

RADIOACTIVITY

MADAM CURIE, BIOGRAPHY AND LEGACY



Maria Salomea Skłodowska-Curie[a] (Polish: 7 November 1867 – 4 July 1934), known simply as Marie Curie was a Polish and naturalised-French physicist and chemist who conducted pioneering research on radioactivity. She was the first woman to win a Nobel Prize, the first person to win a Nobel Prize twice, and the only person to win a Nobel Prize in two scientific fields. Her husband, Pierre Curie, was a co-winner of her first Nobel Prize, making them the first-ever married couple to win the Nobel Prize and launching the Curie family legacy of five Nobel Prizes. She was, in 1906, the first woman to become a professor at the University of Paris.

She was born in Warsaw, in what was then the Kingdom of Poland, part of the Russian Empire. She studied at Warsaw's clandestine Flying University and began her practical scientific training in Warsaw. In 1891, aged 24, she followed her elder sister Bronisława to study in Paris, where she earned her higher degrees and conducted her subsequent scientific work. In 1895 she married the French physicist Pierre Curie, and she shared the 1903 Nobel Prize in Physics with him and with the physicist Henri Becquerel for their pioneering work developing the theory of "radioactivity"—a term she coined. In 1906 Pierre Curie died

in a Paris street accident. Marie won the 1911 Nobel Prize in Chemistry for her discovery of the elements polonium and radium, using techniques she invented for isolating radioactive isotopes. Under her direction, the world's first studies were conducted into the treatment of neoplasms by the use of radioactive isotopes. She founded the Curie Institute in Paris in 1920, and the Curie Institute in Warsaw in 1932; both remain major medical research centres. During World War I she developed mobile radiography units to provide X-ray services to field hospitals.

While a French citizen, Marie Skłodowska Curie, who used both surnames, never lost her sense of Polish identity. She taught her daughters the Polish language and took them on visits to Poland. She named the first chemical element she discovered polonium, after her native country.

Marie Curie died in 1934, aged 66, at the Sancellemoz sanatorium in Passy (Haute-Savoie), France, of aplastic anemia likely from exposure to radiation in the course of her scientific research and in the course of her radiological work at field hospitals during World War I. In addition to her Nobel Prizes, she received numerous other honours and tributes; in 1995 she became the first woman to be entombed on her own merits in the Paris Panthéon, and Poland declared 2011 the Year of Marie Curie during the International Year of Chemistry. She is the subject of numerous biographical works.

Krakowskie Przedmieście 66, Warsaw, where Maria did her first scientific work, 1890–91

Life in Paris

In late 1891, she left Poland for France. In Paris, Maria (or Marie, as she would be known in France) briefly found shelter with her sister and brother-in-law before renting a garret closer to the university, in the Latin Quarter, and proceeding with her studies of physics, chemistry, and mathematics at the University of Paris, where she enrolled in late 1891.

She subsisted on her meagre resources, keeping herself warm during cold winters by wearing all the clothes she had. She focused so hard on her studies that she sometimes forgot to eat. Skłodowska studied during the day and tutored evenings, barely earning her keep. In 1893, she was awarded a degree in physics and began work in an industrial laboratory of Gabriel Lippmann. Meanwhile, she continued studying at the University of Paris and with the aid of a fellowship she was able to earn a second degree in 1894.

Skłodowska had begun her scientific career in Paris with an investigation of the magnetic properties of various steels, commissioned by the Society for the Encouragement of National Industry.

That same year, Pierre Curie entered her life: it was their mutual interest in natural sciences that drew them together. Pierre Curie was an instructor at The City of Paris Industrial Physics and Chemistry Higher Educational Institution (ESPCI Paris). They were introduced by Polish physicist Józef Wierusz-Kowalski, who had learned that she was looking for a larger laboratory space, something that Wierusz-Kowalski thought Pierre could access. Though Curie did not have a large laboratory, he was able to find some space for Skłodowska where she was able to begin work.

Their mutual passion for science brought them increasingly closer, and they began to develop feelings for one another. Eventually, Pierre proposed marriage, but at first Skłodowska did not accept as she was still planning to go back to her native country. Curie, however, declared that he was ready to move with her to Poland, even if it meant being reduced to teaching French. Meanwhile, for the 1894 summer break, Skłodowska returned to Warsaw, where she visited her family.

She was still labouring under the illusion that she would be able to work in her chosen field in Poland, but she was denied a place at Kraków University because of sexism in academia. A letter from Pierre convinced her to return to Paris to pursue a PhD.

At Skłodowska's insistence, Curie had written up his research on magnetism and received his own doctorate in March 1895; he was also promoted to professor at the School. A contemporary quip would call Skłodowska "Pierre's biggest discovery".

On 26 July 1895, they were married in Sceaux; neither wanted a religious service. Curie's dark blue outfit, worn instead of a bridal gown, would serve her for many years as a laboratory outfit. They shared two pastimes: long bicycle trips and journeys abroad, which brought them even closer. In Pierre, Marie had found a new love, a partner, and a scientific collaborator on whom she could depend.

New elements

In 1895, Wilhelm Röntgen discovered the existence of X-rays, though the mechanism behind their production was not yet understood. In 1896, Henri Becquerel discovered that uranium salts emitted rays that resembled X-rays in their penetrating power. He demonstrated that this radiation, unlike phosphorescence, did not depend on an external source of energy but seemed to arise spontaneously from uranium itself. Influenced by these two important discoveries, Curie decided to look into uranium rays as a possible field of research for a thesis

She used an innovative technique to investigate samples. Fifteen years earlier, her husband and his brother had developed a version of the electrometer, a sensitive device for measuring electric charge. Using her husband's electrometer, she discovered that uranium rays caused the air around a sample to conduct electricity. Using this technique, her first result was the finding that the activity of the uranium compounds depended only on the quantity of uranium present. She hypothesized that the radiation was not the outcome of some interaction of molecules but must come from the atom itself. This hypothesis was an important step in disproving the assumption that atoms were indivisible

In 1897, her daughter Irène was born. To support her family, Curie began teaching at the École Normale Supérieure. The Curies did not have a dedicated laboratory; most of their research was carried out in a converted shed next to ESPCI. The shed, formerly a medical school dissecting room, was poorly ventilated and not even waterproof. They were unaware of the deleterious effects of radiation exposure attendant on their continued unprotected work with radioactive substances. ESPCI did not sponsor her research, but she would receive subsidies from metallurgical and mining companies and from various organizations and governments.

Curie's systematic studies included two uranium minerals, pitchblende and torbernite (also known as chalcocite). Her electrometer showed that pitchblende was four times as active as uranium itself, and chalcocite twice as active. She concluded that, if her earlier results relating the quantity of uranium to its activity were correct, then these two minerals must contain small quantities of another substance that was far more active than uranium.

She began a systematic search for additional substances that emit radiation, and by 1898 she discovered that the element thorium was also radioactive. Pierre Curie was increasingly intrigued by her work. By mid-1898 he was so invested in it that he decided to drop his work on crystals and to join her.

The [research] idea [writes Reid] was her own; no one helped her formulate it, and although she took it to her husband for his opinion she clearly established her ownership of it. She later recorded the fact twice in her biography of her husband to ensure there was no chance whatever of any ambiguity. It [is] likely that already at this early stage of her career [she] realized that... many scientists would find it difficult to believe that a woman could be capable of the original work in which she was involved.

She was acutely aware of the importance of promptly publishing her discoveries and thus establishing her priority. Had not Becquerel, two years earlier, presented his discovery to the Académie des Sciences the day after he made it, credit for the discovery of radioactivity (and even a Nobel Prize), would instead have gone to Silvanus Thompson. Curie chose the same rapid means of publication. Her paper, giving a brief and simple account of her work, was presented for her to the Académie on 12 April 1898 by her former professor, Gabriel Lippmann. Even so, just as Thompson had been beaten by Becquerel, so Curie was beaten in the race to tell of her discovery that thorium gives off rays in the same way as uranium; two months earlier, Gerhard Carl Schmidt had published his own finding in Berlin.

At that time, no one else in the world of physics had noticed what Curie recorded in a sentence of her paper, describing how much greater were the activities of pitchblende and chalcocite than uranium itself: "The fact is very remarkable, and leads to the belief that these minerals may contain an element which is much more active than uranium." She later would recall how she felt "a passionate desire to verify this hypothesis as rapidly as possible.". On 14 April 1898, the Curies optimistically weighed out a 100-gram sample of pitchblende and ground it with a pestle and mortar. They did not realize at the time that what they were searching for was present in such minute quantities that they would eventually have to process tonnes of the ore.

In July 1898, Curie and her husband published a joint paper announcing the existence of an element they named "polonium", in honour of her native Poland, which would for another twenty years remain partitioned among three empires (Russian, Austrian, and Prussian) December 1898, the Curies announced the existence of a second element, which they named "radium", from the Latin word for "ray". In the course of their research, they also coined the word "radioactivity".

To prove their discoveries beyond any doubt, the Curies sought to isolate polonium and radium in pure form. Pitchblende is a complex mineral; the chemical separation of its constituents was an arduous task. The discovery of polonium had been relatively easy; chemically it resembles the element bismuth, and polonium was the only bismuth-like substance in the ore. Radium, however, was more elusive; it is closely related chemically to barium, and pitchblende contains both elements. By 1898 the Curies had obtained traces of radium, but appreciable quantities, uncontaminated with barium, were still beyond reach. The Curies undertook the arduous task of separating out radium salt by differential crystallization. From a tonne of pitchblende, one-tenth of a gram of radium chloride was separated in 1902. In 1910, she isolated pure radium metal. She never succeeded in isolating polonium, which has a half-life of only 138 days.

Between 1898 and 1902, the Curies published, jointly or separately, a total of 32 scientific papers, including one that announced that, when exposed to radium, diseased, tumour-forming cells were destroyed faster than healthy cells.

In June 1903, supervised by Gabriel Lippmann, Curie was awarded her doctorate from the University of Paris. That month the couple were invited to the Royal Institution in London to give a speech on radioactivity; being a woman, she was prevented from speaking, and Pierre Curie alone was allowed to. Meanwhile, a new industry began developing, based on radium. The Curies did not patent their discovery and benefited little from this increasingly profitable business.

Nobel Prizes

1903 Nobel Prize diploma

Marie Curie's business card as professor at the Faculty of Sciences

In December 1903 the Royal Swedish Academy of Sciences awarded Pierre Curie, Marie Curie, and Henri Becquerel the Nobel Prize in

Physics, "in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel." At first the committee had intended to honour only Pierre Curie and Henri Becquerel, but a committee member and advocate for women scientists, Swedish mathematician Magnus Gösta Mittag-Leffler, alerted Pierre to the situation, and after his complaint, Marie's name was added to the nomination. Marie Curie was the first woman to be awarded a Nobel Prize.

Curie and her husband declined to go to Stockholm to receive the prize in person; they were too busy with their work, and Pierre Curie, who disliked public ceremonies, was feeling increasingly ill. As Nobel laureates were required to deliver a lecture, the Curies finally undertook the trip in 1905. The award money allowed the Curies to hire their first laboratory assistant. Following the award of the Nobel Prize, and galvanized by an offer from the University of Geneva, which offered Pierre Curie a position, the University of Paris gave him a professorship and the chair of physics, although the Curies still did not have a proper laboratory. Upon Pierre Curie's complaint, the University of Paris relented and agreed to furnish a new laboratory, but it would not be ready until 1906.

On 19 April 1906, Pierre Curie was killed in a road accident. Walking across the Rue Dauphine in heavy rain, he was struck by a horse-drawn vehicle and fell under its wheels, fracturing his skull and killing him instantly. Curie was devastated by her husband's death. On 13 May 1906 the physics department of the University of Paris decided to retain the chair that had been created for her late husband and offer it to Marie. She accepted it, hoping to create a world-class laboratory as a tribute to her husband Pierre. She was the first woman to become a professor at the University of Paris.

Curie's quest to create a new laboratory did not end with the University of Paris, however. In her later years, she headed the Radium Institute

(Institut du radium, now Curie Institute, Institut Curie), a radioactivity laboratory created for her by the Pasteur Institute and the University of Paris. The initiative for creating the Radium Institute had come in 1909 from Pierre Paul Émile Roux, director of the Pasteur Institute, who had been disappointed that the University of Paris was not giving Curie a proper laboratory and had suggested that she move to the Pasteur Institute. Only then, with the threat of Curie leaving, did the University of Paris relent, and eventually the Curie Pavilion became a joint initiative of the University of Paris and the Pasteur Institute.

In 1910 Curie succeeded in isolating radium; she also defined an international standard for radioactive emissions that was eventually named for her and Pierre: the curie. Nevertheless, in 1911 the French Academy of Sciences failed, by one or two votes, to elect her to membership in the academy. Elected instead was Édouard Branly, an inventor who had helped Guglielmo Marconi develop the wireless telegraph. It was only over half a century later, in 1962, that a doctoral student of Curie's, Marguerite Perey, became the first woman elected to membership in the academy.

Despite Curie's fame as a scientist working for France, the public's attitude tended toward xenophobia—the same that had led to the Dreyfus affair—which also fuelled false speculation that Curie was Jewish. During the French Academy of Sciences elections, she was vilified by the right-wing press as a foreigner and atheist. Her daughter later remarked on the French press's hypocrisy in portraying Curie as an unworthy foreigner when she was nominated for a French honour, but portraying her as a French heroine when she received foreign honours such as her Nobel Prizes.

In 1911 it was revealed that Curie was involved in a year-long affair with physicist Paul Langevin, a former student of Pierre Curie's, a married man who was estranged from his wife. This resulted in a press scandal that was exploited by her academic opponents. Curie (then in

her mid-40s) was five years older than Langevin and was misrepresented in the tabloids as a foreign Jewish home-wrecker. When the scandal broke, she was away at a conference in Belgium; on her return, she found an angry mob in front of her house and had to seek refuge, with her daughters, in the home of her friend, Camille Marbo.

1911 Nobel Prize diploma

International recognition for her work had been growing to new heights, and the Royal Swedish Academy of Sciences, overcoming opposition prompted by the Langevin scandal, honoured her a second time, with the 1911 Nobel Prize in Chemistry. This award was "in recognition of her services to the advancement of chemistry by the discovery of the elements radium and polonium, by the isolation of radium and the study of the nature and compounds of this remarkable element." Because of the negative publicity due to her affair with Langevin, the chair of the Nobel committee, Svante Arrhenius, attempted to prevent her attendance at the official ceremony for her Nobel Prize in Chemistry, citing her questionable moral standing. Curie replied that she would be present at the ceremony, because "the prize has been given to her for her discovery of polonium and radium" and that "there is no relation between her scientific work and the facts of her private life".

She was the first person to win or share two Nobel Prizes, and remains alone with Linus Pauling as Nobel laureates in two fields each. A delegation of celebrated Polish men of learning, headed by novelist Henryk Sienkiewicz, encouraged her to return to Poland and continue her research in her native country. Curie's second Nobel Prize enabled her to persuade the French government to support the Radium Institute, built in 1914, where research was conducted in chemistry, physics, and medicine. A month after accepting her 1911 Nobel Prize, she was hospitalised with depression and a kidney ailment. For most of 1912, she avoided public life but did spend time in England with her friend and

fellow physicist, Hertha Ayrton. She returned to her laboratory only in December, after a break of about 14 months.

In 1912 the Warsaw Scientific Society offered her the directorship of a new laboratory in Warsaw but she declined, focusing on the developing Radium Institute to be completed in August 1914, and on a new street named Rue Pierre-Curie (today rue Pierre-et-Marie-Curie). She was appointed director of the Curie Laboratory in the Radium Institute of the University of Paris, founded in 1914. She visited Poland in 1913 and was welcomed in Warsaw but the visit was mostly ignored by the Russian authorities. The institute's development was interrupted by the coming war, as most researchers were drafted into the French Army, and it fully resumed its activities in 1919.

World War I

During World War I, Curie recognised that wounded soldiers were best served if operated upon as soon as possible. She saw a need for field radiological centres near the front lines to assist battlefield surgeons, including to obviate amputations when in fact limbs could be saved. After a quick study of radiology, anatomy, and automotive mechanics, she procured X-ray equipment, vehicles, and auxiliary generators, and she developed mobile radiography units, which came to be popularly known as petites Curies ("Little Curies"). She became the director of the Red Cross Radiology Service and set up France's first military radiology centre, operational by late 1914. Assisted at first by a military doctor and her 17-year-old daughter Irène, Curie directed the installation of 20 mobile radiological vehicles and another 200 radiological units at field hospitals in the first year of the war.

Later, she began training other women as aides.

In 1915, Curie produced hollow needles containing "radium emanation", a colourless, radioactive gas given off by radium, later identified as radon, to be used for sterilizing infected tissue. She provided the radium

from her own one-gram supply. It is estimated that over a million wounded soldiers were treated with her X-ray units. Busy with this work, she carried out very little scientific research during that period. In spite of all her humanitarian contributions to the French war effort, Curie never received any formal recognition of it from the French government.

Also, promptly after the war started, she attempted to donate her gold Nobel Prize medals to the war effort but the French National Bank refused to accept them. She did buy war bonds, using her Nobel Prize money. She said:

“I am going to give up the little gold I possess. I shall add to this the scientific medals, which are quite useless to me. There is something else: by sheer laziness I had allowed the money for my second Nobel Prize to remain in Stockholm in Swedish crowns. This is the chief part of what we possess. I should like to bring it back here and invest it in war loans. The state needs it. Only, I have no illusions: this money will probably be lost”.

She was also an active member in committees of Polonia in France dedicated to the Polish cause. After the war, she summarized her wartime experiences in a book, *Radiology in War* (1919).

Postwar years

In 1920, for the 25th anniversary of the discovery of radium, the French government established a stipend for her; its previous recipient was Louis Pasteur, who had died in 1895. In 1921, she was welcomed triumphantly when she toured the United States to raise funds for research on radium. Mrs. William Brown Meloney, after interviewing Curie, created a Marie Curie Radium Fund and raised money to buy radium, publicising her trip.

In 1921, U.S. President Warren G. Harding received her at the White House to present her with the 1 gram of radium collected in the United

States, and the First Lady praised her as an example of a professional achiever who was also a supportive wife. Before the meeting, recognising her growing fame abroad, and embarrassed by the fact that she had no French official distinctions to wear in public, the French government offered her a Legion of Honour award, but she refused. In 1922 she became a fellow of the French Academy of Medicine. She also travelled to other countries, appearing publicly and giving lectures in Belgium, Brazil, Spain, and Czechoslovakia.

In August 1922 Marie Curie became a member of the League of Nations' newly created International Committee on Intellectual Cooperation. She sat on the committee until 1934 and contributed to League of Nations' scientific coordination with other prominent researchers such as Albert Einstein, Hendrik Lorentz, and Henri Bergson. In 1923 she wrote a biography of her late husband, titled *Pierre Curie*. In 1925 she visited Poland to participate in a ceremony laying the foundations for Warsaw's Radium Institute. Her second American tour, in 1929, succeeded in equipping the Warsaw Radium Institute with radium; the Institute opened in 1932, with her sister Bronisława its director. These distractions from her scientific labours, and the attendant publicity, caused her much discomfort but provided resources for her work.

In 1930 she was elected to the International Atomic Weights Committee, on which she served until her death. In 1931, Curie was awarded the Cameron Prize for Therapeutics of the University of Edinburgh.

Death

1935 statue, facing the Radium Institute, Warsaw

Curie visited Poland for the last time in early 1934. A few months later, on 4 July 1934, she died aged 66 at the Sancellemoz sanatorium in Passy, Haute-Savoie, from aplastic anemia believed to have been

contracted from her long-term exposure to radiation, causing damage to her bone marrow.

The damaging effects of ionising radiation were not known at the time of her work, which had been carried out without the safety measures later developed. She had carried test tubes containing radioactive isotopes in her pocket, and she stored them in her desk drawer, remarking on the faint light that the substances gave off in the dark. Curie was also exposed to X-rays from unshielded equipment while serving as a radiologist in field hospitals during the First World War. When Curie's body was exhumed in 1995, the French Office de Protection contre les Rayonnements Ionisants (OPRI) "concluded that she could not have been exposed to lethal levels of radium while she was alive". They pointed out that radium poses a risk only if it is ingested, and speculated that her illness was more likely to have been due to her use of radiography during the First World War.

She was interred at the cemetery in Sceaux, alongside her husband Pierre. Sixty years later, in 1995, in honour of their achievements, the remains of both were transferred to the Paris Panthéon. Their remains were sealed in a lead lining because of the radioactivity. She became the second woman to be interred at the Panthéon (after Sophie Berthelot) and the first woman to be honoured with interment in the Panthéon on her own merits.

Because of their levels of radioactive contamination, her papers from the 1890s are considered too dangerous to handle. Even her cookbooks are highly radioactive.] Her papers are kept in lead-lined boxes, and those who wish to consult them must wear protective clothing. In her last year, she worked on a book, *Radioactivity*, which was published posthumously in 1935.

Legacy

Marie Curie Monument in Lublin

The physical and societal aspects of the Curies' work contributed to shaping the world of the twentieth and twenty-first centuries. Cornell University professor L. Pearce Williams observes:

The result of the Curies' work was epoch-making. Radium's radioactivity was so great that it could not be ignored. It seemed to contradict the principle of the conservation of energy and therefore forced a reconsideration of the foundations of physics. On the experimental level the discovery of radium provided men like Ernest Rutherford with sources of radioactivity with which they could probe the structure of the atom. As a result of Rutherford's experiments with alpha radiation, the nuclear atom was first postulated. In medicine, the radioactivity of radium appeared to offer a means by which cancer could be successfully attacked.

In addition to helping to overturn established ideas in physics and chemistry, Curie's work has had a profound effect in the societal sphere. To attain her scientific achievements, she had to overcome barriers, in both her native and her adoptive country, that were placed in her way because she was a woman.

She was known for her honesty and moderate lifestyle. Having received a small scholarship in 1893, she returned it in 1897 as soon as she began earning her keep. She gave much of her first Nobel Prize money to friends, family, students, and research associates. In an unusual decision, Curie intentionally refrained from patenting the radium-isolation process so that the scientific community could do research unhindered. She insisted that monetary gifts and awards be given to the scientific institutions she was affiliated with rather than to her. She and her husband often refused awards and medals. Albert Einstein reportedly remarked that she was probably the only person who could not be corrupted by fame.

The curie (symbol Ci), a unit of radioactivity, is named in honour of her and Pierre Curie (although the commission which agreed on the name

never clearly stated whether the standard was named after Pierre, Marie, or both).

The element with atomic number 96 was named curium (symbol Cm).

Three radioactive minerals are also named after the Curies: curite, sklodowskite, and cuprosklodowskite.