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Professor George C. de Hevesy

Professor George C. de Hevesy, of the Institute for Organic Chemistry and Biochemistry, at the University of Stockholm, Sweden, is to be this year's Nuclear Pioneer Lecturer. Although he is known first of all for his numerous pioneering investigations and his eminence as a teacher, he very properly is a first-hand reporter and historian of some of the most momentous events in the history of science.

Professor de Hevesy was born in Budapest August 1, 1885. He earned the doctoral degree at the University of Freiburg in 1908. He then went to Zurich for postgraduate work in physical chemistry. He was one of twenty in the audience attending Einstein's inaugural lecture as Associate Professor of Theoretical Physics. In 1911, to prepare for investigations suggested by Haber, he went to Rutherford's Laboratory in Manchester to become familiar with techniques for studying the conductivity of electricity in gases. During the years 1911-1914, he was associated with the discovery of the atomic nucleus, the use of a forerunner of Geiger's Beta Counter for detecting alpha particles, the setting up of the first X-ray spectograph by Moseley, and the discovery of cosmic rays by Hess. He visited Madame Curie in her laboratory many times after he began work with Radium D in 1912.

Professor de Hevesy's most notable investigations started with his failure to separate Radium D (Pb^{210}) from large amounts of radioactive lead chloride, at Lord Rutherford's request. After over a year of exhaustive disheartening effort, he decided to try and make the best of the situation and reverse the problem. In 1913, along with F. A. Paneth, he added pure Radium D to a known amount of lead salt so as to follow the paths of lead atoms "by using Radium D . . . as an indicator." In 1923, he used the tracer principles for the first time in a biological problem: Thorium B (Pb^{212}) to study the absorption and translocation of lead nitrate in bean plants. He was the first to use stable isotopes in clinical isotope dilution studies when in 1934 he used deuterium oxide to measure body water and its turnover. Following the discovery of artificial radioactivity in 1935, he initiated the use of artificial radioisotopes (P^{32}) as tracers in biological problems. In 1936 he described the principles of neutron activation analysis and published the first results using this technique two years later. In 1942 he described the first *in vitro* radioisotopic labeling of erythrocytes with its clinical use for measuring blood volume. His investigations have also included the fields of geochemistry, biochemistry, medicine, and radiobiology. His work has continued undiminished with his output of scientific papers being numerous and significant.

Professor de Hevesy created the tracer concept, established the classical principles of its use, and made the pioneering application of the technique, first with natural radioisotopes, then stable isotopes, and finally, artificial radioisotopes. It seems entirely justified to equate the importance of the isotopic tracer technique with that of the microscope. He and others using isotopic tracer techniques have revolutionized concepts of the metabolism of living systems.

As would be expected, honors have come to him from throughout the world. He received the Nobel Prize in Chemistry in 1943 and the second Atoms for Peace Award in 1959. He has been awarded four honorary degrees.

Professor de Hevesy has been an honorary member of the Society of Nuclear Medicine since 1959. He has expressed his pleasure in joining with us on this occasion to honor the memory of Madame Curie and her contemporaries.

Marie Curie and Her Contemporaries

THE BECQUEREL-CURIE MEMORIAL LECTURE[1]

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MARIA SKLODOWSKA'S YOUTH

Marie Curie was Polish born, her maiden name was Sklodowska. Her father was a high school teacher, an able physicist; her mother was a teacher as well. They were keen patriots and most unhappy about the sad fate of their fatherland. Poland was under the heel of tsarist Russia. Supervisors were sent from Moscow to verify if the school children were brought up as Russian patriots and were taught extreme loyalty towards the Tsar, his family, and the Russian Government. Father Sklodowska got into difficulties with the supervisors, difficulties which further contributed to Marie Sklodowska's hatred towards the tsarist regime. The hatred was so deeply rooted that Maria and her schoolmates cheered the news of the murder of the Tsar Nicolaus the Second.

She was a hard worker with a sharp brain, the best scholar of her class. Finishing highschool not yet 18 years old she became a governess in the house of a well-to-do family, trying to make some money that would enable her to study outside Poland. Both Germany and Austria were enemy countries occupying Polish territory. She chose France, a free country, where science and art had a high standing.

Maria Sklodowska left for Paris and intended to return to Warsaw after finishing her studies. The goal at which she aimed ardently was to work for her country. She first hesitated on what to study, the choice being between sociology, literature and science. She finally decided on the last mentioned discipline.

While governess for three years she earned little money. In those days the German railways had four classes. The fourth class was much like a freight car in which just a bench was placed. Maria Sklodowska could only afford a fourth class ticket when travelling through Germany. She arrived in Paris in the fall of 1891 with a minimum of luggage.

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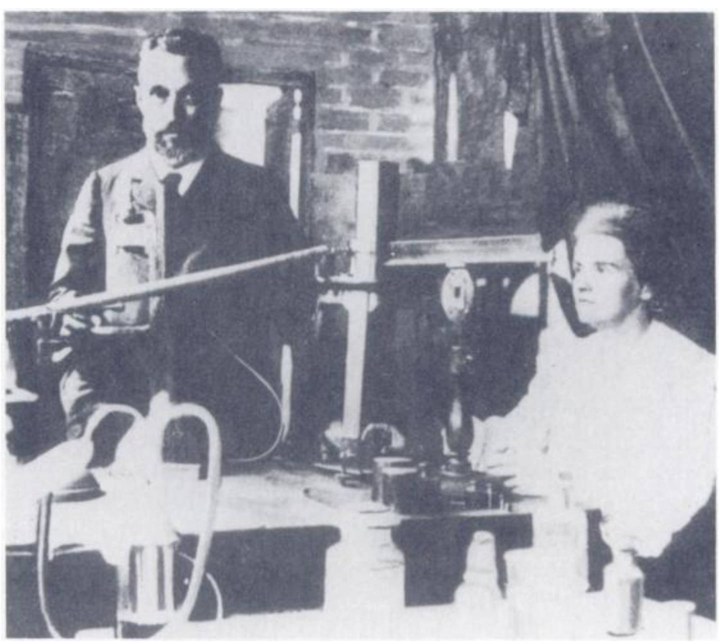
Henri Becquerel



Pierre and Marie Curie in laboratory where Radium was discovered about 1904.

STUDENT IN PARIS AND MARRIAGE

Aided by her brother-in-law, an M.D., she could rent a room on the 6th floor, below the roof of an old large apartment house. She had 3 francs a day to live on and could only afford to buy two or three sacks of coal yearly which she had to carry up to her room herself. The room was cold and she was lonely, but, as she wrote home, she could concentrate undisturbed on her studies. What little money she had she mostly invested in books; hardly any was left for food. While attending a lecture at the Sorbonne she fainted. Her brother-in-law soon found out that she was suffering from a pronounced anaemia. He was interested in finding out what she ate and looked around in her room. The kitchen utensils were unused, she lived on cherries and chocolate. He took her to his apartment for a while to bring her in a better shape.

Maria Sklodowska who attended the first lecture at the Sorbonne on the 3rd November, 1891, soon found out that her French was poor and that the teaching of physics in the Polish schools lagged much behind what was taught to French children. But she worked hard and passed her examination with the best grade.

After obtaining her degree she was given a stipend by the Society For The Promotion Of the Interest Of The French Industry. She was to compare the magnetic properties of French steel samples handed her by the famous Professor Le Chatelier. Maria Sklodowska was to carry out the investigation in the physics department of the Sorbonne which was under the direction of Professor Lipmann, a very distinguished physicist who was the first to take coloured photographs and later obtained the Nobel prize for his work.

The room available in the physics laboratory was very restricted, furthermore Professor Lipmann wished her to help him. She had to analyse minerals, catalogue his collection of rock samples, and so on. This was an unhappy state of affairs and when she met a compatriot, the physicist Kowalski, professor in the University of Neuchatel, who visited Paris, she complained about her unsatisfactory placement in Lipmann's institute. Kowalski was on friendly terms with a young but already famous physicist, Pierre Curie, and promised Maria Sklodowska to contact her with him in the hope that he might place her in his laboratory.

Pierre Curie was born in Elsasse in 1854 as the son of a medical practitioner. I did not have the privilege of meeting him. He suffered, at only 47 years of age, an untimely death. Deep in his thought, pondering about his problems, he was knocked down by a heavy horse-driven lorry in the crowded streets of Paris. But I happened to know Marie Curie quite well. I never failed to call on her when passing through Paris. I was sure to find her in her laboratory surrounded by girl assistants carrying out experiments, crystallizing, precipitating. In the twenties, when calling on her I also met her daughter Irene and her assistant Joliot who later became her son-in-law. The subject of the doctoral thesis of the latter was the electrochemistry of polonium, a problem in which a decade earlier we were much interested with my late friend Paneth. Thus we had common interests.

I recall vividly a visit, when engaged in the concentration of actinium in a lanthanum sample obtained from pitchblende, Madame Curie presented me with a specimen of actinium concentrate. I always considered this specimen as one of my most precious belongings. Each time I look at the bottle containing the sample I find it deeper and deeper coloured indicating the long span of years which have passed since I met this remarkable personality and great pioneer.

Pierre Curie was much impressed by Maria Sklodowska. She was very intelligent, had a solid knowledge of physics, was straight forward, shared his radical views on politics, which she acquired in her youth and never changed. She was a beautiful girl as well. Pierre Curie wished to marry her, but she declined. She felt as a patriot it was her duty to return to Poland and to work for her country. They then discussed the possibility for Pierre Curie to follow her to Warsaw, but finally decided that they should marry in Paris. The wedding took place on the 26th of July, 1895.

They had 300 francs monthly to live on. Not much, but more than the monthly 90 francs Maria Sklodowska had at her disposal while a student. The purchasing power of money was in those days very much greater than today and the pretensions of the scientist very much smaller.

Shortly after being married the Curies were reading periodicals one evening. Marie Curie happened to glance at a paper published in the *Comptes Rendus*, the Proceedings of the Paris Academy of Sciences, in which Henry Becquerel announced the discovery of a radiation emitted by uranium. Before picturing the impression which the reading of this paper made on Marie Curie, I wish to be permitted to describe the happenings which preceded Becquerel's discovery.

HENRY BECQUEREL'S DISCOVERY

It was the progress made in producing high vacua which made it possible to carry out experiments of the type done by Crookes, Hittorf, J. J. Thomson, Lenard, and others. These experiments led to the discovery of the electron and the elucidation of its properties. It was his interest in this type of problems which induced Röentgen to study electric discharge through a vacuum tube. The phosphorescence of a screen covered with barium platinum cyanide which by chance happened to be placed in the vicinity of the vacuum tube led to the discovery of Roentgen rays.

The discovery made understandably an immense impression on his contemporaries, especially on the physicists, but on none a greater impression than on the eminent French scholar Henry Becquerel.

Becquerel was born in Paris, December 15, 1852. When 26 years old he was appointed to the Museum of the History of Natural Sciences as aid to his father, who was professor of physics in this institution. In 1892 he became successor to his father filling a chair already rendered illustrious by his father and grandfather, and earlier, by Gay-Lussac. The Becquerel family furnishes to students of heredity a most striking illustration of transmitted capacity. Their scientific activity covers nearly the whole of the nineteenth century and part of the twentieth. The phenomenon of phosphorescence which fascinated Henry Becquerel was a field in which both his father and grandfather were much interested. The news of Röentgen's discovery, the phosphorescence shown by the walls of the discharge tube and of the barium platinum cyanide screen under the effect of the newly discovered rays deeply impressed Becquerel. The idea passed his mind that possibly all substances showing the phaenomenon of phosphorescence may emit Röentgen rays.

He soon found that sun-excited uranium acted on a photographic plate protected by black paper from the effect of light. His observation made him tremendously happy. He then devised another experiment in which, between the plate and the uranium salt, he interposed a sheet of black paper and a small cross of thin copper. On bringing the apparatus into daylight the sun had gone, so it was put back into the dark cupboard and left there for another opportunity of insolation. But the sun persistently kept behind clouds for several days. Tired of waiting, Becquerel developed the plate. To his astonishment instead of a blank, as expected, the plate had darkened under the uranium as strongly as if the uranium would have been previously exposed to sunlight, the image of the copper cross shining out white against the black background.

This was the beginning of a long series of experiments which led to the discovery of the Becquerel rays in the same year (1896) in which the Röentgen rays were discovered.

DISCOVERY OF POLONIUM AND RADIUM

The reading of the paper of Becquerel deeply impressed Marie Curie and induced her to remark to her husband that she doubted that uranium should be the only element emitting the new type of rays. She added that she intended to investigate all existing elements in the search of radiating ones. With the enthusiasm and energy which characterized her, she started the next morning to initiate her studies. She took one element after the other looking for the same type of radiation as is emitted by uranium. It did not take her long to discover that thorium emits Becquerel rays.

Marie Curie then concentrated her interest on minerals containing uranium. Pitchblende, one of the first minerals investigated by her, contains about 60 per cent of this element, and as already found by Becquerel that the intensity of radiation emitted by an uranium compound is proportional to its uranium content, she expected 1 gram of pitchblende to act on her measuring instrument with the same intensity as does 0.6 gram of uranium. She was much impressed to find the intensity of radiation emitted by 1 gram of pitchblende several times that of 1 gram of uranium. It was clear to her that pitchblende must contain an unknown element many times more radioactive per unit of weight than uranium.

The result of her investigation of the radioactivity of pitchblende and also of the copper uranium phosphate mineral chalcolite, was presented to the Paris Academy of Sciences by Professor Lipmann on the 12th of April 1898, by the man in whose laboratory she felt so unhappy when faced with the task to compare the magnetic properties of steel samples; an unhappiness which resulted in her meeting Pierre Curie. The same year her study on the magnetic properties of steel samples was published as well.

The paper introduced by Marie Curie to the Paris Academy of Sciences in April 1898 in which she reported on the radioactivity of pitchblende and chalcolite was followed on the 18th of July by a joint paper of Pierre and Marie Curie announcing the discovery of polonium which they separated with bismuth from pitchblende. But the latter was, even after the removal of polonium, exhibiting a strong activity, thus must have contained another radioactive body.

Half a year later the Curies announced the discovery of the body looked for, which they precipitated with barium and called radium. Barium sulfate precipitates played a most important role in the history of radioactivity. When isolating radium this element was coprecipitated with barium; so was ThX in Rutherford and Soddy's experiments which lead to their theory of successive atomic transformations. Nuclear fission was detected by Otto Hahn by precipitating barium sulfate and demonstrating that the activity observed is due to barium.

The Curies did not doubt for a moment that they had discovered two new elements, polonium and radium. However, the French chemists were critical; they wished the elements to be isolated and their atomic weights determined before they were willing to acknowledge their discovery. Considering that 1 part of radium is found in about 5 million parts of pitchblende it was clear that an isolation of radium requires large amounts of pitchblende.

The only uranium mine in those days was that of Joachimsthal (now called Joachim) located in Bohemia, now Czechoslovakia. The mines were Austrian state property. Uranium had no great value in those days. It was mainly used in the glass industry. Uranium containing glass has a beautiful green colour. Large silver ore deposits made Joachimsthal famous. Coins minted from 1519 onwards in Central Europe and Scandinavia contained Joachimsthal silver. Being minted from Joachimsthal, silver the coins were called Thaler in Central Europe, Daler in Scandinavia and—Dollar in the United States of America. The word dollar originates thus from Joachimsthal.

The influential Austrian geologist Sues was instrumental in putting forward the request of the Curies for pitchblende to the Austrian Government which generously presented them with 10,000 kg of pitchblende.

The premises at the disposal of the Curies where they had to separate radium were very primitive, without heating and proper ventilation, but which did not prevent them from working with great enthusiasm. In 1902, only 45 months after the discovery of the new element, they succeeded in preparing 100 mg. of radium. While Pierre Curie was mainly interested in the study of the radiation emitted, Marie Curie did the chemical work.

While working on the isolation of radium they discovered the induced radioactivity and interpreted this phaenomenon as due to radium emanation "infecting" the surroundings of radium salts. They noted among other things that radium incessantly produces heat and measured exactly the heat produced.

The Curies had a modest income only, their family being enlarged, they had to fill teaching posts to earn money. Marie had to teach physics at a high school for girls. This took much of her time and energy.

It was only in 1904 that they could leave their primitive premises and move into a better laboratory in Rue Cuvier belonging to the School of Physics and Chemistry of the City of Paris, where all their work was done. It was in 1909 that Madame Curie obtained an up-to-date laboratory erected at the suggestion of the director of the Pasteur Institute, Rous, simultaneously with the erection of an institute for Curie therapy in close vicinity of the former.

BIOLOGICAL EFFECTS OF RADIUM RAYS

Two years after the discovery of radium, Giesel, a manufacturer of chemicals in Braunschweig in Germany, succeeded in preparing small amounts of radium chloride and soon Wakhoff and he found that the rays emitted by radium have a destructive action on the epidermis. The reading of papers of Wakhoff and of Giesel published in 1900 induced Pierre Curie to place a radium sample for 10 hours on his arm and to study its effect on the skin. He was most enthusiastic about the appearance of an erythema which covered a surface of about 6 sq.cm of his skin. Later a wound became visible which healed after a lapse of 4 months but not without leaving a mark behind.

Henry Becquerel reacted in a very different way. He traveled to London where he had to address the Royal Society. There was a tube containing radium chloride in his waistcoat pocket and on arriving home in Paris he discovered a wound on his chest produced by the radiation emitted by the radium sample. He was very much upset and reproached the Curies to have discovered a substance which emitted a radiation having such an unpleasant effect.

A few years later trials were made to cure lupus erythematosis and cancer with the aid of radium rays. It was uterine cervical cancer which was first treated with Curie therapy in 1905. The treatment of this type of cancer remains the chief therapeutic application of radium rays. When writing a contribution on this topic, the present author followed the statistical data on irradiation of uterine cervical cancer up to 1955. Until that date 360,000 cases were recorded and their number today cannot be much less than 500,000.

The successful medical application of radium was a source of immense satisfaction to Madame Curie. When Pierre Curie was delivering his Nobel lecture in 1903 no therapeutic results were yet obtained with radium rays, but Pierre Curie emphasized the importance of the biological effects of radioactive radiation and remarked among others that in the hands of a criminal radium could become a very dangerous substance.

THE CURIES AND BECQUEREL OBTAIN THE NOBEL PRIZE

To have obtained the Nobel prize contributed enormously to the fame of the Curies and helped them to obtain more generous support of their investigations.

They obtained jointly half of a physics prize, the other half being allotted to Henry Becquerel. In 1911 Madame Curie obtained the chemistry prize alone, thus being the only person who ever obtained two Nobel prizes.

In 1935, 24 years later, her daughter Irene—who, as a young girl, witnessed the previous handing over of the Nobel prize to her mother by the King of Sweden—and her husband Frédéric Joliot obtained the prize for their fundamental discovery of artificial radioactivity. The Curie family was thus now in possession of five Nobel medals.

One year before becoming a Nobel laureate Pierre Curie, strongly pressed by his friends, applied for a seat in the Academy of Sciences of Paris. His application was dismissed however. The Curies' fame had not yet sufficed to become a member of the Paris Academy of Sciences. He was elected in 1905 while Marie Cuire failed to become a member. She was elected a member of the Academy of Medicine in 1922.

After the tragic death of Pierre Curie his wife continued her research alone; she further purified radium, determined its atomic weight and prepared metallic radium. She also had much trouble with the production of an international radium standard.

In the earlier phase of her activities, Madame Curie had restricted laboratory facilities and had to fight economic difficulties. With increasing fame both her laboratory facilities and her personal economy improved more and more. Andrew Carnegie realized the immense importance of her work and supported her laboratory from 1907 onward.

In 1920 on the initiative of Mrs. Meloney, the women of the United States collected 100,000 dollars to enable her to purchase 1 gram of radium. The gift was handed over to her in Washington by President Harding and she was most heartily welcomed and fêted by numerous institutions during her stay in the United States.

MARIE CURIE'S AILMENTS AND DEATH

Marie Curie had a powerful adversary, this was her poor health. She was plagued by cataracts, had difficulties with her kidneys, her lungs, she felt weak for long periods and succumbed to an aplastic anaemia in 1934 in the Hills of Savoy. How far the handling of strongly radioactive substances was responsible for her ailments and death is difficult to answer. Her mother suffered from tuberculosis which may explain her lung trouble. Already in 1910 when meeting Madame Curie at the Solvay Congress in Brussels, Rutherford wrote to his wife: ". . . Madame Curie was there. She looked very wan and tired and much older than her age. She works much too hard for her health. Altogether she was a very pathetic figure." She carried out all that fabulous work in spite of being handicapped by poor health. Her life illustrates the mighty power inherent in the passion for scientific research. Mme. Curie (Rutherford wrote in his obituary note in Nature) retained her enthusiasm for science and scientific investigation throughout her life. Quiet, dignified and unassuming, she was held in high esteem and admiration by scientific men throughout the world.

BECQUEREL'S VIEW ON THE ORIGIN OF THE ENERGY OF RADIATION

Henry Becquerel was pondering on the source of the energy incessantly given off by uranium shortly after the discovery of the radiation emitted by that element. He considered several explanations arriving finally at the view put forward in an evening discourse at the Royal Institution in London on March 7, 1902, six years after making his fundamental discovery. "The origin of this energy," he said "is an enigma. On the material hypothesis it does not seem improbable to liken the phaenomenon to the emission of perfume by an odorous body; to compare the emanation to a kind of gas the particles of which are of the order of magnitude of those of the electrolytic ions; and to identify the radiation with cathode rays produced by the dislocation of these ions, giving at the same time an emission of X-rays. The dissipation of energy therefore can be associated with the disintegration of active matter." He then added: "However it explains most the facts, no accurate experiment exists which gives sanction to this hypothesis."

ATOMIC TRANSFORMATION

After the lapse of less than 10 years, in 1902 ingenious experiments were devised which proved unambiguously that we are faced in the phaenomenon of radioactivity with atomic transformation, not with a single one but a series of successive transformations, that while an almost infinitesimal fraction of uranium is transformed daily some of the transformation products of uranium, such as radium A, disappears almost quantitatively in the course of minutes. The radiations emitted represent energy released in the course of the transformation process. These results, some of the most important ones achieved in the course of the history of the natural sciences, are due to Rutherford and Soddy.

ERNEST RUTHERFORD

Rutherford was the seventh son of a farmer of very modest means living at Nelson, New Zealand. In 1935, when I delivered the Scot lectures in the University of Cambridge, I had the unique privilege to stay with Rutherford. One evening he was in high spirits and told me the history of his first experiment. When he was a little boy he was sent to fetch the cow of the family and a trunk of wood as well. He got the ingenious idea to fix the trunk to the tail of the cow, which he found to be a great help. Reaching home he noticed, however, that the trunk was gone and so was the tail of the cow—happenings which had the most unpleasant consequences for him.

Rutherford had more success with his later experiments. In the Canterbury

College of the New Zealand University he began research on the magnetic properties of iron, exposed to high frequency oscillations. He succeeded in his trials to produce electric waves in those pre-marconian days and to pick these up at a distance of a few kilometers. This very promising work was interrupted when he was awarded, in 1895, an 1851 Exhibition Science Scholarship to study under J. J. Thomson in Cambridge.

The Cavendish Laboratory where he was to work was the most famous physical laboratory in those days being engaged mainly with the study of the properties of the electron and the conduction of electricity in gases. J. J. Thomson, the director, had a remarkable instinct for knowing which were the problems most worth working on and the general nature of methods of investigation most likely to succeed.

Rutherford carried out very successful researches in these fields. When starting his work at the Cavendish Laboratory he tried to find out whether the ions produced by uranium behaved in the same manner as those produced by X-rays and ultra-violet light. He found it to be so. He quickly noticed that there were two types of rays present which he called, from the first letters of the Greek alphabet, alpha and beta rays. The α rays were cut off, or absorbed, by a stout sheet of paper, but the β rays were a hundred times as penetrating. He published his work when he was later at McGill in Montreal.

The penetrating γ rays were discovered by Villard in Paris in 1900.

In a paper published by Rutherford jointly with J. J. Thomson in 1896 the important hypothesis was put forward that the conductivity of electricity through gases produced by irradiation with Röentgen rays is due to the formation of positively and negatively charged particles.

In the Cavendish and also in the Manchester Institute the laboratory steward an able, versatile, experienced man, highly interested in the work going on and in the research workers, played quite an important role in the running of the laboratory. This was the case even in some other laboratories in those days. I worked for a short time with the great German chemist Haber who was the first to produce ammonia from nitrogen of the atmosphere by availing himself of a catalytic process, which was a very great advance. The name of Haber's laboratory steward very appropriately was Kirchenbauer (church builder). When discussing experiments to be carried out, Haber usually introduced the discussion with the words "If God and Kirchenbauer so wish we shall carry out the following experiment . . ."

To be appreciated by the laboratory steward spoke much in favour of a young physicist. J. J. Thomson's eminent laboratory steward who served later under Rutherford as well, had a great admiration for the young Rutherford and recalled, approvingly, decades after Rutherford left the Cavendish, that none of the young physicists working in this laboratory could swear as forcefully at his apparatus as did the young Rutherford.

Mainly due to the successful work carried out in the Cavendish Laboratory, Rutherford was offered, in 1908 when only 27 years old, the chair of physics in the McGill University of Montreal.

THE ALPHA RAYS

In 1902 Rutherford succeeded in deflecting α rays emitted by radium both by a magnetic and an electric field arriving at the conclusion that the mass of the α-particle was about twice that of the hydrogen atom. The proof that the α-particles consisted of charged atoms of matter projected with an enormous velocity at once threw a flood of light on radioactive processes, in particular on investigations of fundamental importance carried out simultaneously by him in collaboration with Frederic Soddy.

SUCCESSIVE ATOMIC TRANSFORMATION

In contrast to radium, thorium compounds were easily available and this fact induced Rutherford and Soddy to study the radioactivity of thorium. They dissolved thorium nitrate in water, added a small amount of barium nitrate and precipitated the barium as sulphate. Testing the radioactivity of the lattter they found it strongly active while the activity of the thorium nitrate simultaneously decreased. The daily measurement of the activity of both fractions brought out that the barium precipitate lost its activity with time while the thorium fraction recovered its original activity hand in hand with the first mentioned losses. This was, in those days, a startling observation.

Rutherford mentioned, when recalling these early days, that they moved the barium precipitate into a neighbouring room to see if the phaenomenon they observed depended on the presence of thorium in the vicinity of the barium sulphate.

It did not, however, take them long to find an explanation of their remarkable observation. Thorium is transformed into another element at an exceedingly slow rate. We are, however, not faced with a single transformation process but with a series of transformations. ThX, into which thorium is transformed, is converted by disintegration into a new element as well, not at a slow rate as is thorium, but rapidly. After the lapse of a few weeks ThX is almost fully transformed, while the thorium nitrate sample recovers its original ThX content.

THORIUM EMANATION

When passing an air stream through the ThX sample the air was found by them to be radioactive, a very short living body, thorium emanation, being formed. To prove that they discovered a gaseous element Rutherford and Soddy wished to condense it by cooling the air stream with liquid air. No liquid air was available in Montreal. They had to fetch a liquid air plant from Europe. The plant arrived and the whole personnel of the physics institute went to the harbour to fetch it in the early hours of the morning. In the late hours of the night the plant was fitted up, liquid air produced and demonstrated that the strongly radioactive air stream entering a U-shaped tube is not active any more when leaving the liquid air cooled tube—an example of Rutherford's mighty pushing power. At the same time most of his work was carried out without visible effort in a most remarkable way.

Today we read about the sequence of thorium series, of uranium series, and it all looks so simple. To establish these series required an immense ingenuity and a tremendous work carried out almost exclusively by Rutherford and his school. Beside elucidation of the series of transformation, the properties of different types of radiation were among other topics studied with great energy in Rutherford's laboratory.

Always intensely occupied with the progress of his own work, Rutherford had the patience to listen to every young man when he felt he had any reasonable idea on his mind.

COUNTING OF α-PARTICLES

The tool which Rutherford appreciated more than any other was the α-particle and it was the study of the behaviour of α-rays which led him to his greatest success.

In 1902, as already mentioned, he succeeded in deflecting α-particles from their path with the aid of a magnetic and also of an electric field, and he could conclude that the mass of the α-particle was about twice that of the hydrogen molecule. About the same time, when putting forward their theory of successive disintegration with Soddy they remarked: "The results obtained so far point to the conclusion that the beginning of the succession of chemical changes taking place in radioactive bodies is due to the emission of the α-rays, i.e. the projection of a heavy charge from the atom".

From the numerous investigations of Rutherford in which α-particles were involved one of the most outstanding ones was the counting of the scintillations and thus the number of α-particles falling on a screen of phosphorescent zinc sulfide. The number of the scintillations per second on a screen agreed with the number of α-particles impinging on it counted by the electrical method.

The electrical counting method of α-particles was worked out by Rutherford and Geiger. The latter was Rutherford's assistant for eight years. Later, when filling the chair of physics in the University of Kiel he constructed the Geiger-Müller tube for counting of β-particles. Geiger, a very able experimental physicist and congenial man, could not forsee what an immensely important role his tube would have in the development of atomic sciences and atomic industry.

THE NUCLEUS OF THE ATOM

The counting of scintillations produced on a zinc sulphide screen with the aid of a microscope was a device of extreme simplicity. It was when applying this device that Rutherford discovered the existence of the atomic nucleus, a discovery which I had the very great privilege to witness from close quarters.

A minute fraction of the α-particles was deflected strongly from their path which was interpreted by Rutherford to be due to the presence of a positively charged nucleus in the centre of the atom which strongly deflects only α-particles passing nearby. From the deflection figures he calculated the nucleus to have a radius of 10^{-15} cm. which compares with the radius of the atom making out 10^{-8} cm.

Already in those days Rutherford anticipated the presence in nuclei of a heavy neutral constituent of a mass closely coinciding with that of protons. I heard him repeatedly discuss the probable existence of such particles and the difficulties one would encounter when trying to locate them. The neutron was discovered in his laboratory two decades later by Chadwick who was his assistant in the Manchester days.

NIELS BOHR

In the spring of 1912 on a Sunday afternoon which I spent in Rutherford's hospital house I asked him from where the β-particles emitted by the atoms originate. Do they come from the nucleus or from the outer part of the atom? Rutherford answered: "ask Bohr," and Niels Bohr who was present explained that the β-particles connected with an atomic transformation, the β-particles emitted, for example, when atoms of radium B are transformed into atoms of radium C originate from the nucleus and these only. The name nucleus was suggested by Bohr. The latter saw with a fabulous foresight the whole development which the science of the atom would take in the years to come. It was, at that date, clear to him that while the explanation of the radioactive disintegration had to be sought in the constitution of the nucleus, the ordinary physical and chemical characteristics of the elements manifested properties of the surrounding electron configurations. He saw also that we have to base the physical and chemical properties of an element on the nuclear charge; on the atomic number, as it was called later, which is a multiple of the elementary unit of electricity. He remarked that, "Argon is the wrong argon", because, and this Bohr realized at a time when the notion of isotopes had not yet emerged, the heavy argon-40 is represented to an abnormal extent in the isotopic mixture making out argon. We know today that the disintegration of K^{40} leads to the formation of Ar^{40} adding an ever-increasing amount of this heavy argon isotope to its isotopic mixture.

Bohr had also foreseen in 1913 the possible existence of tritium and stated his view in a discussion following the talk of J. J. Thomson at the Birmingham meeting of the British Association of Advancement of Science in which also Marie Curie, Raleigh, Oliver Lodge, Ramsey, Larmor and Lorentz participated.

Rutherford did not appreciate in his Manchester days, some of the prestations of theoretical physicists but he had the greatest admiration for the scientific genius and unique personality of Niels Bohr. Through all the years he took much interest in his work including that in the philosophical implication of quantum theory.

Rutherford had the greatest admiration for the accomplishments and personality of Marie Curie but in spite of this he was not always anxious to share her company. This is not necessarily a contradiction. Madame Curie loved to talk shop and to discuss details of chemical operations which she was carrying out. Rutherford occasionally discussed his own problems as well, but he liked to talk about politics, discuss problems of economics, talk about his friends and so on. He had no interest in chemistry and no great appreciation of chemists. He was highly amused about obtaining the Nobel prize for chemistry in spite, as he told us, of his utter lack of knowledge in the field of chemistry. When proposing the toast of the Chemical Engineering Congress of the World Power Conference in 1936, Rutherford remarked: "I cannot claim to be a chemist, but, on the other hand, I have often raided the borders of the chemist like a moss-trooper and returned with some loot",—an extreme understatement.

The above remarks further explain why in spite of his admiration of Marie Curie he did not always eagerly seek her company. At the Solvay Congress in Brussels in 1922 where both participated, we young people were instructed to look after Madame Curie which I did with the greatest enthusiasm. Her quiet dignity and power had to impress one and I considered it a unique privilege to be permitted to talk with her on problems of the chemistry of rare earth elements in which in connection with the separation of actinium she was much interested and which interested me as well in those days.

Possibly none of the great personalities about whom I have had the privilege to talk to you was more honoured, and collected more glory than Marie Curie in the later phase of her career. But none experienced so much hardship as she did in the earlier phase of her life and even in the course of her early scientific career. She experienced bodily and mentally cruel times. When these times were gone she lost her beloved husband and most closest collaborator when only 47 years old. In spite of all the glory experienced in the later part of her life, the above mentioned happenings left behind a trace of bitterness in her soul. This bitterness speaks from her biography of Pierre Curie in which she writes, "Our society in which a keen desire prevails for luxury and riches does not grasp the value of science. She does not understand that the science is a part of her most valuable heritage. She does not realize that science is the fundament of all progress, which facilitates human life and reduces suffering. Neither the authorities nor private charity provide science and the scientist with the support and means which are a necessity which is unavoidable if a successful work has to be carried out."

Times have changed radically to the better since these words were written. In achieving this change the marvellous accomplishments of Marie Curie and her great contemporaries, which influenced all branches of science and many of medicine, had a great share.