Madame Curie Memorial Lecture.

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Some Important Dates.

1867, November 7th	Birth of Marie Sklodowska in Warsaw.
1891	Came to Paris.
1895, July 25th	Married Pierre Curie.
1897	Irène Curie born.
1904	Eve Curie born.
1906, April 19th	Pierre Curie killed in Paris.
1906	Marie Curie professor at the Sorbonne.
1934, July 4th	Marie Curie died in Haut-Savoie of anæmia.
1898, July 18th	Discovery of polonium.
1898, December 26th	Discovery of radium.
1898	Discovery of the radioactivity of thorium.
1899	Discovery of induced activity.
1903	Davy medal of the Royal Society (with Pierre Curie).
1904	Nobel Prize in Physics (with Henri Becquerel and Pierre Curie).
1911	Nobel Prize in Chemistry.
1922	Member of the Academy of Medicine of Paris.
1903	First visit to England.
1921	Ovation in the United States.
1923	Silver Jubilee of Radium in Paris.
1928	Last visit to the United States.
1929	Last visit to England.
1932	Ovation at Warsaw.
1903	Doctoral thesis " Sur les Substances Radioactives."
1910	" Traité de Radioactivité."
1921	" La Radiologie et la Guerre."
1924	" L'Isotopie et les Eléments Isotopes."

We are here to-night to pay respect to a former Honorary Fellow of our Society and a very great woman—the greatest woman in science of our time. If ever we have a full-length, authoritative life of Madame Curie in English, I hope the story will be told with the sympathy, insight, and detachment with which Arnold Bennett traced from girlhood to the end the lives of Sophia and Constance in his great book " The Old Wives' Tale." The plain story of Marie Sklodowska—afterwards to become Marie Curie—from the early days in Warsaw, where she was born, through her struggles there and in Paris to a wide and enduring fame, with the minor ups-and-downs given their place amid the successes and the tragedy—and she did not escape tragedy and malice—till her death last summer in Savoy, should make a moving narrative. Her life, because of its connection with the wonderful flowering in physics and chemistry in the period 1896—1904, needs little help from an artist to give it interest or significance. No biographer has occasion to sentimentalise over her because she was a woman, or to make out that in her special subject in science she was first and the rest nowhere.

Marie Sklodowska, born in 1867, was the youngest of a family of five. The parents were school teachers in the capital of oppressed Poland, Warsaw. The father taught mathematics and physics; the mother, before her death when Marie was only nine, supervised a school for young girls. The old phrase " Plain living and high thinking " suffices to describe the home; it was " highbrow " in the good sense; things of the mind were thought important in it. The only brother was afterwards to become a doctor, and still practises in Warsaw. One sister studied medicine, married a Paris doctor, and now, a widow, is in charge of the Curie Radium Institution at Warsaw. A second sister became a school mistress. The eldest died comparatively young. At school Marie Sklodowska seems to have had most aptitude in mathematics, physics, and nature study. On leaving she acted for a short time as a private teacher or governess, but in 1891 she had accumulated sufficient funds to leave home and enter the Sorbonne in Paris to study afresh. There she lived in

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the economic way in which many students live, enduring hardships gladly or without comment, making study the principal thing. Various examinations were successfully passed before she began her work for her doctorate in the laboratory of Professor Lippmann. It was there in 1894 she first saw Pierre Curie. After a short visit to Poland she decided to make France her home, and in 1895 married Pierre Curie in Paris. He was 36, already distinguished for his pioneer work in magnetism and crystallography, and probably the most promising physicist working in Paris. He had just before been given a professorship at l'École de Physique et de Chimie, though with a poorly equipped laboratory and an inadequate stipend. There were no private means. The young couple started their life together in a very small way, working in the laboratory part of the day, and doing routine jobs or teaching during the rest, to eke out existence; living the happy, simple, economic, and occasionally rather anxious intellectual life, on which those who have emerged from it without bitterness or scar always look back as one of the happiest of times. The doctoral work began on the mechanical properties of certain steels, but the discovery in 1896 in a near-by laboratory by Henri Becquerel of the radioactivity of uranium, later to change the face of physics and inorganic chemistry, induced her to abandon the steels and enter the new field. Thus began her creative period, ending about 1903, when she alone or in conjunction with her husband discovered the radioactivity of thorium, found the new element polonium, discovered and isolated radium, and, generally speaking, invented radioactivity on its chemical side.

During this period, in 1897, a daughter, now Mme. Irène Curie-Joliot, destined to be hardly less distinguished in radioactivity than her mother, was born. Three years later the father was given a more remunerative post at the Faculté des Sciences, which was again bettered in 1904. Its close was marked by a visit, in 1903, of M. and Mme. Curie to London to receive, appropriately enough, the Davy medal of the Royal Society, and, in the following year, to Stockholm to get jointly with Henri Becquerel a Nobel Prize in Physics. This settled the financial position for a time. During the London visit, Professor Curie demonstrated in this very room at the Royal Institution that odd paradox—as it then seemed—the heat emission from radium at the temperature of liquid oxygen.

The years 1903 to 1911 may be taken as Madame Curie's second period. This was creatively of much less importance, but it witnessed the consolidation of most of the work done in the earlier. Polonium and radium were extracted on much larger scales, and studied by her and others both from the purely chemical and from the radioactive side. Radium became the great source of radioactive material in the research laboratories of the world, and began to find a therapeutic use in hospitals. It was prepared in the metallic state by Madame Curie and collaborators; its atomic weight was determined accurately, and its purified chloride selected as a standard of radioactivity. A good deal of miscellaneous work of permanent importance was also done. In 1904 the younger daughter was born, but in 1906 came tragedy: Professor Curie was knocked down by a lorry in Paris and killed. The widow succeeded her husband in his professorship, being the first woman professor at the Sorbonne and director of the new Radium Institute. The professorship was raised in status two years afterwards. In 1911 she again got a Nobel Prize, this time for Chemistry, and this time with no one to share it with her. After 1911 she did no work of final importance. She kept to the old paths, improved the older methods, got her data more accurate, directed research, and did much valuable work, but nothing corresponding with the discovery of radium and polonium came from it. Her attitude became protective and maternal rather than creative. She was constantly returning to the old work to meet criticism of it, to keep, so to speak, its honour bright—as, for example, in 1929, when it was seriously suggested that polonium decayed at different rates in different parts of the United States of Soviet Russia—or in seeing how her favourite elements, polonium and radium, could be of use in some discovery made by others. She continued actual work or the supervision of work till nearly the end, and never departed from the standard of the perfectly competent and interested research worker. Her last researches were with S. Rosenblum on the α-particles of varying initial velocity, emitted by different products of the actinium disintegration series.

Characteristics.

Madame Curie was about the middle height and of homely appearance. She dressed unostentatiously and, after her husband's death, generally in black. Her face was pale and not animated in repose; but for her large intelligent eyes, she would have seemed plain. She spoke quietly and with dignity but was not a ready talker. She was always willing to discuss science with those interested, provided they took the lead. Her face lit up as she spoke, and one understood the attraction she possessed for those who were interested in what she was saying. She went grey fairly early and always looked rather frail. She did everything with a quiet earnestness. Her work was part of herself. She was always unassuming and quite unspoiled by success. She was never particularly enthusiastic about the work of others when she talked, but she had no jealousy; she was in that respect uncompetitive. She was a clear and interesting lecturer in the formal manner of the French, but not a popular expositor; the ready word, the hearty manner, the eagerness to invite or continue discussion, which are the possessions of more than one of the distinguished male workers in physics of this land, were not hers. After about 1910 she learned English and eventually came to speak it well. She always had a small band of workers in her Radium Institute in Paris, but it never grew to a large school in which work was done on a very wide front; that kind of leadership happened not to be hers. She kept within a narrow field and did magnificently within it. Theoretical aspects—the study of the nucleus, for example—and mathematical treatment of physical and chemical problems did not interest her intimately. Her experimental work tended towards simplicity and straightforwardness rather than to elaboration, except perhaps when the method or the apparatus had been devised by her husband or his brother. All she did was done neatly and accurately. Her critical powers were excellent, and this is seen in her own publications as well as in all the work she directed.

*Early Days of Radioactivity.**

We are doubtless tired of being told that modern physics and chemistry began with the discovery of *X*-rays in the November of 1895; nevertheless it is a fact. Henri Becquerel, following up this work, discovered the radioactivity of uranium in February, 1896, in an examination of the double sulphate of uranium and potassium. (How few of us know that our own Silvanus Thompson was at similar work! Claim is made for his simultaneous and independent discovery of radioactivity in his biography published in 1920.) The subject, despite its difficulty, and the small number of workers in the field, went forward rapidly, largely because there were to hand the extraordinarily delicate methods of measurement of the rays or particles, shot out by radioactive bodies, which the gaseous ionisation work of J. J. Thomson and Rutherford had developed. Becquerel showed that the radiation from uranium was common to all uranium preparations and to the element itself, and that it could both affect a photographic plate and discharge positively and negatively electrified bodies. In a way the experimental physicists were ready for all this. The α-particle had its prototype in the canal rays of Goldstein (1886), the β-particle in the electron of the discharge tube, and the non-deflectable γ-ray in the *X*-ray itself. The α-particle was afterwards to be identified with helium, but this new terrestrial element had been conveniently discovered by Ramsay in cleveite in 1895, and the technique of its manipulation needed little development. It is clear that these preliminary discoveries—helium, the electron, the *X*-ray—were the necessary precursors of radioactivity. Anybody before then could have discovered the radioactivity of uranium had he possessed either a gold-leaf electroscope or a dry photographic plate, but, in fact, he could have done little or nothing about it before 1896 because the significance of what was occurring would totally have escaped him.

But there were difficulties, and the greatest was the failure of most physicists to visualise

* Has it been pointed out before that many of the early workers had peculiar surnames or were working far from home? There were Soddy and Eve, Russ and Makower, Bragg and Kleeman, Joly and Crookes—all British, in different parts of the Empire. Rutherford was a New Zealander at Cambridge and in Montreal, Bragg a North-countryman in Adelaide, Soddy an Englishman in Canada, Madame Curie a Pole in Paris.

the atom as the simple, discrete, concrete entity we now naïvely assume it to be. It was the chemists who gave them a lead there. Physicists of the Faraday–Clerk Maxwell tradition, like Kelvin, failed for a time to distinguish in their minds atoms from molecules or, alternatively, so to theorise as to believe atoms definitely existed. Becquerel at the beginning thought radioactivity was a form of fluorescence; Stokes, President of the Royal Society, suggested it was "calorescence"; Silvanus Thompson inclined to "hyper-phosphorescence"; but these views were quickly dropped. Sir William Crookes thought that radioactive atoms might derive their energy through their peculiar ability to extract it from the surrounding gas; particles of the gas arrived at the radioactive atom with high energy and departed with low, the energy thus conveniently obtained being later emitted. As late as 1903, Kelvin suggested that the radioactive atom absorbed, not kinetic energy from a gas, but unknown radiations traversing all space, thus keeping its temperature, as was experimentally the case, above that of the surroundings, as a black body in sunshine did above that of a neighbouring white one. Different altogether were the theories of Rutherford in 1901, Perrin, 1901, and J. J. Thomson, 1903. They believed the energy of radioactivity must come somehow from within the atom. These views, in the event, were the forerunners of the complete disintegration theory of Rutherford and Soddy of 1903. To the attainment of the simple view of radioactivity that has been ours since then, Madame Curie made a most valuable contribution from the chemical side by producing the concrete fact that new radioactive elements existed. Becquerel proved in a way that radioactivity was atomic, but he did not see the importance of his results.

It was Madame Curie's great merit to have seen how important an atomic property might be, and to have made this the basis of her experimental work. She first showed that uranium preparations were radioactive, independently of their source, previous history, or chemical treatment. Using the Cambridge electrical method of measurement, she found that some uranium ores were as much as four or five times more radioactive than they should be on their uranium content. She found a mineral was not abnormally radioactive *qua* mineral; a mineral made artificially was no more radioactive than it should be. She made the correct deduction from her surprising results, namely, that pitchblende, the mineral with the most abnormal radioactivity, must contain in small amount a new radioactive substance proportionately many times more reactive than uranium itself. This supposed substance must be in small amount and new, for it was unlikely that in a well-known mineral like pitchblende any detectable quantity of a new element could be present. This location of radioactivity in concrete atoms of chemical elements was the opening move in the break-away from the abstract theories of the radioactive process of people such as Kelvin and Stokes. And it had important practical results. Madame Curie treated pitchblende just like any ordinary mixture that required a qualitative analysis: she put it "through the groups." It was fortunate that her pitchblende, containing as it did bismuth, rare earths, calcium, and barium, in addition to lead and uranium, was impure, otherwise she might have got her radioactive elements down in the wrong groups because, in absence of convenient adsorbers, their very small concentration would have kept them soluble in all precipitating reagents. Her technique was simple. She examined at every stage of the chemical work whether the radioactivity was in a precipitate or not by the ionisation method. She found in July, 1898, a new radio-element that kept with bismuth in the simple chemical operations. She called this polonium. In December she found a second, similar chemically to barium, and to this she gave the very fine name of radium. There were actually two other elements she might have found: radio-lead, the β-particle element now called radium-*D*, and actinium, the rayless body that generates the active radio-actinium. The former must have been separated from the bismuth with the lead, and the latter from the uranium with the rare earths; but neither was radioactive like polonium and radium. Their identification depended upon the growth of their radioactive products, a fact not then known, and a thing in any case which takes time. It is therefore excusable, and indeed more than excusable, that these later gleanings were not first crops.

The question how much of all this work was due to Madame Curie, how much to her husband, must arise in the minds of all of us. Who, now, could satisfy our curiosity? And does it matter very much? Some of the work was actually joint work with her husband and with M. Bemont. Pierre Curie was a very able man—but a physicist. It is undeniable that Madame Curie was the chemist of the partnership; the general attack on the problem from the chemical side both in conception and in execution was hers or largely hers. The physical measurements made by Pierre Curie were important, and his suggestions how the joint work should be done were valuable, but it was the chemical work alone that was at this stage vital. Moreover, it is clear both from Madame Curie's doctoral thesis printed in 1903 and from Pierre Curie's work with others, that Madame Curie took a simpler view of radioactivity than her husband. In January, 1902, they announced their view that radioactivity was an atomic phenomenon and that each atom acts as a constant source of the emission of energy. But whether the energy was inherent in the atom, as Rutherford and J. J. Thomson thought, or collected from the surroundings and later emitted, as Crookes earlier and Kelvin later thought, they left undecided. They postulated both views but urged neither. There is some evidence, however, that both inclined to one side—the wrong one—and that the inclination of the husband was more pronounced than that of his wife. That, indeed, was generally the attitude of the Paris physicists at the time. None of them was able to distinguish between the important and the trivial in experimental work, or to formulate theory like Rutherford, the young research worker of Cambridge and McGill University in Montreal; none had his imaginative power. Whatever may be said of the pioneer workers in radioactivity, it cannot too plainly be asserted that the subject owes its remarkable development largely to one whose extraordinary insight into the ways of Nature is without parallel since the time of Newton. It is owing to his direction that neither time nor energy was lost in the different research laboratories in following paths that would have led nowhere.

Radium.

After radium had been detected in quantities much below those capable of showing any property other than radioactivity, it was prepared in quantity—though actually only in amounts of the order of 0·1 g.—by large-scale methods. In a mineral containing 3 kg. of uranium we now know there is present about 1 mg. of radium. In 1000 kg. of Joachimstal pitchblende, which contained about 60% of uranium as metal, there were present about 200 mg. of radium. The Austrian government generously gave Madame Curie a ton of uranium residues from the Joachimstal mine, and scientific societies and private individuals helped financially to defray the cost of the long and laborious work of separation; but the principle was simple: she merely had to keep her eye on the barium. Whatever were the impurities, whatever chemical operations were carried out, the radium always cleaved to the barium, eschewing all else. She got first about 20 kg. of barium salts about 30 times as radioactive as uranium itself, and then 8 kg. about 60 times as radioactive. From this, radium was purified by fractional crystallisation of chlorides, the radium chloride being much the less soluble. The process was followed by the electrical method, by the spectroscope, and, at times, by eye. (Crystals of radiferous barium were at first colourless, in a few hours they became yellow, and later became orange or even rose-red. The rapidity of this coloration was a function of the barium present, and a maximum for a definite proportion of radium and barium.) In those days spectroscopic evidence was considered more convincing than radioactivity as evidence of a new element; for what eventually was called radium might have turned out to be just some induced or modified form of barium. Becquerel, indeed, who was, like Madame Curie, in Paris, was committed to an induction theory of radioactivity and was a powerful influence. Madame Curie's work made nonsense of such a view. New spectrum lines were revealed as soon as there was one part of radium in about 8000 of barium. The long crystallisation process, which could have been greatly shortened had she used the bromide instead of the chloride, eventually gave her several hundred milligrams of nearly pure radium chloride. Atomic-weight determinations of the increasingly pure material, then rightly the criterion of chemical respectability, rose from 137, through 146 and 175, finally to 225, attained with 90 mg. of chloride in 1902. There was no doubt that radium was a new, completely definite, alkaline-earth element with a place awaiting it in the Periodic Classification; when atomic numbers were allotted a decade later, it was given 88.

By 1907 she had repeated the work with 400 mg. of radium chloride and obtained the value 226·2 (subsequently recalculated to 226·4). The reaction was $RaCl_2$: AgCl, silver being taken as 107·8 and Cl as 35·4. The increase of more than a unit could not wholly be ascribed to increase in purity of the salt; it was due to better reagents and vessels, and to the accuracy which could be attained with more reasonable amounts of material. This time there was not more than 0·1% of barium in the radium. In 1910 Madame Curie and Debierne isolated pure radium metal by the electrolytic method of Guntz. They used a platinum–iridium anode, 10 g. of a mercury cathode, and an aqueous solution of radium chloride equivalent to about 100 mg. of the metal. The electrolysed radium amalgamated easily. Mercury was removed by distillation in hydrogen; a brilliant white metal which melted sharply at 700° remained. This metal behaved chemically as befitted its place in the Periodic Classification. It decomposed water, formed a very soluble hydroxide, and a black nitride (presumably of formula Ra_3N_2) insoluble in water, easily decomposed by hydrochloric acid. The metal was much more volatile than barium, being closer to calcium in volatility. It was not anticipated that any startling results would emerge from this work; it was merely an experiment in manipulation, worth doing once. The fractional sublimation of the metals in a vacuum as a possible means of ridding the radium of barium was the only new point of chemical interest.

On the recommendation of an International Committee which met in Brussels in 1910, Madame Curie prepared a radium standard, sealed in a thin glass tube, of 21·99 mg. of the pure radium chloride used by her in the determination of the atomic weight. The source of the radium was uraninite, containing only a trace of thorium, from St. Joachimstal. Meanwhile, Professor Otto Hönigschmid had prepared three specimens of radium chloride, weighing 10·11, 31·17, and 40·43 mg., from the radium whose atomic weight he had found to be 225·95. In 1912 the specimens were compared carefully. The Paris and the Austrian standard agreed within the errors of measurement (which were definitely not greater than 0·3% and probably much less). 31·17 Mg. on the Austrian standard was 31·24 on Madame Curie's; 10·11 was 10·13. As the standards were entirely independent, the agreement was a testimonial to the care and accuracy of Madame Curie and of Professor Hönigschmid. Madame Curie's standard became the International Radium Standard which has since been preserved at the Bureau des Poids et Mesures at Sèvres, near Paris. The 31·17-mg. Austrian standard, kept at the Academy of Sciences in Vienna, became a reserve standard.

The accepted value of the atomic weight of radium—that of O. Hönigschmid, 225·95—we now believe, from the general results of F. W. Aston, to be low. Those results indicated that 226·1 is a likelier value. If this be so, Madame Curie's value is not so far out as it seems. At a Conference in Brussels in 1910, a new unit of radioactivity, the Curie, was decided upon, *viz.*, the amount of any product in the uranium–radium disintegration series in equilibrium with 1 g. of radium element. The name was chosen in honour of Pierre Curie. In the discussion it was strongly urged by some members that the Curie would be more suitable for use if it were merely a thousandth of what ultimately it was fixed to be; for, in 1910, a gram of radium was a legendary amount, many laboratories made shift with fractions of a milligram, and the sensitivity of instruments, as well as rarity and cost, encouraged the use of small amounts. The logical French mind, however, wished to identify the new unit with the unit of mass, the gram, and not, for mere convenience, with a fraction of it. The suggestion that the Curie should be what now is a millicurie, however, prevailed in the committee (which included Madame Curie) and was temporarily adopted. But after that meeting she must have thought what a poor miserable thing the new unit was going to be, a mere thousandth of what she had hoped! It did not seem proper that such a thing should bear her husband's name. So next day the Curie was fixed as she desired—a thousand times the original suggested value. To-day, as a consequence, despite the amounts of radium now available, we still struggle with terms like "millicurie," "microcurie," and even "millimicrocurie."

Polonium.

Polonium was precipitated with bismuth, from which Madame Curie effected a partial separation of it by purely chemical methods. The chemical work was less clear-cut; at first she doubted if polonium was of the same class of radioactive substance as radium. There was an outside possibility that the activity of polonium was entirely induced by the proximity of substances themselves radioactive—in which case it would have to be agreed that polonium had the power of acquiring atomic activity semi-permanently. There was, secondly, a possibility that, while the activity of polonium was inherent, it might be spontaneously destroyed under some conditions other than those obtaining in the ore (where, of course, it was not destroyed). No opinion could then be given. About this time, W. Marckwald concentrated the polonium (which he called radiotellurium) by dipping a rod of bismuth into a hydrochloric acid solution of the radioactive bismuth obtained from pitchblende residues. He also effected a notable separation with stannous chloride. From the first, Madame Curie noticed that the radioactivity of this substance, unlike uranium, unlike thorium, unlike radium, was not permanent but decayed steadily with lapse of time. Marckwald thought at one time that Madame Curie's product was a mixture giving β-rays as well as α-particles, and could not understand, being what it was, why it resembled bismuth chemically so much as she said. He had doubts also whether it decayed with time. His preparation and her polonium were identical, however, in emitting α-particles which were easily absorbed by matter, and by 1906 there was no doubt of their identity in the pure states. Polonium or radiotellurium was the top member of Group VIB of the Periodic Classification which included selenium and tellurium; this missing element was afterwards to be given the atomic number 84, and was shown, just as much as radium, to be an element, despite the minute amount of it available—despite, also, its decaying to half-value in the short period of 140 days.

By 1910 Madame Curie and M. Debierne had isolated as much as 2 mg. of polonium estimated to be nearly 5% pure—then a remarkable achievement of chemical skill and pertinacity. From about 2 tons of uranium mineral, 200 g. of residue were concentrated, having, weight for weight, an α-particle activity 3500 times that of uranium, the whole of the activity being due to polonium. This was concentrated by chemical methods to 1 g., and found to have traces of mercury, silver, tin, gold, palladium, rhodium, lead, zinc, barium, calcium, and aluminium. The gram was concentrated to 2 mg. by electrolysis, of which 0·1 mg. was thought to be polonium. This preparation contained new spectral lines, and it was hoped that, as they diminished in intensity with the decay of the polonium, those of lead would take their place. The result of this hope seems not to be recorded. It was at that time fairly certain that lead was the end product of the uranium–radium series and the direct product of polonium, yet it did not then occur to Madame Curie, or to anybody who expressed himself in print, that the atomic weight of that lead must be abnormal in being at least one unit below the accepted value for ordinary lead, 207. Later, in 1913, when the importance of this discrepancy had been pointed out by others, she worked on the atomic weights of different leads, finding low, though not minimal, values for uranium-lead, and high, though not maximal, values for thorium-lead, but these results came too late to give to the developing subject the impetus the earlier observations might have done.

Induced Activity.

The Curies in Paris in 1899 for radium, and Rutherford at McGill in 1900 for thorium, independently discovered the phenomenon which began to be known as "excited" or "induced" activity; that is, they observed that every substance which remained near a radium or thorium preparation became in time itself radioactive. Rutherford suggested in explanation that thorium and possibly other radioactive bodies generated what he called an emanation or gaseous material which, first, by moving about, and secondly, by in some way producing particles of radioactivity, accounted for excited activity. The latter radioactivity was material; it was dissolved by some acids and not by others; it could be rubbed off by the finger or by sand-paper. The explanation he gave then is that which is now accepted. The Curies, however, took another view. They considered it beyond dispute that their preparations of radium could neither sublime nor otherwise distil at the ordinary temperature on the surfaces where the excited radioactivity made its appearance. And they could not accept at first the view that the emanation was real and material.

There was no spectroscopic evidence of the gas they found; moreover, it was patent that in time it disappeared even when kept in a sealed vessel. The view of the emanation, stated unambiguously by Madame Curie in her thesis, was that it was only a form of radioactive energy stored in the surrounding gas in a form hitherto unknown. Logically, it followed that the excited activity could not be material, and hence it was thought to be, and called, "induced." The crux of the matter was the nature of the emanation. If it were a gas, there was obviously a mechanism of transport of radioactive material independent of the sublimation or distillation of the very solid particles of radium or thorium preparations. The decisive experiment—sealing up the radium—soon decided which school of thought was right, but the positiveness of both the Curies on the stored-up-energy theory of the emanation, and the fact that their neighbour Becquerel was committed to an induction theory of radioactivity, carried them away from the simple, concrete view which was afterwards to triumph so magnificently. Madame Curie was soon to accept the material theory of excited radioactivity, but she and the French school continued to use "induced activity" as a term for several years afterwards. The jargon of those days—"induced activity," "excited activity," "emanation"—suggests that the very early attitude to those experimental facts was not unlike that towards some mysterious thing like mesmerism or hypnotism where "emanations," "passes," "excitations," and "inductions" have always been common form. There is little doubt that the understanding of the cause and nature of radioactivity was retarded by the fixed idea held then in Paris that radioactivity was an unchanging phenomenon, not something which decayed with time. It was an argument against the real nature of the emanation that it disappeared in time. To us now, of course, this disappearance is no difficulty. As the gaseous matter decays, so are produced the solid particles of radioactivity which all the dispute had been about. But that view had yet to be put forward; it awaited the classical work of Rutherford and Soddy in 1902—1903. Moreover, it was not a final fact that the radium emanation when kept in a sealed vessel decayed to nothing. The Curies themselves were the first to find evidence of the existence of "active deposit of slow-change" (now called radium-*D*, -*E*, and -*F*), which remained after the radium emanation and its "quick-changing products" had ceased to be detectable.

The Second Period.

After the initial creative impulse, at its height between 1897 and 1903, had spent itself about 1910, Madame Curie was content to keep the old work going, to further all the scientific interests she had acquired in the creative period, and, as was said above, to keep untarnished the honour of both the facts and the theories of radioactivity in which she had interest; her work became secondary, not creative. When Sir William Bragg showed, in 1904, that the ionisation produced by the α-particles from radium and its short-lived products extended into the gas a well-defined distance—the range—and then abruptly ended, Madame Curie was able at once to confirm this phenomenon for the simpler α-particles from her radio-element polonium. In 1908, an extraordinary series of observations emanated from the chemical laboratories of Gower Street. Copper and its salts were supposed by Sir William Ramsay and A. T. Cameron to be disintegrated by the radium emanation into such alkali metals as potassium, sodium, and lithium. Elements can now be disintegrated by α-particles and other atomic projectiles, but that work was in no sense an anticipation of this. Madame Curie and Mlle. Gleditsch, concentrating chiefly on lithium, were unable to confirm that work; they traced the alkali metals to impurities in the vessels and reagents used, and rendered it probable, though not certain, that this accounted for all the observations of Ramsay and Cameron. In 1911 actinium, which had been discovered by Madame Curie's methods by Debierne in Paris in 1899 and till then regarded as a long-lived element, was found by Madame Curie to have a half-period of the order of only 20 years. This result raised the important question, happily now solved, why its production from uranium—a necessary consequence of its short period—had not been experimentally observed. In 1913 she made a defensive contribution to an idea that was periodically being attacked, namely, that the rate of decay of a radioactive body was quite independent of temperature, concentration, pressure, or even geography. With Kamerlingh Onnes she showed that immersion of a strong radium source in liquid helium for 90 minutes did not affect the penetrating γ-radiation by 0·1%, and probably by not more than 0·02%, of its activity at the ordinary temperature. And one of the last pieces of work she did was to criticise destructively a series of experiments made in Russia, where it was alleged that her own element polonium disintegrated at different rates in different parts of that land—capriciously, for there was found no general correlation between latitude and rate of decay. Happily, the preparation conformed to the accepted value of the half-value period in the two great cities of Moscow and Leningrad. There are, of course, no such real variations. The results were seriously put forward and equally seriously rebutted, but workers in the future may be permitted to regard the episode as a jest: Russia chaffing Poland on a sensitive point.

The War.

The War rightly interrupted Madame Curie's purely scientific work, but not, of course, her activities. The "Union des Femmes de France," one of the three French Red Cross societies, gave her the management of its *X*-ray service. Another, the "Patronage National des Blessés" got her to establish installations wherever they were urgently needed. Later, Madame Curie, acting with the "Service de Santé," created a school of radiology for nurse-specialists, which from 1916 till the close of the War achieved success. She served on many committees. The prestige of her name (and in war time great names had great value), as well as her actual services, was invaluable to her adopted country during that very difficult period. In a little book published in 1921 she gave an account of the *X*-ray and radium-therapy services with which she had been connected during those years.

After the War.

In so far as a worker in science can be a world figure, Madame Curie was a world figure. The concrete discovery of new elements that had surprised the world of science by their oddness and were giving hope of being of decisive value in the cure of cancer, and the fact that she was a woman, later to be widowed in tragic circumstances, all helped to bring her name to the attention of the ordinary person. She had come as an obscure person to Paris from Warsaw, and by pure merit, without any kind of influence, had attained a position which had twice been crowned by the Nobel Prize. Her first visit to the United States in 1921 was like the visit of a queen. On that occasion she was given a gram of radium, which had been subscribed for in her honour, by the women of America. The presentation was made her at the White House by the President himself, the unfortunate Harding, in a well-phrased speech. In her adopted country, in Paris on the 25th anniversary of the discovery of radium, in December, 1923, she was the centre of a great gathering of French notabilities, with the President at their head. A pension of 40,000 francs a year was then settled on her and her daughters. Later, in 1932, all Poland with their President received her like royalty as she attended the opening of the Curie Radium Institution in her native Warsaw. The little teacher who had left Poland in the early 'nineties with her hard-won savings to renew her study in the great French capital then returned in triumph. No praise is so sweet as that of those who knew us when we were young, unknown, and immature. What contrasts must have presented themselves to her! What thoughts must have passed through her mind as she recalled all that had happened to her, to her relations and friends, and to her loved country during those forty years! The whirligig of time had brought its change, yet it had not spoiled the essential woman in her.

As her scientific work eased in the years after the War, that of her elder daughter became more and more energetic. The tragedy that had entered Madame Curie's life and partly crippled her work—the loss of her husband—had some compensation in the promise of this daughter. Like her mother, the daughter had been brought up in a home where both parents had had at times to practise economy. Like her mother, she was in time to marry one of the most promising physicists in Paris. Like her mother, she was, with her husband, to make a discovery—the artificial radioactivity of the light elements—of immense importance and promise in the subject of atomic physics. We in science are the last to suggest that history repeats itself, but these similarities in mother and daughter are just worth noting. Madame Curie was the only person ever to get a Nobel Prize twice, though not, of course, the only one to deserve the double honour. It seems likely—it is, indeed, very probable—that in due time daughter and son-in-law also will partake of this emolument. When they obtain it, a family record will be established in prizes as remarkable as deserved.

It does not detract from Madame Curie's greatness to say as a last word that she was fortunate. She was fortunate in being in Paris, and in being there at just the right time. She was fortunate in being married to Pierre Curie, and in being a conscientious, hard-working, clear-thinking chemist when physicists were plentiful and chemists both rare and essential. It was well also, I think, that she was not too clever at a time when mere cleverness was some bar to original thought. She had assuredly a great opportunity, but she had the brains and the courage to seize it, and tenaciously to retain it.

" Radium," " Polonium," the " Curie " are words for all time. They will rightly keep Madame Curie's name alive as long as science lasts.