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MARIE SKLODOWSKA-CURIE AND HER CONTRIBUTION TO RADIOACTIVITY, CHEMISTRY AND SCIENCE

MARIA SKŁODOWSKA-CURIE - JEJ WKŁAD DO RADIOAKTYWNOŚCI, CHEMII I NAUKI

Abstract: Scientific life of Marie Sklodowska-Curie, physicist and chemist of Polish origin, is presented. Together with her husband Pierre Curie and thanks to the quantitative approach to their study, they **discovered** two new radioactive elements: polonium (July 1898) and radium (December 1898) - it was the beginning of radiochemistry. She assumed that the radioactivity is the result of a decay of atoms (1898-1900). This assumption was proved in 1902 by E. Rutherford and F. Soddy. She found that the radiation of the radioactive substances causes chemical reactions. That was **the beginning of the radiation chemistry**. She established (1929) that the half-life of a particular kind of atomic nuclei does not depend on the external conditions, *ie* it is impossible to affect the radioactive decay in any way. Marie Sklodowska-Curie is the founder of **radiochemistry** as well as **medical radiology**.

She won the Nobel Prize two times: in 1903 **in physics** (1/2 together with her husband; H.A. Becquerel won the other half) for the discovery of radioactivity and in 1911 **in chemistry** (being employed at the Sorbonne) for advancement of chemistry by the discovery of the elements radium and polonium, by isolation of radium and the study on the nature and compounds of this remarkable element.

Keywords: Marie Sklodowska-Curie, polonium, radium, radioactivity, radiochemistry

Abstrakt: Przedstawiono działalność naukową Marii Skłodowskiej-Curie, fizyka i chemika, Polki pracującej we Francji. Dzięki ilościowemu podejściu do badań wraz z mężem Piotrem Curie odkryła dwa radioaktywne pierwiastki - polon (lipiec 1898) i rad (grudzień 1898), co dało początek **radiochemii**. Ona przyjęła, że promieniotwórczość jest wynikiem rozpadu atomów (1898/1900). Założenie to zostało potwierdzone w 1902 roku przez E. Rutherforda i F. Soddy'ego. Małżonkowie Curie jako pierwsi wykorzystywali **radioaktywność** do odkrycia i wyizolowania nowych pierwiastków chemicznych. Maria stwierdziła, że promieniowanie substancji radioaktywnych powoduje reakcje chemiczne, co zapoczątkowało **chemię radiacyjną**. Maria Skłodowska-Curie jest również współtwórcą **radioterapii**, której to poświęciła się przede wszystkim w latach 20. i 30. ubiegłego stulecia.

Maria Skłodowska-Curie została dwukrotnie wyróżniona Nagrodą Nobla: w 1903 roku z fizyki (1/2 nagrody przypadła małżonkom Curie, drugą połowę otrzymał H.A. Becquerel) za odkrycie radioaktywności, a w 1911 roku z chemii (była wtedy profesorem na Sorbonie) za wkład w rozwój chemii poprzez odkrycie radu i polonu, wyizolowanie radu i badania nad naturą związków tych pierwiastków.

Słowa kluczowe: Maria Skłodowska-Curie, polon, rad, radioaktywność, radiochemia

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Marie Sklodowska-Curie and her Contribution to Radioactivity, Chemistry and Science

Worldwide poll

In 2009, the American scientific magazine **New Scientist** carried out a worldwide poll **on the most inspirational woman in science**. **Mme Curie** received nearly as many as twice the votes cast for the candidate in second place.

Marie Sklodowska-Curie

(7th November 1867 - 4th July 1934)

was a physicist and chemist of Polish origin and upbringing and, subsequently, French citizen.

She was the **first woman** who has got a PhD in physics and subsequently was **professor at the University of Paris.**

She was a pioneer in the field of radioactivity, the **first person honored twice with Nobel Prize,** receiving one in physics and later on, one in chemistry.

The International Year of Chemistry

In the year 2010 the **IUPAC** *(International Union of Pure and Applied Chemistry*) and **UNESCO** (*United Nations Educational, Scientific and Cultural Organization*) put forward a proposal to the **UNO** (*United Nations Organization*) to declare the year **2011 as THE INTERNATIONAL YEAR OF CHEMISTRY** (**IYC 2011**).

The United Nations Organization supported fully the idea.

In the year **2011** is a centenary of the **second** Nobel Prize awarded to **Marie Sklodowska-Curie** by the Nobel Committee (**MSC100**).

Marie loved the quarter very much

Birthplace

Marie Sklodowska-Curie, née **Maria Sklodowska, was born on 7th November 1867, in Warsaw, Poland**.
Her parents, Bronislawa and Wladyslaw Sklodowski, **were teachers**; they had 5 children.

Marie and her sisters would often play **a game imagining a genius doctor** who finds a miracle cure. Marie's dream of science and medicine used for humanitarian purposes would last for her entire lifetime, and would eventually **come true**.

Schooldays

Marie attended a gymnasium for girls, from which she graduated on the 12th June 1883, when **she was just under 16 years old**. She was the best student and was awarded a **gold medal as the valedictorian of her class**. She had acquired proficiency at a few foreign languages: Russian and French (taught at the school), as well as German and English.

University studies in Warsaw

She commenced her (informal) higher studies (1890) in Warsaw at the so-called **Flying University**.

Father with daughters (from the left) Marie, Bronislawa and Helena

University studies in Warsaw

Marie acquired her qualification in chemistry (knowledge and skills) at the **Chemical Laboratory of the Museum of Industry and Agriculture**, a Polish business institution. The laboratory was headed by **Prof. N. Milicer** [1842-1905], who was a student of the famous German chemist **Prof. R. W. Bunsen** [1811-1899], while another staff member **was Dr L. Kossakowski**.

Napoleon Milicer

University studies in Warsaw

At this Warsaw laboratory, Marie was taught a systematic course on chemical analysis, both qualitative and quantitative, which included the analysis of **minerals**.

University studies in Warsaw

Therefore, in this laboratory, Marie came to **master the chemical laboratory techniques** that would later be needed to isolate polonium and radium from uranium ore. She stressed this explicitly during a lecture delivered in Warsaw (1913):

If Professor N. Milicer and Dr L. Kossakowski had not taught me chemical analysis properly, I would not have been able to isolate polonium and radium.

University studies in Paris


RÉPUBLIQUE FRANÇAISE.

Diplôme de Licencié ès Sciences physiques.

Le Ministre de l'Instruction publique,

Then, upon moving to the University of Paris, she studied **physics** (1891-1893), she was the **best** student of that year and **mathematics** (1891-1894), she was **the second best**.

To become acquainted with Pierre Curie

At a small party, organized by Professor J. Wierusz-Kowalski [1866-1927] from the Freiburg University, CH, Marie met **Dr Pierre Curie**, who worked at the Technical College of Physics and Chemistry (ESPCI). After a short time, he wanted to be as close to her as possible.

The marriage

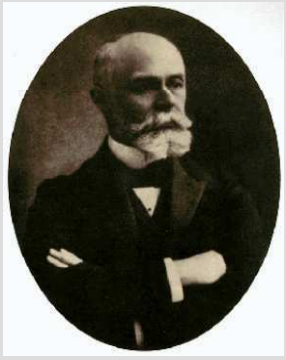
But Marie was a Polish patriot, as the majority of the young Polish intelligentsia were in those times, so she wanted to work in Poland. However, after a few months and some hesitation, Marie realized that she and Pierre were made one for another.

The marriage

They were married in a simple ceremony on 26th July 1895.

Becquerel rays

At the time (on 1st March 1896), Professor H. Becquerel, discovered - **by chance** - that uranium salts emitted rays which resembled X-rays. He showed that this radiation, **seemed** to **arise spontaneously from uranium itself**. Becquerel had in fact discovered radiation, which was known for a while as "Becquerel rays."

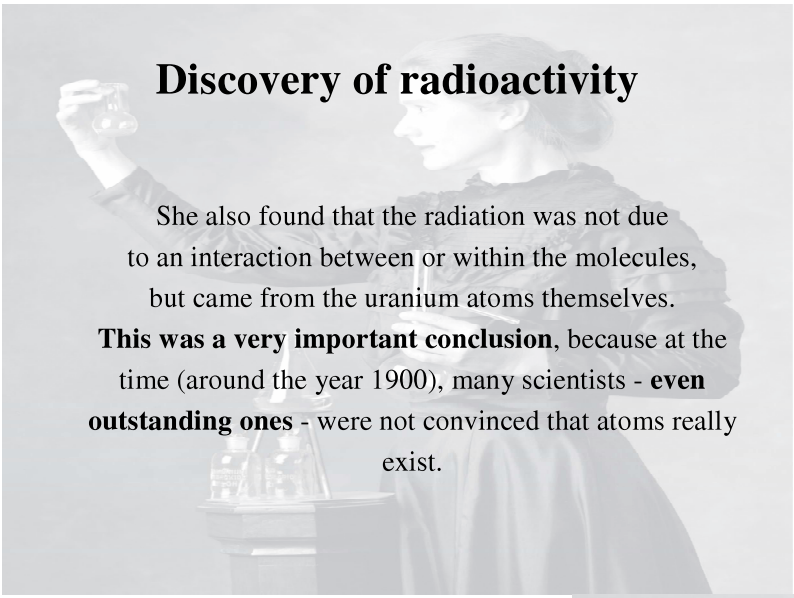


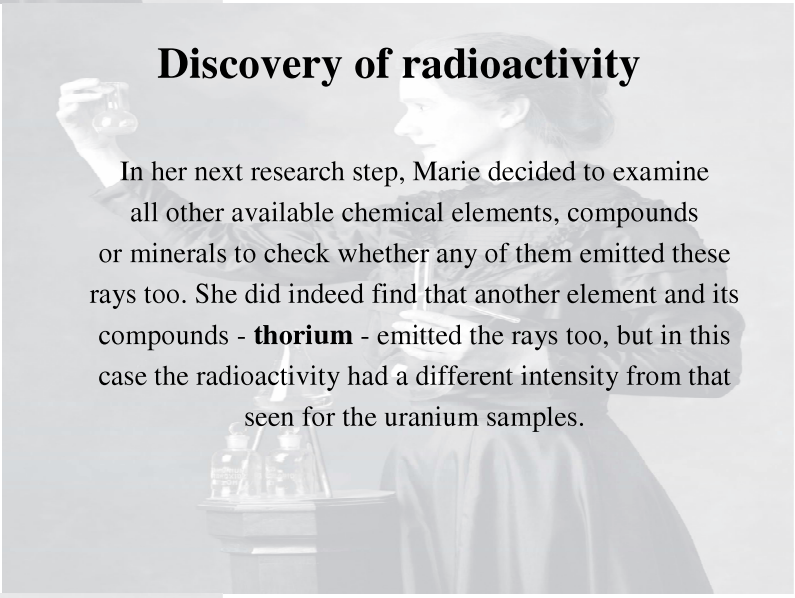
Discovery of radioactivity

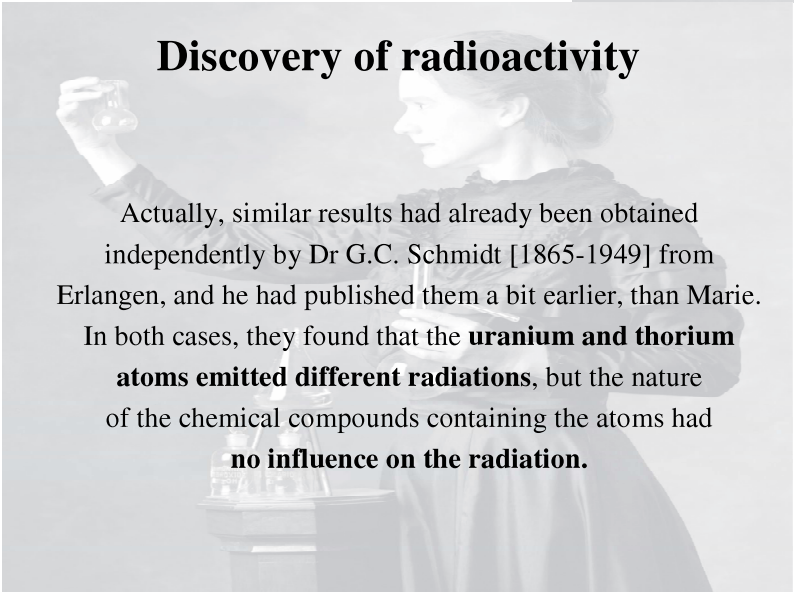
In 1897, Marie decided to begin the research work that she intended to present as her Ph.D. She considered the Becquerel rays as a possible field of study. She began by repeating Becquerel's experiment with the uranium compounds, measuring their ionization efficiencies.

Discovery of radioactivity

From the beginning of her investigations, Marie used an advanced tool of measurements: the Curies piezoelectric quartz electrometer. Using the electrometer, she discovered that the ionization efficiency of uranium rays **depended only on** the quantity of uranium present in the sample.


Discovery of radioactivity
She also found that the radiation was not due to an interaction between or within the molecules, but came from the uranium atoms themselves.
This was a very important conclusion, because at the time (around the year 1900), many scientists - **even outstanding ones** - were not convinced that atoms really exist.


Discovery of radioactivity
In her next research step, Marie decided to examine all other available chemical elements, compounds or minerals to check whether any of them emitted these rays too. She did indeed find that another element and its compounds - **thorium** - emitted the rays too, but in this case the radioactivity had a different intensity from that seen for the uranium samples.


Discovery of radioactivity
Actually, similar results had already been obtained independently by Dr G.C. Schmidt [1865-1949] from Erlangen, and he had published them a bit earlier, than Marie.
In both cases, they found that the **uranium and thorium atoms emitted different radiations**, but the nature of the chemical compounds containing the atoms had **no influence on the radiation.**

Discovery of radioactivity

The next step in Marie's systematic studies included three uranium minerals (pitchblende, chalcolite and autunite). Her electrometer showed that **pitchblende was four times as active as metallic uranium** itself, and **chalcolite was twice as active**.

Discovery of radioactivity

She concluded that, if her earlier results relating the quantity of uranium to its radioactivity were correct, then these **two minerals must contain some quantities of other elements** that were **far more active** than uranium itself.

Discovery of radioactivity

To check this conjecture, she synthesized a compound with the same chemical composition as that of chalcolite $\{Cu(UO_2)_2(PO_4)_2 \cdot (8–12)H_2O\}$.
The synthetic compound emitted the rays to some extent (*due to the content of uranium*). But its radioactivity was much smaller than that of the natural mineral.
So Marie realized that natural chalcolite as well as pitchblende **contain** some elements that show **much stronger radioactivity** than uranium itself.
She **decided** to isolate **these elements**.

Discovery of radioactivity

Pierre Curie was also sure that what she had discovered was not a spurious effect. He was so intrigued that he decided to postpone (for a while) his own work on crystals to help her.

On 14th April 1898 they - optimistically - weighed out a 100 g sample of pitchblende and ground it with a pestle and mortar.

Discovery of radioactivity

They did not realize at the time that what they were searching for was present in **very small** quantities that they would eventually have to process tonnes of the ore. Here Marie assumed the role of **a chemist**, extracting and purifying the fraction containing the elements searched for, while Pierre focused on **the physical** (mainly electrical) measurements. So the Curies undertook the arduous task of separating out radioactive salts by **differential crystallization**.

Discovery of radioactivity

Pitchblende is a complex mineral; the chemical separation of its constituents was a task that required hard work. On 18th July 1898, the Curies obtained a sample which displayed emission that was **400 times bigger** than that of **uranium**.

Discovery of radioactivity

They published a paper together that announced the existence of an element which they named **polonium** in honor of Marie's native country. In this communication, the term "**radioactivity**" was introduced.

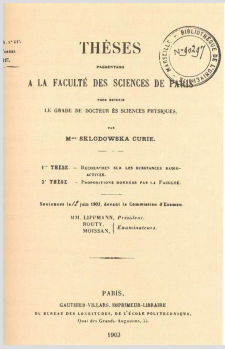
Discovery of radioactivity

On 26th December 1898, the Curies (helped by G. Bémont [1857-1932]) announced the existence of a second element, which they named **radium** (*from the Latin word "radius", which means a ray*) due to its intense radioactivity.

A sample that contained only a very small quantity of **radium chloride** provided by the Curies was investigated using emission spectroscopy by E. Demarçay [1852-1904] from Paris University, he detected a new line at $\lambda = 381.48$ nm, thus confirming the existence of a new chemical element.

Discovery of radioactivity

Marie presented the research data (*gathered in 1897-1902*) in her **Ph.D. thesis**. On 12th June 1903, the University of Paris awarded her a Ph.D. in physics.



THÈSES

PRÉSENTÉES

A LA FACULTÉ DES SCIENCES DE PARIS

POUR OBTENIR

LE GRADE DE DOCTEUR ÈS SCIENCES PHYSIQUES.

PAR

Mme SKLODOWSKA CURIE.

1re THÈSE. — RECHERCHES SUR LES SUBSTANCES RADIO-ACTIVES.

2e THÈSE. — PROPOSITIONS DONNÉES PAR LA FACULTÉ.

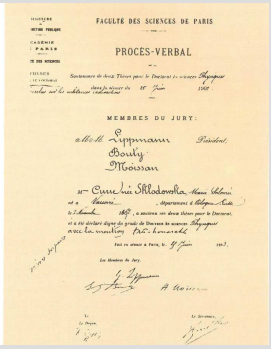
Soutenues le 12 juin 1903, devant la Commission d'Examen.

MM. LIPPMANN, *Président.*
BOUTY,
MOISSAN, *Examinateurs.*

PARIS.

GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE

1903



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M. Lippmann *Président.*

Bouty

Moissan

Mme Curie née Sklodowska

Discovery of radioactivity

From the beginning, there was some debate over the source of the radiation observed. Marie was rather inclined to assume that the radioactivity was the result of the decay of atoms (1898-1900), but Pierre was not convinced of this idea at all.
Eventually, the atomic decay was demonstrated in 1902 by E. Rutherford [1871-1937] and F. Soddy [1877-1956].

Discovery of radioactivity

The Curies decided **not to patent** their extraction process, but to provide details of it for radium chemical extraction **for free**.

Radiochemistry and radiation chemistry

Thus, Marie was the founder of **radiochemistry** - the chemistry of radioactive elements, although this term was actually introduced in 1911 by F. Soddy. She also discovered that the **radiation causes chemical reactions**, which marked the **beginning of radiation chemistry**.

Atomic mass of radium

In 1902, from a ton of pitchblende, she obtained 0.1 g of **radium chloride** (*its radioactivity was **109 times more intense** than the same amount of uranium*), and determined its chemical and physical properties, including a rough estimate of its atomic mass **(225 ± 1)**.

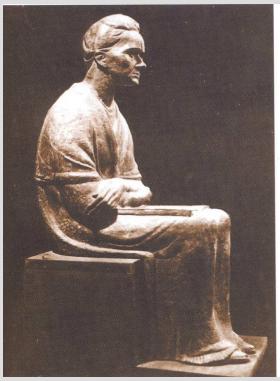
This determination made it possible to establish **its position** in the periodic table of the elements.

Isolation of pure polonium

After obtaining a greater amount of $RaCl_2$, Marie was able to determine the **radium atomic mass** more precisely. In 1907, she found that it was equal to **226.45 ± 0.50**; (now 226.025). In 1910, together with A. Debierne [1874-1949], she obtained **metallic radium** through the electrolysis.

She was worked out a method to determine small amounts of radium by measurement of radon concentration. Marie also isolated **pure polonium** and subsequently determined its chemical and physical properties.

Primary standard of radium



Following the decision of the Second International Radiological Congress in Brussels (1910), **Marie prepared the primary standard of radium** in 1911, and delivered it to *Bureau International des Poids et Mesures* in **Sèvres**.

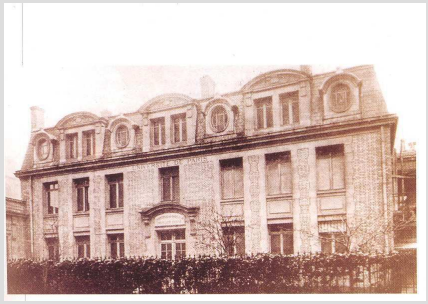
She founded a world center for studies in nuclear chemistry and physics.

First Nobel Prize

In 1903, the **Nobel Prize in Physics** was awarded to **Henri Becquerel**, **Pierre Curie** and **Marie Sklodowska-Curie** *in recognition of the extraordinary services they have rendered by their joint researches on* ***the radiation phenomena*** *discovered by Professor Henri Becquerel.*

First Nobel Prize

Marie was, the first woman to receive the Nobel Prize.
The Sorbonne gave (1904) **Pierre a professorship** and **Marie became the Director of Research** of his laboratory.



Three years later *(on 19th April 1906)*, Pierre was killed in a street accident. The Physics Faculty of Sorbonne decided to retain the Chair of General Physics and Radioactivity, and **passed it to Marie**.
She was the **first woman** working as **professor** at the **Sorbonne** and in the whole **France**.

Second Nobel Prize

In 1911, Marie was awarded with a **second Nobel Prize** - this time in **Chemistry**: *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.*
This made Marie Sklodowska-Curie **the first person to win two Nobel Prizes** in two different fields of natural sciences.

Second Nobel Prize

Nobel Prizes for Irene and Frédéric Joliot-Curie

Furthermore, her daughter **Irene Joliot-Curie** [1897-1956] and her son-in-law, **Frederic Joliot-Curie** [1900-1958] would later also share a Nobel Prize - which they obtained **in 1935** for the discovery of **artificial radioactivity** in 1934.

This is the only case of a mother and daughter attaining this great honor.

Radium Institute

Marie Sklodowska-Curie's second Nobel Prize made it possible for her to request funding for the construction of her growing laboratory (which was attracting many researchers, including those from abroad).

Radium Institute

Following this request, the University of Paris and the Institut Pasteur decided to build the Radium Institute (***Institut du radium, now the Institut Curie***), which was eventually constructed in 1914 and was a focus for research in chemistry, physics, and medicine. She was the Head of the Physico-Chemical Department there, while Dr. C. Regaud [1870-1941] ran the Department of Life Sciences. Both departments worked closely together.

War broke out

On 3rd August 1914, war broke out between Germany and France, and soon German troops were approaching Paris.
Marie, after taking along to countryside her two daughters, she decided to go to the front to help wounded soldiers.

Les petites Curies

At the front, she organized a mobile X-ray service, *eg* she obtained 20 privately owned automobiles which were then fitted with X-ray equipments and taken to the front line. These ambulances were nicknamed ***les petites Curies.***

Mobile radiological service run by Marie Sklodowska-Curie. The trucks were used to carry X-ray equipments that was employed (among other purposes) to search for shrapnel in the bodies of wounded soldiers (1914-18).

At the front-line

Working at the front-line, Marie very often served as an apparatus operator or ambulance driver, sometimes even performing car repairs - changing a wheel while standing in the mud! The solders at the front quickly got to know this elderly woman with a few gray hairs, but they found it difficult to believe that such a great scientist had come to help preserve their lives and health. Marie was also helped in this work for a year by her 17-year-old daughter, Irene.

Fund-raising in America

In 1921, Marie was given a triumphant welcome when she toured the United States to raise funds for research on radium. She obtained the 1 g of radium *needed for the Radium Institute in Paris*.

M. Sklodowska-Curie in the White House with Warren G. Harding [1865-1923], President of the United States

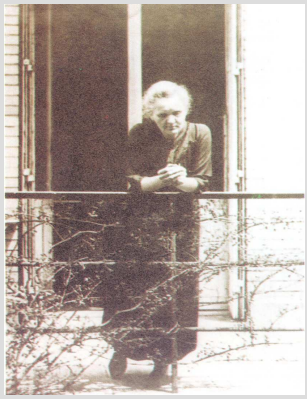
Fund-raising in America

Her second American tour in 1929 enabled her to equip the Radium Institute in Warsaw (*founded in 1925, and currently known as the Maria Sklodowska-Curie Memorial Cancer Center and Institute of Oncology*) also with 1 g of radium.

M. Sklodowska-Curie in the White House with Herbert C. Hoover [1874-1964], President of the United States

Contacts with Polish scientists

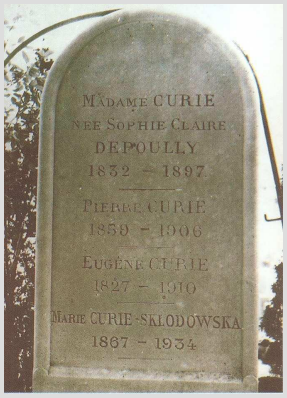
Marie was in contact with other Polish scientists throughout her whole period of scientific activity. She also published her doctoral dissertation (*Badanie ciał radioaktywnych*, Warszawa 1904) in her native language. Her paper in Roczniki Chemii (1926, **6**, 355-361) entitled *The present state of polonium chemistry* was printed in Polish.



Contacts with Polish scientists

Many Poles have worked in the Curie's laboratory in Paris, including J. K. Danysz [1884-1914], one of the inventors of β-spectroscopy, and L. Wertenstein [1887-1945]. In **1913**, the **Radiological Laboratory of the Warsaw Scientific Society** (WTN) was founded in Warsaw. Marie was asked to be the Head of this laboratory, and she accepted the invitation. However, because she could not leave Paris, the laboratory was actually managed by a deputy director - initially J. K. Danysz, and later L. Wertenstein. Finally, in 1926, she became the Honorary Head of this institute.

Last days and resting-place



Being ill, Marie Sklodowska-Curie went to the **Sancellemoz** Sanatorium in Passy, in the Sabaudian Alps for recovery. She died there on **4th July 1934** due to aplastic anemia (leukemia) that was almost certainly contracted as a result of her exposure to the radiation from the radioactive sources that she investigated. She was initially interred at the cemetery in **Sceaux**, alongside her husband Pierre.

Last days and resting-place

Sixty years later (on **20th April 1995**), in honor of their achievements, the remains of both of the Curies were transferred to the **Pantheon in Paris**.

She became the first - and so far the only - woman to be honored in this way.

In summary

- Marie Sklodowska-Curie, along with her husband Pierre, discovered two new radioactive chemical elements: **polonium and radium**.
- The Curies qualitatively isolated both of these elements, while Marie later obtained them in their pure states.
- They were the first to show that **chemical element** could be **transmuted** into another one.
- The Curies were the first **to use radioactivity as a tool for isolating new chemical elements** from a complex matrix.

In summary

- **Marie was the founder of radiochemistry** and **radiation chemistry**.
- She provided the information on isolating radium and polonium **free of charge**.
- Much of her research was directed towards the **use of radioactive substances in medicine** - mainly in diagnostics and for curing cancer (**so her childhood dream came true**).

In summary

Without their pioneering work, the history of atomic and nuclear research would be very different *eg* in **1909**, Ernest Rutherford with his co-workers (*H. Geiger* [1882-1945] *and E.G. Marsden* [1889-1970]) **used a sample of radium to bombard a thin gold foil with alpha particles**. In **1911**, the data he obtained from this experiment led him to **formulate the planetary model of the atom** - a model that is still valid (with some refinements) today.

In summary

In **1919**, by bombarding nitrogen atoms with alpha particles

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

Rutherford carried out the first artificial nuclear reaction: ***he split the atom***.

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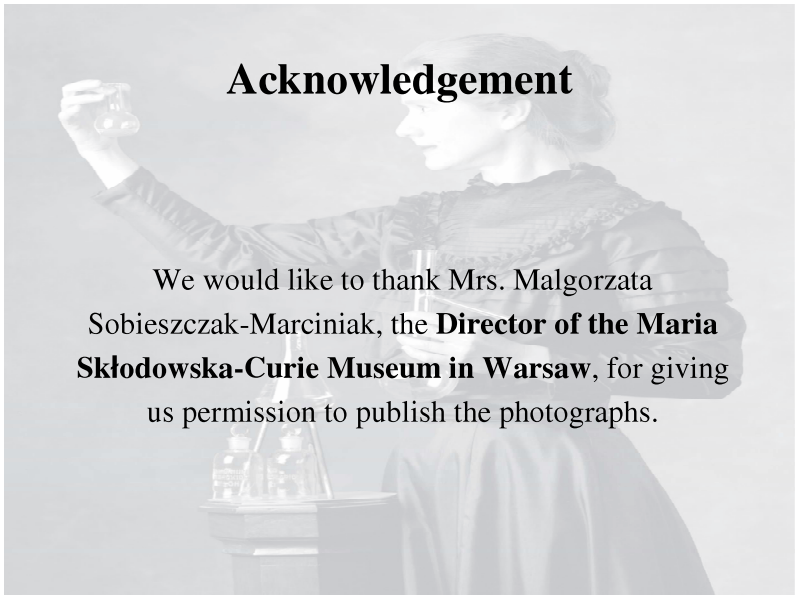

Acknowledgement

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