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The legacy of Maria Curie Skłodowska

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ABSTRACT

Maria Skłodowska Curie left us a great legacy. Her discovery of polonium and radium was incomparably greater than the mere discovery of new elements. Its significance lay in the discovery of a new form of matter, namely radioactive one, but also in her unveiling of the internal property of its atoms. Subsequently emitted radiation went on to play the role of a "natural accelerator" for both scientific research and in medical radiotherapy. It was thanks to these discoveries that the field of nuclear physics arose just a few decades later. As importantly the work of Maria Curie Skłodowska during the Great War demonstrated how important pure scientific discovery can be for society and its welfare.

1. INTRODUCTION

November 5th, 1906 was for many Parisians a very special day. Crowds were gathered in front of the building where Maria Curie was to become the first woman in the history of the Sorbonne to give an inaugural lecture. Many people, even from outside of Paris, had come especially for the occasion. They came in order to see the eminent scientist but more especially to greet the first woman Nobel Prize winner in physics. During its long history, the Sorbonne had never had such a lecture, given by a woman, and curiosity had driven many to attend what was to be a unique occasion.

Maria Curie was to present the lecture which had been due to be given by her late husband, Pierre Curie, who had been tragically killed in a street accident and with whom she had won the Nobel Prize. The crowd of people who wanted to attend Maria Curie's lecture was growing. But in the auditorium there were only one hundred and twenty seats, most of which would host the students for whom the lecture was intended, numerous journalists and invited guests. The first row was occupied by Maria Curie's pupils from the Normal Superior School for girls in Sévres. The auditorium was completely full.

2. PHYSICS MORE IMPORTANT

> "When one considers the progress that has been made in physics in the past ten years, one is surprised at the advance that has taken place in our ideas concerning electricity and matter...."
>
> (Marie Curie, Inaugural lecture November 5th 1906 [1])

At one thirty the Dean gives the sign to start the lecture and thirty-nine-year old Maria Curie begins:

> "When one considers the progress that has been made in physics in the past ten years ……"

And she develops for the audience the picture of atoms of matter which, contrary to their name, appear to be divisible. She describes the atoms of negative electricity – indivisible electrons, which are always the same independently of what source they are from. Conversely, the carriers of positive electricity are completely different as they are less mobile and resemble canal rays. Maria Curie then explains the electric properties of gases. Normally they are insulators but when irradiated with X- rays or with rays from radioactive bodies they are able to conduct electricity.

Coming to radioactivity, Maria Curie stresses a completely new aspect of atoms. Radioactive atoms are not stable and while emitting radiation they are converted into atoms of another element and release energy that far exceeds the energy outcome of chemical reactions. The radioactive decay of one gram of radium produces heat equal to that produced from burning one ton of coal.

Concluding, Maria Curie explained why she expected there to be a further and rapid increase in our knowledge. It was a message to scientists.

> "At the end I would indicate the general significance of radioactivity. In physics radioactive bodies, due to their radiation, constitute a new tool of research …. Through their numerous effects in chemistry, physiology and a possible influence on meteorological conditions these bodies expand the

> sphere of their interactions over the whole of science and one may expect that their role for natural science will increase." [1]

The last sentence of the lecture concerned solar energy.

> "There is no absurdity in admitting that the energy we obtain from the sun has its origin partially or total from radioactive bodies contained therein."[1].

It sounded like a prophecy. Much later physicists learnt that energy from radioactive decays and solar energy are both the results of the same mechanism – the creation of strongly bound α particles. Maria Curie left the auditorium to a tumultuous ovation.

Fig. 1 "L'Illustation" of November 10th, 1906 reports on Maria Curie's lecture

During her lecture Maria Curie never deviated from physics for a single moment. She never gave any indication that the lecture was anything special. Yet it was, both socially and personally. For the Sorbonne because it violated a tradition preserved for centuries and for herself because fate had decided that she was lecturing in place of her late husband who had died only a few months before in a tragic accident. The lecture focused on physics from the first word to the very last sentence; because at that place and that time physics was more important.

3. THE RADIATION OF POLONIUM AND RADIUM CREATES NUCLEAR PHYSICS

> "In physics the radiation of radioactive bodies constitutes a new tool for research."
>
> (Marie Curie, Inaugural lecture November 5th 1906 [1])

The first decades of twentieth century confirmed the words of Maria Curie that the radiation of radioactive bodies was a very important tool for studying the structure of matter and its properties.

Let us imagine that in a given field of science a revolutionary discovery is made, which provides science with dramatically new techniques with which to perform laboratory investigations. Clearly, such a development would enable faster progress and result in many important results. Unfortunately, such discoveries are very rare.

Nevertheless, it happened with the discovery of polonium and radium by Maria and Pierre Curie. The intensive radiation emitted by these elements played the role of future accelerators. The energy of α particles emitted by radioactive radium and polonium was a few MeV. It was significantly larger than the energy obtained with the cyclotron built in 1931 by Ernest Lawrence. Moreover, it was easy to work with radioactive beams. It did not require, apart from common sense, any special technical knowledge.

The expectation of Maria Curie that the radiation of radioactive bodies would lead to discoveries has proved true. These discoveries are common knowledge, but it is worth emphasizing that they were both extraordinary and unexpected.

1911 Ernest Rutherford, after an eighteen-months analysis of the scattering of α particles on thin gold foil, published the information that, in atoms, there were very small nuclei which carry nearly the whole atomic mass. This followed from the observation of the backward reflections of α particles by the foil. Later Rutherford recalled:

> "it was as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

1919 Ernest Rutherford performed the first nuclear reaction. He introduced the radon source of α particles into a vessel filled with nitrogen and covered one side with a scintillating screen. This caused flashes on the screen. Their appearance indicated that the screen was hit by nuclei of hydrogen. As the vessel contained pure nitrogen the hydrogen had to be produced by α particles. It turned out that their collisions with nuclei of nitrogen produced nuclei of oxygen and nuclei of hydrogen, the last being named by Rutherford 'protons'.

$$\alpha + {}^{14}N \rightarrow {}^{17}O + p$$

When working on alpha-nitrogen collisions, Rutherford had less time for research as antisubmarine defense and the war was persisting. To justify himself he said:

> "If, as I have reason to believe, I have disintegrated the nucleus of the atom, this is of greater significance than the War."

1921 Salomon Rosenblum, working in the laboratory of Maria Curie, investigated the energy spectrum of α particles emitted from Thorium C and found that they are not mono energetic. This was proof that nuclei of lead ^{208}Pb produced from alpha decays can exist in various energy states. It was the origin of nuclear spectroscopy

1932 James Chadwick explained that the electrically penetrating neutral radiation which was produced by α particles hitting boron or beryl is not a gamma radiation. It is composed of neutral particles with a mass close to that of a proton. These particles were named "neutrons",

$$\alpha + {}^{11}Be \rightarrow {}^{14}N + n$$

For his discovery James Chadwick was awarded the Nobel Prize for physics in 1935.

1934 In January Irene and Frederic Joliot-Curie, while irradiating aluminum with α rays from polonium, obtained radioactive phosphorus ^{30}P, which emitted rays different from those of polonium, radium, uranium and thorium. It emitted recently discovered positrons.

$$\alpha + {}^{27}Al \rightarrow {}^{30}P + n$$
$${}^{30}P \rightarrow {}^{30}Si + e^{+} + \ldots$$

Maria Curie died in July in the same year but not before she learned that Irene and her husband had discovered "artificial radioactivity". They were awarded the Nobel Prize for chemistry in 1935.

As a result of the discovery of the rays of polonium and radium, within a quarter of century, of which war occupied four years, the basis of nuclear physics in its present form was established.

Fig. 2 Maria Curie measuring the radioactivity.

4. FROM LABORATORY TO RADIUM INSTITUTE

> "I accepted this heavy heritage, in the hope that I might build up some day, in his memory, a laboratory worthy of him, which he never had…"
>
> (Maria Curie, "Pierre Curie" [2])

Shortly after the death of Pierre Curie in April 1906 the Faculty of Sciences of the Sorbonne proposed that Maria Curie took over the Chair, tragically left by Pierre Curie. The decision whether to accept the offer was not easy. Maria Curie was not convinced that she would be able to fulfill the duties of such a post. On the other hand she felt responsible for the Chair and for the future of laboratory research. Finally, she agreed to accept the Chair as assistant professor. Maria Curie was the first woman to occupy such a position in the history of the Sorbonne. Two years later she became titular professor.

In parallel with her family duties and university obligations Maria Curie undertook intensive laboratory research. One problem was of particular importance to her. Incontestable proof that radium is a chemical element was still missing. For this purpose, a macroscopic amount of pure radium was needed. This would allow the optical spectrum of radium to be studied which would confirm whether or not it was a new element. After very hard and tedious work Maria Curie extracted from uranium ore 4 decigrams of very pure radium chloride. This allowed her to accurately measure the atomic weight of radium. This was an important argument that radium was an element. However not everybody was convinced. Lord Kelvin (William Thomson), a person of a great authority in the scientific community maintained that radium was a helium-lead compound. In fact, both helium and lead exist as final products of radium decays. However, lead appears at the end of the uranium-radium series. According to Lord Kelvin, the "molecule" of radium was built of one atom of lead and five atoms of helium. Its total atomic weight was therefore 226 atomic mass units – the radium atomic weight obtained by Maria Curie.

Nevertheless, in spite of the general acceptance that radium was a chemical element, Maria Curie felt that it is her duty to show to those unconvinced the precise nature of the matter called radium discovered by her and Pierre. In 1910, twelve years after the discovery of radium, Maria Curie in collaboration with Andre Debierne obtained pure metallic radium and finally removed all doubts as to whether radium was an element. As usual she fulfilled her duty to the very end.

In 1911 Maria Skłodowska Curie was awarded a second Nobel Prize, this time for chemistry,

> "...for her services in 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." (1911 Nobel Citation)

The second Nobel Prize for Maria Curie Skłodowska was an extraordinary event. Even her opponents had to admit her extraordinary capabilities. Maria Curie was the only female laureate of the Nobel Prize in physics until 1963 when Maria Goepert –Mayer together with Hans Jensen received the Nobel Prize in physics for the shell model of atomic nuclei.

While still together, Maria and Pierre Curie had discussed plans to build a new large laboratory for their research. Shortly after the death of Pierre, the University authorities proposed to open a public subscription to finance the construction of the laboratory for Maria Curie. She did not accept this proposal because she was afraid that it was merely an expression of compassion for her and sympathy for her loss of Pierre Curie, which would go with time.

However, in 1908 the President of the University and the Director of the Pasteur Institute decided that both institutions would together finance the construction of Radium Institute, composed of two laboratories. One would be for the research of radioactivity in physics and chemistry under the leadership of Maria Curie; the other – for research in biology and medicine oriented towards curie therapy (therapy with radium), under the leadership of an eminent professor of medicine, Claudius Regaut. The two laboratories would be independent but would collaborate in developing knowledge of radium and its applications.

Maria Curie enthusiastically set out to prepare plans for the future laboratory. With her mind filled with ideas, she also insisted on large and empty rooms to allow for further development of the laboratory.

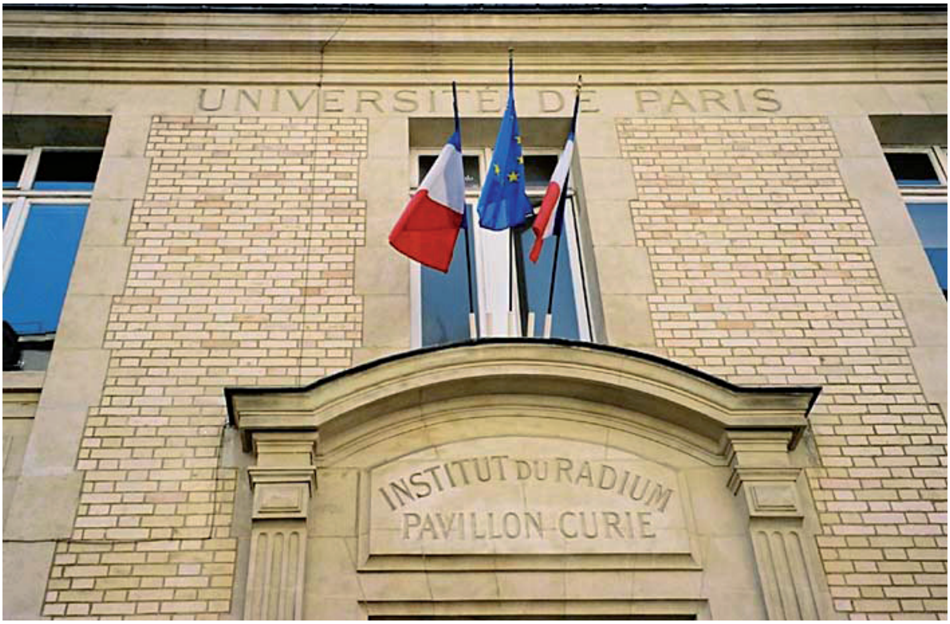

Fig. 3. The construction of Pavilion Curie was completed in July 1914.

Finally, in July 1914, the construction was completed. Maria Curie could read the inscription engraved in stone above the main entrance: "Radium Institute, Pavilion Curie". She expected that her collaborators and students would soon move to the new laboratory and she would be able to continue her interrupted work. However it turned out that they had to wait. War was engulfing Europe.

5. THE GREAT WAR

> "Having no possibility to serve my unlucky country stained with blood after hundreds of years of suffering I decided to give all my forces to my adopted country."
>
> (Maria Curie to Paul Langevin, January 1st 1915 [3])

The war started on August 1st, 1914, when German troops entered French territory. Hospitals were soon filled with the wounded and the dying. Maria Curie realized that they had practically no x-ray apparatus. Without such apparatus it was difficult, painful and time consuming to localize bullets and fragments of shrapnel in the bodies of the wounded. The first x-ray apparatus to reach hospitals in Paris and its environs was acquired by Maria Curie from University laboratories. The x-ray units were operated by volunteers from the university who had not been mobilized and had been found and recruited by Maria Curie. Later, when the action of Maria Curie received financial support x-ray, the sets were installed in some 200 hospitals. The operators were trained by Maria Curie and her daughter, Irene.

In order to be able to provide x-ray service for the many field hospitals Maria Curie created a team operating mobile x-ray systems. They were installed on cars and run from dynamos operated by car engines. Funds allowed for the construction of twenty mobile x-ray sets. They were commonly called "little Curies". A few cars were offered by friends of Maria Curie and the rest were bought. In order to be able to reach urgently hospitals which had asked for an x-ray system Maria Curie passed her driving test and personally drove the cars with the x-ray sets along the almost impassable roads.

After the war Maria Curie wrote:

> "The history of the war radiology is a striking example of how large and unforeseen is the range of practical applications pure scientific discovery can have in certain conditions." (Maria Curie, La Radiologie et La Guerre [4])

However, it is worth remembering that the war activity of Maria Curie showed that scientific discovery in itself is insufficient. Applying a discovery in practice requires hard work, considerable skill and often considerable sacrifice.

Some people now argue that it was not the work with radium as such which shortened the life of Maria Curie, but rather the long exposure to radiation from her x-ray systems during four years of war. This was fatal for her but she desperately wanted to ease the suffering of the injured and make the work of surgeons more effective.

There is one episode from the beginning of the war which is worth recalling. When in the first days of the war it became more and more probable that Paris would be surrounded and occupied, Maria Curie decided to stay. She believed that in the case of German occupation her presence in the Radium Institute could prevent the destruction of the Institute and its equipment. She did not want, however, to risk the loss of the precious radium. Maria Curie left Paris for Bordeaux carrying the radium protected with lead in an overcrowded train. There she left the radium with the Science Department of Bordeaux University returning by troop train to increasingly menaced Paris the very next day.

History likes to repeat itself. Similar care for radium, this time of Polish radium, was shown by Professor Franciszek Łukaszczyk, the Director of the Radium Institute in Warsaw. He twice took away radium from Warsaw saving it from destruction and robbery, first in September 1939 during the bombing of Warsaw and then in August 1944 during the Warsaw Uprising.

6. THE PEACE

> „To hate the very idea of war, it ought to be sufficient to see once what I have seen so many times all through those years”
>
> (Maria Skłodowska-Curie, [2])

The War ended in autumn 1918. Earlier, in 1915, Maria Curie had transported her equipment from the old laboratory to the new Pavilion Curie of the Radium Institute. Work gradually started. With time the number of collaborators grew – new ones joined and there were those returning after demobilization. Among them were quite a few researchers from Poland.

Soon, the laboratory of Maria Curie in the new Radium Institute became an important scientific centre for research into radioactivity. The research initiated by Maria Curie on atomic alpha decay lead in 1921 to the aforementioned discovery by Salomon Rosenblum of excited states of atomic nuclei. Maria Curie in the new laboratory restarted research on polonium. Her results in this field were an important contribution to chemistry. She found the way to prepare very intensive polonium sources of alpha particles. Such a source was used in 1932 by Irene and Frederic Joliot-Curie for their discovery of artificial radioactivity.

The memory of the cruelties of the late war made people afraid for the future of mankind. To prevent future wars the President of the United States, Thomas W. Wilson proposed the establishment of an international organization whose aim would be the avoidance of military conflicts. In 1920 The League of Nations was created. It organized the International Committee for Intellectual Collaboration. Maria Curie was shortly the Vice President of the Committee. She undertook actions to facilitate the international cooperation of scientists such as the unification of symbols and terminology and the publications of chemical and physical tables. She also tried to assure the right of scientists to their intellectual properties when used by industry.

Fig. 4 Maria and Pierre Curie in their laboratory. They never patented their discoveries

May be that Maria Curie changed her mind on this last subject after her personal experience. Maria and Pierre Curie never patented any of their results nor the methods to reach them. She admits in her Autobiographical

Notes [2] that if she and Pierre had taken a different attitude she would have had no difficulty financing her researches and even those of the whole Radium Institute. Maria Curie ends these considerations:

> "Yet, I still believe that we were right" [2].

It shows that throughout her life and work Maria Curie placed a concern for others and a concern for the betterment of people before her own interests and demanded of herself the highest moral conduct.

7. "….CALLED POLONIUM AFTER THE NAME OF THE COUNTRY OF ORIGIN OF ONE OF US"

> "If the existence of this new metal is confirmed, we suggest that it should be called polonium after the name of the country of origin of one of us."
>
> (Maria and Pierre Curie, Report to Academy 1898)

It is difficult to overestimate the importance of the gift which Maria Curie Skłodowska offered her country. Naming one of the discoveries made by herself and by her husband after Polonia (Latin name for Poland) bore witness to the fact that Poland existed although it was missing on maps for a centaury.

Maria Curie kept close contacts with Poland and with Poles in Paris and frequently visited Poland for family and other reasons.

Organized in 1907, the Society of Science in Warsaw elected, in 1911, Maria Curie Skłodowska as an Honorary Member. The following year the Society decided to create the Miroslaw Kernbaum Laboratory of Radiology in Warsaw. The delegation representing Polish scientists together with Henryk Sienkiewicz, the Polish laureate of the Nobel Prize in literature, arrived in Paris to invite Maria Curie Skłodowska to Warsaw as Laboratory Director.

Henryk Sienkiewicz addressed himself to Maria Curie: "Very Honorable Lady, condescend to transfer your splendid scientific activity to us, to our country, to the capital ….." [3]. But Maria Curie was too much attached to France and to Paris. Living in Warsaw would mean abandoning the laboratory in the Radium Institute which was built specially for her. Thus, after some hesitation she promised only to help organize the Warsaw Laboratory. She prepared its financial plan taking in account its scientific programme. Two of her collaborators - Jan Danysz and Ludwik Wertenstein - came to Warsaw to organize its work on the spot.

In 1913 Maria Curie visited Warsaw and took part in the Laboratory's opening ceremony and kept contact with Warsaw until this contact was cut off by the War.

After the War, when Poland regained its independence, the Warsaw Radiology Laboratory of the Society of Science in Warsaw restarted its activity. The laboratory was directed by Ludwik Wertenstein, previously the assistant of Maria Curie Skłodowska. His friend and collaborator, Jan Danysz, had lost his life at the very beginning of the war. Research was conducted with the radium source of alpha particles and the Laboratory achieved world standard. Marian Danysz, a co-author of the hyper nucleus discovery and Jozef Rotblat, future winner of Nobel Prize for Peace, both started their scientific work in the Laboratory.

In Poland the greatest memorial to Maria Curie Skłodowska is the Radium Institute in Warsaw, now the Centre for Oncology – the Maria Curie Skłodowska Institute. When the twenty fifth anniversary of the radium discovery was celebrated in Paris Maria Curie Skłodowsks admitted:

"My most fervent wish is for a Radium Institute to open in Warsaw".

In December 1924 the Polish Anti-Cancer Committee asked the population of Poland to support "The national gift for Maria Curie Skłodowska" which had to be the Radium Institute in Warsaw. The reaction was both spontaneous and positive. The University of Warsaw offered land in Wawelska Street for the construction of the Institute, which allowed the work to be started by the end of the following year. Maria Curie Skłodowska, the President of Polish Republic, Stanisław Wojciechowski, representatives of the Polish government, the Ambassador of France and numerous Warsaw citizens took part in the ceremony to lay the corner stone.

The construction of the Radium Institute took five years and the first patient was accepted in January 1932. The official opening took place on May 29th that same year, in the presence of Maria Curie Skłodowska, the Polish President Ignacy Mościcki and Professor Claudius Regaut from The Radium Institute in Paris. Maria Curie Skłodowska handed over to the Institute one gram of radium bought for the Warsaw Institute with the money granted to Maria Curie Skłodowska in 1929 by the President of the United States, Herbert C. Hoover as a gift from the American nation.

'The most fervent wish" of Maria Curie has been fulfilled. The Radium Institute in Warsaw started the treatment of patients. Maria Curie

Skłodowska always considered the medical use of radium rays to be very important. In her Autobiographical Notes she wrote:

"It may be easily understood how deeply I appreciate the privilege of realizing that our discovery had become a benefit to mankind, not only through its great scientific importance, but also by its power of efficient action against human suffering and terrible disease. This was indeed a splendid reward for our years of hard toil."[2]

7. THE HERITAGE

On July 4th, 1934 Maria Curie Skłodowska passed away. She left her research, the guidance and caring of her collaborators and students, her initiatives and her many efforts for society and science. But she also left behind for us the great legacy of her achievements.

The discovery of polonium and radium was incomparably greater than the mere discovery of new elements. It demonstrated that matter existed in Nature that was previously unknown. Even after the discovery of Becquerel radiation nobody suspected the existence of a strongly radiating substance the radioactivity of which is the internal property of its atoms.

The discovery of strongly radioactive polonium and radium made accessible the sources of α radiation, which played the role of "the natural accelerators". It was thanks to these discoveries that nuclear physics arose a few decades later.

Radium and radon radioactive sources increased the efficacy of radiotherapy known in France as "curietherapie". It was thanks to Maria Curie Skłodowska that Radium Institutes were organized in France and abroad with the aim of developing knowledge of radioactivity and its healing applications.

During the barbarity which was the Great War Maria, Curie Sklodowska equipped hospitals with x-ray apparatus to heal the pain of the injured and ease the work of surgeons. She has shown how important a pure scientific discovery can be for society and its welfare.

Maria Curie Skłodowska was deeply attached to Poland, her mother country. The name "polonium" given to the first radioactive element to be discovered by herself and her husband shows this beyond doubt.

Fig. 5 Maria Curie Skłodowska has left for us the great legacy of scientific achievements and the example how to use them for the betterment of people.

The legacy of Maria Curie Skłodowska was aptly summed up by members of the French Academy of Sciences, Professors: Robert Guillaumont and Bernd Grenbow:

> "Her unwavering belief in the hypothesis of radioactivity as an atomic property and her spirit of adventure and readiness to pursue unorthodox thinking **changed the course of history."** [5]

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