculated absorption coefficients for high-frequency radiations differ materially from one another on these three theories, and in particular the theory of Klein and Nishina gives a greater absorption coefficient for a given high-frequency radiation. For radiations of individual energy more than 100 million volts, the coefficient is about five times greater than that given by the formula of Dirac.

Unfortunately the experimental evidence available from a study of the absorption of the most penetrating gamma-rays from radioactive bodies is not complete enough to give a definite test of the validity of these theories. However, Mr. Gray, of the Cavendish Laboratory, who has made a careful examination of existing data on the absorption of gamma-rays, informs me that the evidence as a whole is more in accord with the theory of Klein and Nishina than with the earlier theories of Compton and Dirac. It is evident, however, that in view of the importance of the question, a careful determination is required of the absorption and scattering of gamma-rays, of as definite frequency as possible, in order to distinguish between the various theories.

It is of interest to note that the absorption coefficient of the most penetrating type of radiation, deduced by Millikan and Cameron from their experiments, is in excellent accord with that to be expected on the Klein-Nishina theory for a quantum of energy 940 million volts—the energy demanded for the transformation of the internal energy of the proton into radiation. Although this agreement is suggestive, our theories of absorption are at present too uncertain to place much weight upon it. Even if subsequent experiment should prove the correctness of an absorption formula within a certain range of frequency corresponding to the gamma-rays there would still be the need of extrapolating the formula over a very wide range, say from quantum energies of 3 million volts to 1,000 million volts, to include the ultra-penetrating rays observed in our atmosphere.

In addition there are a number of new factors which may have to be taken
into consideration when we are dealing with the passage of very high-frequency radiation through matter. In the ordinary theories, the scattering of the radiation is supposed to be confined to the extra-nuclear electrons, but if we are dealing with a quantum of energy corresponding to the order of 100 million volts, it is not unlikely that the nuclear electrons may be effective in scattering as well as the outer electrons. Such an effect is to be expected if the energy of the quantum is large compared with the energy required to release an electron from the nucleus. In addition there is always the possibility, and even the probability, that such energetic radiations or the swift electrons liberated by them may be able occasionally to disintegrate the nucleus of the atom in their path.

For all these reasons, it is evident that much more information is required before we can draw any but tentative conclusions as to the nature of the penetrating radiations in our atmosphere. So far, experiments have been mainly confined to measuring the ionisation produced in a sealed electroscope. Further experiments are required, which will give us definite indication of the energy of the swift electrons present in the atmosphere, for this will give us valuable information on the maximum frequency of the radiation present, quite independently of the exact accuracy of our theories of absorption.

Continued observations made in a Wilson expansion chamber should throw much light on the nature of the particles which produce the ionisation in a closed vessel, and with the addition of a magnetic field of sufficient intensity the curvature of the tracks of beta-rays should enable us to determine their individual energy. Experiments of an analogous kind have already been made with an expansion chamber by Skobelzyn, in order to determine the relative intensities of the main gamma-rays emitted by radium C. In the course of these experiments he has observed on several occasions the trails of very energetic beta-particles, probably arising from the ultra-penetrating radiation in our atmosphere.

During the present year Prof. Hans Geiger has developed a modified form of beta-ray counter, which records each beta-particle entering a vessel of considerable volume in any direction. This new method is so delicate that it may prove very useful in counting and even recording the number of beta-particles produced by the penetrating radiation. While it is to be hoped that in the years to come we may have available for study in our laboratories swifter beta-rays and higher-frequency radiation than we have to-day, we can hardly hope in the near future to produce artificially radiations, atoms and electrons.
which have an individual energy of the order of 100 million to 1000 million volts, such as are present in our atmosphere.

It is thus of great interest and importance to use every promising method of attack to throw light on the nature and origin of these penetrating radiations and the effects arising in their transmission through matter. The magnitude of the effects to be observed is small and not easy to measure with accuracy; but with the ever-increasing delicacy of methods of attack we may hope to gain much further information. The study of these extraordinarily penetrating radiations is not only of great interest in itself, but also for its promise of throwing new light on fundamental processes in our universe connected with the building up and destruction of atoms. It may take many years of faithful experiment before the evidence is sufficient to test the correctness of the numerous interesting speculations that have been advanced to account for the origin and nature of these radiations.

We now pass to the presentation of the medals.

The Copley Medal is awarded to Sir Charles Parsons, O.M., F.R.S.

In the world of mechanical engineering the genius of Charles Parsons has opened up a new era. He has originated and developed a new type of thermal engine entirely flexible and adaptable, and capable of high efficiency, combined with concentration of power never even imagined before.

By continuous practical effort for the past 45 years, aided by remarkable mathematical insight acquired in his University days, he has perfected the parallel-flow compound steam turbine, and has applied it successfully to electric generation and to marine propulsion, both attaining to an unprecedented scale. In this progress there have been involved great ingenuity in practical design and careful research into the dynamics of the flow of steam between fixed and moving blades, and the scientific determination of the best proportions for the successive stages of expansion and the degrees of superheating. The result has been that while the utilisation of heat in the best triple-expansion reciprocating steam engine amounts to 17 per cent. of the whole, the Parson's large central station turbines now convert 25 per cent. into mechanical power, and in still larger turbines 28 per cent. is anticipated.

The first steam turbine of 4 kilowatts was used in 1885 for electric lighting. This was followed by the development of turbines of increasing power, reaching 5,000 kilowatts in 1910. At present turbines of 20,000 and 30,000 kilowatts are in operation.

The application to marine propulsion was signalised in 1897 by the appearance
of the "Turbinia," a small experimental craft of 200 tons, developing the extraordinary speed of 33 knots. Large turbine-driven destroyers for the Navy rapidly followed. In 1904 the cruiser "Amethyst," of 3,000 tons, was propelled by Parsons turbines of 14,000 h.p., with success so conspicuous that all new warships of all classes were fitted with steam turbines, so that by 1912 the Royal Navy had 7 million horse-power of Parsons turbines in operation. In the merchant navy progress was equally rapid. The first turbine vessel was the Cunard liner "Carmania," and now all large high-speed liners, such as the "Aquitania," are turbine-driven.

During this remarkable development numerous problems arose, urgently demanding a solution, involving a precise study of jet velocities, leakage, turbulent flow and vacuum augmenters. The phenomena involving cavitation of screw propellers opened up new fields, of abstract as well as practical interest.

Naturally other eminent inventors have taken a share in this progress, but they would doubtless all concur that Sir Charles Parsons has been greater in the scientific development of thermal power produced by steam than any engineer since James Watt.

A recent side-product of Sir Charles Parsons' activities, here stimulated by heredity, has been the revival of the British scientific industry, once conspicuous, of optical glass and telescopic construction, while some of his hours of relaxation have been spent in the strenuous endeavour to crystallise carbon into diamonds by catastrophic processes.

The Rumford Medal is awarded to Prof. Friedrich Paschen.

Prof. Paschen is especially distinguished for his important contributions to spectroscopy. He early acquired remarkable skill in the investigation of infra-red radiation and made valuable determinations of the distribution of energy in the spectrum of a black body, giving the first experimental proof of the law that the frequency of maximum energy is proportional to the absolute temperature. He afterwards made numerous observations of the infra-red emission spectra of various elements, which were of fundamental importance for the development of our knowledge of series in spectra, and subsequently for the theory of spectra in relation to atomic structure.

Prof. Paschen has also contributed in a notable degree to the precise measurement and series classification of spectrum lines in general. His masterly analysis of the highly complicated spectrum of neon affords an admirable example of his insight and skill. His work on the spectrum of doubly-ionised
aluminium also stands out conspicuously as giving the first proof of Bohr's deduction that the series in such a spectrum should be characterised by a constant nine times greater than the Rydberg constant which is applicable to the spectra of neutral atoms. Another striking contribution was made by his extremely delicate observations of the fine structure of the lines of ionised helium, which proved to be in close agreement with Sommerfeld's theory, and led to one of the most trustworthy estimates of the mass of an electron. Prof. Paschen has also long been one of the foremost workers on the Zeeman effect, and the results which he has obtained, including the discovery of the well-known Paschen-Back effect, have been invaluable for theoretical discussions.

In all his investigations Prof. Paschen has shown extraordinary skill in the design and manipulation of apparatus, and the whole of his work is characterised by an obvious striving for the greatest attainable precision.

A Royal Medal is awarded to Prof. Arthur Stanley Eddington, F.R.S.

The contributions to knowledge of Prof. Eddington within the past ten years have been mainly in connection with the internal constitution of stars and with the generalised theory of relativity.

By an examination of the conditions of equilibrium of a typical giant star he showed that these were more easily satisfied when account was taken of radiation pressure. His results were somewhat modified when the extent of the ionisation at the high temperature in the interior of a star was pointed out by Jeans and Newall. He formulated a complete theory of the internal structure of a star, assumed to be a non-rotating whirl of atoms and electrons, with radiation gradually forcing its way to the surface; further, he pointed out that the masses of stars, which are found by observation not to vary greatly, ranged about the point where radiation pressure balances gravitation. Later, Eddington obtained a theoretical relation between the mass and absolute luminosity of giant stars. Taking Capella as a starting point, he found agreement with his theoretical results not only among giant stars but also among dwarfs, which had hitherto been supposed to have a liquid or solid nucleus; and he explained this result as due to the closer packing that is possible when atoms are stripped of their outer electrons. The companion of Sirius is the extreme example of this condition.

Eddington has also worked out a mathematical theory of Cepheid variables on the assumption that they are oscillating radially. These extremely bright stars play a fundamental part in several astronomical questions, and
it is of the greatest importance that their physical condition should be investigated.

In connection with the theory of relativity, he conducted in 1919 one of the two eclipse expeditions which verified the deflection of light rays from stars near the sun. He also developed the theory, to a certain extent on the philosophical side, but considerably on the analytical side, especially with regard to the electromagnetic and gravitational fields.

Prof. Eddington has attained international fame by the brilliance of his contributions to astronomical science.

A Royal Medal is awarded to Dr. Robert Broom, F.R.S.

During the course of thirty-three years’ search in Australia and South Africa Dr. Broom has made a very large number of important discoveries in vertebrate palaeontology, embryology and morphology that shed new light upon the problems of the origin of mammals, lizards, crocodiles and birds, the significance of which has been interpreted in his Croonian Lecture (‘Phil. Trans.,’ 1914) and 285 memoirs. His researches represent the most significant contribution made by any one investigator to the determination of the relationships of the main groups of vertebrate animals, and to the definition and solution of the problems involved in the evolution of the higher groups.

At the time when he first went to South Africa, 35 genera and 65 species of fossil reptiles had been identified in the Karoo beds; very little was known of their structure, and the classification was in a state of apparently hopeless confusion. He tripled the number of known genera and quadrupled the number of species. He worked out the details of the anatomy of most of the groups, and established an orderly classification which has now been universally accepted by the scientific world. He is now actively engaged in the investigation of some of the outstanding problems involved in the evolution of mammals and birds.

The Davy Medal is awarded to Prof. Frederick George Donnan, F.R.S.

Prof. Donnan is, like his master van’t Hoff, a man of ideas. Early in his scientific career he wrote on the nature of soap emulsions and on the theory of capillarity and colloidal solutions. Being thus engaged with problems of surface activity, and being also intimately conversant with the electrolytic dissociation hypothesis, he put two and two together and made thereby not four, but a multitude—the mark of original scientific genius. His theory of membrane equilibrium and membrane potential is an
achievement of the first rank, and has been the starting-point of numerous studies not only in the domain of pure chemistry, but more especially in biochemistry, where the conditions for displaying the phenomena he predicted are often encountered. Physiological chemists have seized on his idea and utilised it in many fields of investigation.

Donnan’s researches on surface tension and adsorption at liquid-liquid interfaces have led to results of the greatest interest, and his verification by means of nonyl acid of the Gibbs’ adsorption formula is a most brilliant experimental conception. A by-product of Donnan’s activities during the War is a theory of the action of gas-scrubbers, based on the velocity of absorption of gases by liquids.

Not only has Donnan by his own researches done the highest service to his science—he has founded a school of physical chemistry, whence issues a steady flow of admirable researches, which he has suggested, and of young physical chemists, whom he has inspired.

The Darwin Medal is awarded to Dr. Leonard Cockayne, F.R.S.

The award of a Darwin medal to Dr. Cockayne is fitting because of the distinction of his work in fields in which Charles Darwin himself laboured. That distinction has been gained by the use of the Darwinian method: a true naturalist, Dr. Cockayne has waited patiently upon facts before drawing conclusions. For over thirty years he has made it his task to deepen and widen our knowledge of New Zealand botany in the broadest sense. He has not only worked himself with outstanding ability and untiring energy; he has imparted his enthusiasm to a school of younger colleagues, eager to advance his labours on the lines he has laid down. The excellence of Dr. Cockayne’s work, from the ecological point of view, is recognised by botanists in every country and has made him one of the foremost living students of plant-association; the taxonomic studies rendered necessary by his ecological results have led to those remarkable discoveries of natural hybrids in New Zealand that have won for him a world-wide reputation, and have made on modern thought an impression akin to that produced by the results of Mr. Darwin’s studies of plants under domestication. Dr. Cockayne’s researches have had, on sylvicultural and agricultural procedure, a practical bearing which has been appreciated by, and has influenced the policy of, New Zealand statesmen.

The combination of philosophic outlook and lucid exposition that marks his contributions to natural knowledge, may also explain the invitation, accepted by Dr. Cockayne, to contribute a monograph on the flora of New Zealand to
"Die Vegetation der Erde," edited by Dr. Engler—a compliment no other British botanist has been paid. It does at least account for the remarkable local effect of Dr. Cockayne's book 'New Zealand Plants and their Story.' An eminent Continental ecologist, well acquainted with the philosophic importance of Dr. Cockayne's labours, has said "it is wonderful how Cockayne has succeeded in interesting the population of a new country in botany."

The Sylvester Medal is awarded to Prof. William Henry Young, F.R.S.

Dr. W. H. Young has taken a very prominent part in the development of the modern theory of functions of real variables, and in its application to the theory of Fourier's and other series. During the present century he has published an immense number of memoirs and notes dealing with this branch of mathematics and containing important advances in the subject; many of these are strikingly original, and even the smaller of them throw light on some particular points. His earlier work dealt chiefly with the theory of sets of points, and contains important developments on the lines laid down by G. Cantor and Harnack. He soon proceeded to apply this theory in the integral calculus, and he obtained a general definition of the integral which is essentially equivalent, although somewhat less simple in form, to that given, about the same time, by H. Lebesgue, which latter has become a corner stone of modern analysis. Much of Dr. Young's work has also proved to be a starting point for further investigations by other mathematicians. Instances of this feature in his work are his generalisations of the theorems of Parseval and Riesz-Fischer in the theory of Fourier's series; his investigations on the properties of Fourier's constants and of the series conjugate to Fourier's series. By means of his conception of restricted Fourier's series he was enabled to devise a method by which conditions of convergence, summability, &c., known to hold good for Fourier's series, could be carried over to series of Legendre's and Bessel's functions. Many other investigations in the domain of integration and Fourier's series, too numerous to be mentioned in detail, have contributed notably to our present knowledge in this department of analysis.

The Hughes Medal is awarded to M. Le Duc de Broglie.

Maurice François César, Duc de Broglie, member of the Academy of Sciences, is distinguished especially for his pioneer researches on X-ray spectra and secondary beta-rays. He was one of the first to obtain the complete emission
spectrum of X-rays and to study X-ray absorption spectra, while his work on
the magnetic spectrum of the beta-rays, arising from the passage of X-rays
through matter, has proved of great importance. He founded in Paris a private
laboratory directed by him, which is devoted to researches on X-rays and
allied subjects. An experimenter of unusual skill, he and his co-workers have
made important contributions to knowledge in many fields.

The Respiratory Quotient of the Excess Metabolism of Exercise.

By C. H. Best (Toronto), K. Furusawa (London), and J. H. Ridout (Toronto).

(Communicated by Prof. A. V. Hill, F.R.S.—Received October 4, 1928.)

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INTRODUCTION.

In recent years much controversy has been aroused as to whether the body
uses carbohydrate alone in order to provide energy for the recovery process
from muscular exercise, or whether the other foodstuffs can be used directly
for this purpose. One of us (Furusawa), from a study of the respiratory
quotient of the excess metabolism, concluded that carbohydrate is alone
responsible for supplying the energy for short-lived exercise, while other food-
stuffs must be converted into carbohydrate before they are so used by
muscle (1). This conclusion has been contested by several workers and no
means of reconciling the different observations was apparent.

A new factor, however, has recently been discovered, in the intensity of
the exercise undertaken. This may help to explain the discordant results of
the various workers on this subject. During the spring of 1927 Furusawa,
Hill and Parkinson (2) made a large number of observations on the gaseous
exchange of “sprint running,” in order to determine the “mechanical
efficiency” of this form of very severe exercise. Incidentally the results
revealed a most remarkable phenomenon in respect of the respiratory quotient
of the excess metabolism resulting from such exercise. Briefly stated, the
excess respiratory quotient showed a wide divergence from unity (1.2 to