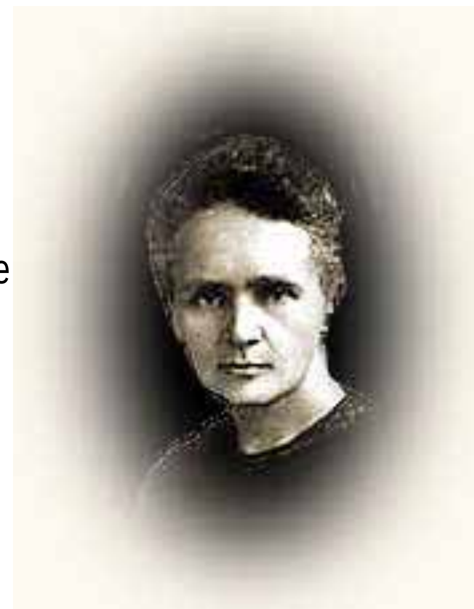
Marie Curie and the Science of Radioactivity

MARIE SKLODOWSKA CURIE opened up the science of radioactivity. She is best known as the discoverer of the radioactive elements polonium and radium and as the first person to win two Nobel prizes. For scientists and the public, her radium was a key to a basic change in our understanding of matter and energy. Her work not only influenced the development of fundamental science but also ushered in a new era in medical research and treatment.



This file contains most of the text of the Web exhibit "Marie Curie and the Science of Radioactivity" at http://www.aip.org/history/curie/contents.htm. You must visit the Web exhibit to explore hyperlinks within the exhibit and to other exhibits.

Site created 2000, revised May 2005

Table of Contents

Polish Girlhood (1867-1891)

Nation and Family

A PRISONER IN CHAINS. That is what Poland seemed like to Maria Sklodowska. Manya, as she was affectionately called, learned to be a Polish patriot from her parents, Bronislawa and Vladislav Sklodowski. At the time of Maria's birth in Warsaw on November 7, 1867, Poland had not been an independent country for most of a century. It had been divided up among Austria, Prussia, and czarist Russia.

Warsaw was in the part of Poland controlled by the czar, who hoped to stamp out Polish nationalism by keeping the people ignorant of their culture and language. But Polish patriots were determined to regain control of their nation. As educators, Maria's parents did their best to overcome restrictions placed on them by their Russian supervisors.

Czar Alexander II preferred to wear a military uniform. When the Czar was assassinated by revolutionary students in 1881, Manya and her best friend Kazia celebrated by dancing around the desks in their classroom.

Polish Schools under Russian Rule

Europe in the late 19th Century. "Poland" including Warsaw, where the Sklodowski's lived, was a province of Russia. Other parts of the nation had been taken over by Prussia and Austria.

Warsaw was then under Russian domination, and one of the worst aspects of this control was the oppression exerted on the school and the child. The private schools directed by Poles were closely watched by the police and overburdened with the necessity of teaching the Russian language even to children so young that they could scarcely speak their native Polish. Nevertheless, since the teachers were nearly all of Polish nationality, they endeavored in every possible way to mitigate the difficulties resulting from the national persecution. These schools, however, could not legally give diplomas, which were obtainable only in the schools of the government.

These schools, entirely Russian, were directly opposed to the Polish national spirit. All instruction was given in Russian, by Russian professors, who, being hostile to the Polish nation, treated their pupils as enemies. Men of moral and intellectual distinction could scarcely agree to teach in schools where an alien attitude was forced upon them. So what the pupils were taught was of questionable value, and the moral atmosphere was altogether unbearable. Constantly held in suspicion and spied upon, the children knew that a single conversation in Polish, or an imprudent word, might seriously harm, not only themselves, but also their families. Amidst these hostilities, they lost all the joy of life, and precocious feelings of distrust and indignation weighed upon their childhood. On the other side, this abnormal situation resulted in exciting the patriotic feeling of Polish youths to the highest degree.

—*from Autobiographical Notes pp. 158-159.*

The birth of Manya, her fifth child, led her mother to resign her position as head of a school, where the family had resided until then. They moved to a boys' high school, where Vladislav taught math and physics and earned a good salary. Eventually, however, the Russian supervisor in charge of the school fired him for his pro-Polish sentiments.

"Constantly held in suspicion and spied upon, the children knew that a single conversation in Polish, or an imprudent word, might seriously harm, not only themselves, but also their families."
--Marie Curie

The five Sklodowski children. From left to right: Zosia died of typhus; Hela became an educator; Maria, twice a Nobel laureate; and JÛzef and Bronya, physicians. "We all had much facility for intellectual work," said Marie. (photo ACJC)

Marie was ten years old when her mother died in May 1878. As an adult Marie remembered it as “the first great sorrow of my life,” which “threw me into a profound depression.” (photo ACJC)

AS HER FATHER WAS FORCED into a series of progressively lower academic posts, the family's economic situation deteriorated. To help make ends meet they had to take in student boarders. Maria was only eight when her oldest sister caught typhus from a boarder and died. That death was followed less than three years later by the death of Madame Sklodowska, who lost a five-year battle with tuberculosis at the age of 42. The surviving family members--Professor Sklodowski; his son Joseph; and his daughters Bronya, Hela, and Maria--drew closer to one another.

Although Sklodowski would never forgive himself for losing the family savings in a bad investment, the children honored him for nurturing them emotionally and intellectually. On Saturday nights he read classics of literature to Maria and her siblings. He also exposed them to the scientific apparatus he had once used in teaching physics but now kept at home, since the Russian authorities had eliminated laboratory instruction from the Polish curriculum.

“I easily learned mathematics and physics, as far as these sciences were taken in consideration in the school. I found in this ready help from my father, who loved science....Unhappily, he had no laboratory and could not perform experiments.”

Manya was the star pupil in her class. Her personal losses did not impede her academic success, but the pleasure of being awarded a gold medal at her high school graduation in 1883 was blunted because it meant shaking the hand of the grandmaster of education in Russian Poland. After graduating at 15, Manya suffered a collapse that doctors thought was due to fatigue or "nervous" problems -- today it might be diagnosed as depression. At her father's urging Manya spent a year with cousins in the country. A merry round of dances and other festivities, it would be the only carefree year of her life.

Manya's secondary school diploma. She later recalled “always having held first rank in my class.” (photo ACJC)

The Floating University

MARIA HOPED, LIKE HER SIBLINGS, to get an advanced degree. Although Joseph was able to enroll in the medical school at the University of Warsaw, women were not welcome there. Maria and Bronya joined other friends in attending the Floating University. This illegal night school got its name from the fact that its classes met in changing locations, the better to evade the watchful eyes of the czarist authorities. Its students' lofty goal went beyond mere self-improvement. They hoped their grass-roots educational movement would raise the likelihood of eventual Polish liberation.

This fly-by-night education could not match the curriculum at any of the major European universities that admitted women. Although Maria understood this fact, at the Floating University she did get a taste of progressive thought and an introduction to new developments in the sciences.

Cossacks parading in Warsaw after Russia crushed a nationalist rising in 1863.

"It was one of those groups of Polish youths who believed that the hope of their country lay in a great effort to develop the intellectual and moral strength of the nation.... we agreed among ourselves to give evening courses, each one teaching what he knew best."*--Marie Curie*

The Governess

The close relationship between Manya and her sister Bronya, shown here in 1886, continued throughout their lives. (Photo ACJC)

MARIA AND BRONYA MADE A PACT: the younger sister, still not 17, would work as a private tutor, setting aside money to pay Bronya's tuition at medical school in Paris and her living expenses there. As soon as Bronya could, she would help subsidize Maria's education.

After two years of teaching various subjects to children from wealthy families, Maria realized she was not saving money efficiently enough. For the next three years she worked as a well-paid governess.

Leaving Home at 15

I was only fifteen when I finished my high-school studies, always having held first rank in my class. The fatigue of growth and study compelled me to take almost a year's rest in the country. I then returned to my father in Warsaw, hoping to teach in the free schools. But family circumstances obliged me to change my decision. My father, now aged and tired, needed rest; his fortune was very modest. So I resolved to accept a position as governess for several children. Thus, when scarcely seventeen, I left my father's house to begin an independent life.

That going away remains one of the most vivid memories of my youth. My heart was heavy as I climbed into the railway car. It was to carry me for several hours, away from those I loved. And after the railway journey I must drive for five hours longer. What experience was awaiting me? So I questioned as I sat close to the car window looking out across the wide plains.

—from Autobiographical Notes p. 163.

Her charges were the children of an agriculturist who ran a beet-sugar factory in a village 150 kilometers north of Warsaw. Maria felt a kinship with her employer when he permitted her in her spare time to teach the illiterate children of his peasant laborers. He encouraged his older daughter to assist Maria, even though he knew the czarist authorities equated such activity with treason. "Even this innocent work presented danger," Maria recalled, as all initiative of this kind was forbidden by the government and might bring imprisonment or deportation to Siberia.

When their governess fell in love with their oldest son, however, her employers were none too pleased. As fond as they were of Maria, they did not welcome the knowledge that their beloved Kazmierz, on vacation from his agricultural engineering course in Warsaw, wanted to marry the penniless girl. Although the couple bowed to his parents' wishes and broke off the engagement, their romantic involvement continued for several years more. As difficult as it was to stay under the same roof as a family that clearly did not welcome her as one of their own, Maria remained in their employ because she took her pact with Bronya seriously.

Marie's continuing romantic interest in Kazmierz Zorawski, whom she met while serving as governess to his younger siblings, helped hold her back from joining Bronya in Paris. (Photo ACJC)

"If [men] don't want to marry impecunious young girls, let them go to the devil! Nobody is asking them anything. But why do they offend by troubling the peace of an innocent creature?" *--letter of Marie Curie to her cousin Henrietta Michalowska, April 4, 1887*

TO FILL HER LONELY HOURS she began a course of self-study. Unsure at first where her academic interests lay, she read sociological studies and works of literature along with physics and chemistry textbooks. By mail she also took the equivalent of an advanced math course with her father. When it became clear that math and the physical sciences were her forte, she took chemistry lessons from a chemist in the beet-sugar factory.

Professor Sklowdowski in Warsaw in 1890, with his daughters Maria (extreme left), Hela, (far right), and Bronya, who was on a visit home from medical studies in Paris. (Photo ACJC)

After returning to Warsaw in 1889, Maria worked as a live-in governess for another year before resuming life with her father and work as a private tutor. During her absence Sklodowski had become director of a reform school, and the new position paid well enough for him to send a monthly subsidy to Bronya in Paris. By arrangement with Bronya, he began to set aside a portion of that subsidy to compensate Maria for the sums she had been sending her sister. Eventually it became clear that by fall 1891, Maria would have enough money to begin studies at the University of Paris--the famous Sorbonne.

Secret Studies In Warsaw

"**I continued my efforts** to educate myself. This was no easy task under the Russian government of Warsaw; yet I found more opportunities than in the country. To my great joy, I was able, for the first time in my life, to find access to a laboratory: a small municipal physical laboratory directed by one of my cousins. I found little time to work there, except in the evenings and on Sundays, and was generally left to myself. I tried out various experiments described in treatises on physics and chemistry, and the results were sometimes unexpected. At times I would be encouraged by a little unhoped-for success, at others I would be in the deepest despair because of accidents and failures resulting from my inexperience. But on the whole, though I was taught that the way of progress is neither swift nor easy, this first trial confirmed in me the taste for experimental research in the fields of physics and chemistry.

Other means of instruction came to me through my being one of an enthusiastic group of young men and women of Warsaw, who united in a common desire to study, and whose activities were at the same time social and patriotic. It was one of those groups of Polish youths who believed that the hope of their country lay in a great effort to develop the intellectual and moral strength of the nation, and that such an effort would lead to a better national situation. The nearest purpose was to work at one's own instruction and to provide means of instruction for workmen and peasants. In accordance with this program we agreed among ourselves to give evening courses, each one teaching what he knew best. There is no need to say that this was a secret organization, which made everything extremely difficult. There were in our group very devoted young people who, as I still believe today, could do truly useful work.

I have a bright remembrance of the sympathetic intellectual and social companionship which I enjoyed at that time. Truly the means of action were poor and the results obtained could not be considerable; yet I still believe that the ideas which inspired us then are the only way to real social progress. You cannot hope to build a better world without improving the individuals. To that end each of us must work for his own improvement, and at the same time share a general responsibility for all humanity, our particular duty being to aid those to whom we think we can be most useful.”

—*from* *Autobiographical Notes* *pp. 167-168.*

“During these years of isolated work, trying little by little to find my real preferences, I finally turned towards mathematics and physics, and resolutely undertook a serious preparation for future work.”

MARIA STILL LACKED real laboratory experience, and she hoped to gain some before her departure. This was no easy task, given the czarist ban on such work. The ingenuity of her cousin Joseph Boguski helped her achieve her illicit goal. A former assistant of Russian chemist Dmitri Mendeleev, Boguski ran the so-called Museum of Industry and Agriculture, which was actually a laboratory aimed at training Polish scientists. One of Boguski's colleagues there gave Maria an intensive chemistry course on Sundays and evenings. More often than not, however, she struggled through experiments on her own, often failing to duplicate the expected results.

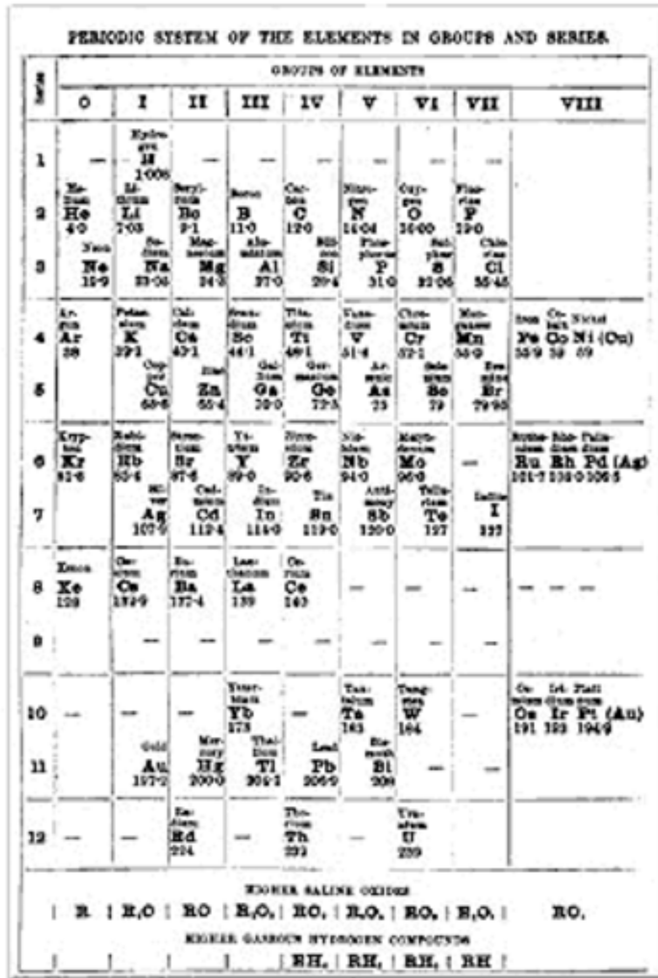
These buildings in the old town of Warsaw (destroyed in World War II and rebuilt) show the high level of beauty and civilization that helped inspire Polish patriots.

Finally, in autumn 1891, Maria Sklodowska set out for Paris. Traveling as economically as possible, she carried not only enough food and reading for the trip but also a folding chair and a blanket: fourth-class travelers through Germany were not provided with seating. “So it was in November, 1891,” she recalled, “at the age of 24, that I was able to realize the dream that had been constantly in my mind for several years.”

Dmitri Ivanovich Mendeleev (1834-1907)

WHO ORGANIZED THE ALPHABET? We will never be able to attribute to a single individual the development of the basic building blocks of writing. Yet we do know the name of the man who devised the method of classifying the basic building blocks of matter. Dmitri Ivanovich Mendeleev was born in Siberia in 1834. When Mendeleev became a professor of general chemistry at the University of St. Petersburg, he was unable to find an appropriate textbook and thus began writing his own. That textbook, written between 1868 and 1870, would provide a framework for modern chemical and physical theory.

Mendeleev first trained as a teacher in the Pedagogic Institute of St. Petersburg before earning an advanced degree in chemistry in 1856.



PERIODIC SYSTEM OF THE ELEMENTS IN GROUPS AND SERIES.

Series	0	I	II	III	IV	V	VI	VII	VIII
1	—	H 1.008	—	—	—	—	—	—	
2	He 4.0	Li 7.03	Be 9.1	B 11.0	C 12.0	N 14.04	O 16.00	F 19.0	
3	Ne 19.9	Na 23.05	Mg 24.3	Al 27.0	Si 28.4	P 31.0	S 32.06	Cl 35.45	
4	Ar 38	K 39.1	Ca 40.1	Sc 44.1	Ti 48.1	V 51.4	Cr 52.1	Mn 55.0	Fe Co Ni (Cu) 55.9 59 59
5		Cu 63.6	Zn 65.4	Ga 70.0	Ge 72.3	As 75	Se 79	Br 79.95	
6	Kr 81.8	Rb 85.4	Sr 87.6	Y 89.0	Zr 90.6	Nb 94.0	Mo 96.0	—	Ru Rh Pd (Ag) 101.7 103.0 106.5
7		Ag 107.9	Cd 112.4	In 114.0	Sn 119.0	Sb 120.0	Te 127	I 127	
8	Xe 128	Cs 132.9	Ba 137.4	La 139	Ce 140	—	—	—	— — —
9		—	—	—	—	—	—	—	
10	—	—	—	Yb 173	—	Ta 183	W 184	—	Os Ir Pt (Au) 191 193 194.9
11		Au 197.2	Hg 200.0	Tl 204.1	Pb 206.9	Bi 208	—	—	
12	—	—	Rd 224	—	Th 232	—	U 239		
HIGHER SALINE OXIDES	R	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4
HIGHER GASEOUS HYDROGEN COMPOUNDS					RH_4	RH_3	RH_2	RH	

Mendeleev's periodic table--notice the gaps. After Marie Curie's discovery of radium in 1898, Mendeleev altered the table in his textbook, noting the atomic weight of the new element (called Rd here--the modern symbol is Ra).

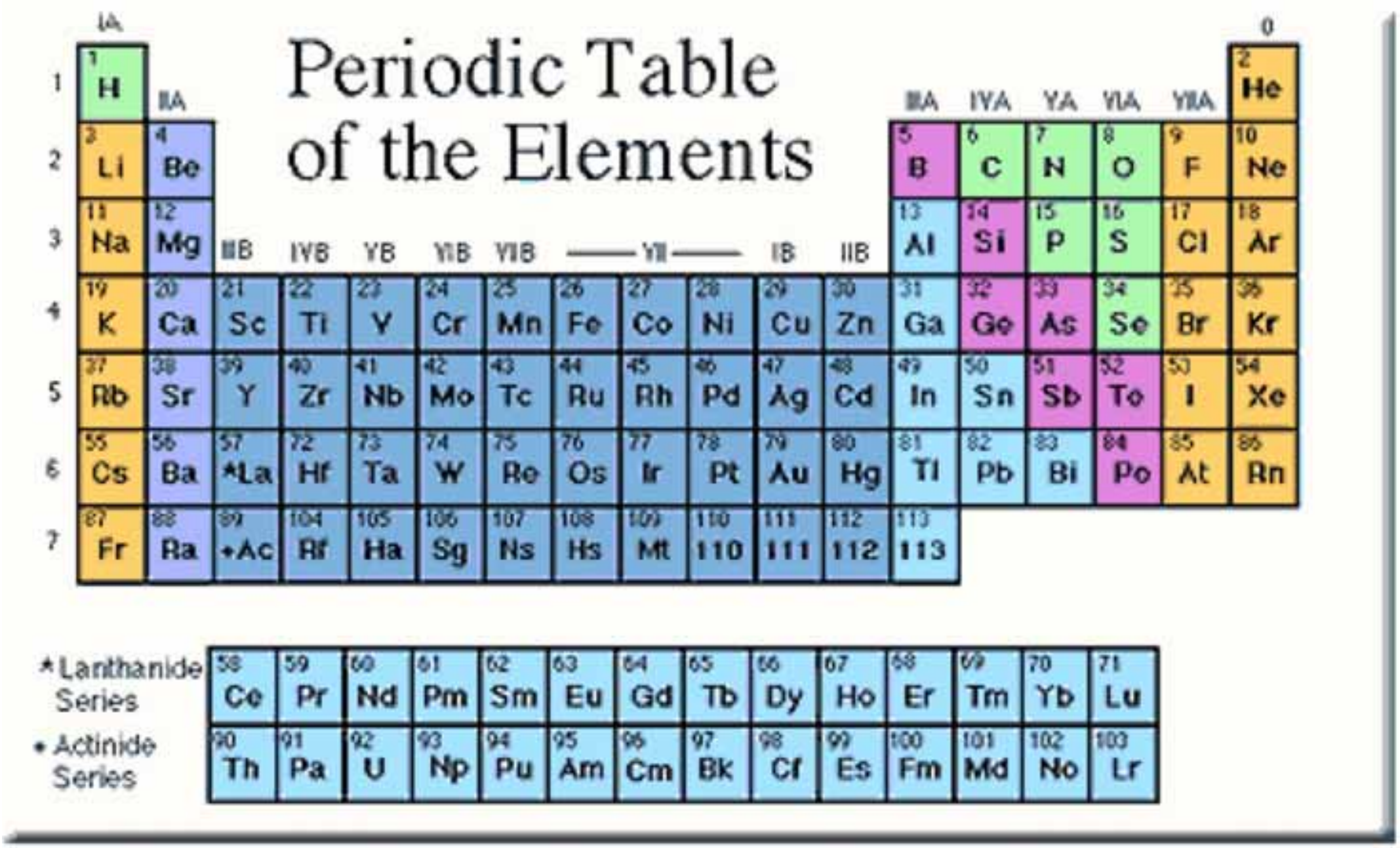
Elements and Their Properties

COMBINATIONS OF 26 LETTERS make up every word in the English language. Similarly, all material things in the world are composed of different combinations of about 100 different elements. An element is a substance that cannot be broken down into simpler substances through ordinary chemistry--it is not destroyed by acids, for example, nor changed by electricity, light, or heat. Although philosophers in the ancient world had a rudimentary concept of elements, they were incorrect in identifying water, for example, as one. Today it is common knowledge that water is a compound, whose smallest unit is a molecule. Passing electricity through a molecule of water can separate it into two atoms of hydrogen and one atom of oxygen, each a separate element.

The ancient concept of elements jibed with today's in noting that elements had characteristic properties. Just as people not only look different from each other but also interact differently with others, so elements have both physical and chemical properties. Some elements form shiny solids, for example, that react readily and sometimes violently with oxygen and water. The atoms of other elements form gases that scarcely interact with other elements.

SCIENTISTS HAD IDENTIFIED over 60 elements by Mendeleev's time. (Today over 110 elements are known.) In Mendeleev's day the atom was considered the most basic particle of matter. The building blocks of atoms (electrons, protons, and neutrons) were discovered only later. What Mendeleev and chemists of his time could determine, however, was the atomic weight of each element: how heavy its atoms were in comparison to an atom of hydrogen, the lightest element.

> **"I began to look about and write down the elements with their atomic weights and typical properties, analogous elements and like atomic weights on separate cards, and this soon convinced me that the properties of elements are in periodic dependence upon their atomic weights."**
> --*Mendeleev*, Principles of Chemistry, *1905, Vol. II*



A modern periodic table.

Classifying the Elements

AN OVERALL UNDERSTANDING of how the elements are related to each other and why they exhibit their particular chemical and physical properties was slow in coming. Between 1868 and 1870, in the process of writing his book, *The Principles of Chemistry,* Mendeleev created a table or chart that listed the known elements according to increasing order of atomic weights. When he organized the table into horizontal rows, a pattern became apparent--but only if he left blanks in the table. If he did so, elements with similar chemical properties appeared at regular intervals--periodically--in vertical columns on the table.

Mendeleev was bold enough to suggest that new elements not yet discovered would be found to fill the blank places. He even went so far as to predict the properties of the missing elements. Although many scientists greeted Mendeleev's first table with skepticism, its predictive value soon became clear. The discovery of gallium in 1875, of scandium in 1879, and of germanium in 1886 supported the idea underlying Mendeleev's table. Each of the new elements displayed properties that accorded with those Mendeleev had predicted, based on his realization that elements in the same column have similar chemical properties. The three new elements were respectively discovered by a French, a Scandinavian, and a German scientist, each of whom named the element in honor of his country or region. (Gallia is Latin for France.) Discovery of a new element had become a matter of national pride--the rare kind of science that people could read about in newspapers, and that even politicians would mention.

Claiming a new element now meant not only identifying its unique chemical properties, but finding the atom's atomic weight so the element could be fitted into the right slot in the periodic table. For radioactive atoms that was a tough challenge. At first these atoms were isolated only in microscopic quantities. The straightforward way to identify them was not by their chemical properties at all, but by their radiations. Until the radioactive atoms could be sorted out with traditional chemistry, some scientists were reluctant to call them new elements.

WHAT MADE THE TABLE PERIODIC? The value of the table gradually became clear, but not its meaning. Scientists soon recognized that the table's arrangement of elements in order of atomic weight was problematic. The atomic weight of the gas argon, which does not react readily with other elements, would place it in the same group as the chemically very active solids lithium and sodium. In 1913 British physicist Henry Moseley confirmed earlier suggestions that an element's chemical properties are only roughly related to its atomic weight (now known to be roughly equal to the number of protons plus neutrons in the nucleus). What really matters is the element's atomic number--the number of electrons its atom carries, which Moseley could measure with X-rays. Ever since, elements have been arranged on the periodic table according to their atomic numbers. The structure of the table reflects the particular arrangement of the electrons in each type of atom. Only with the development of quantum mechanics in the 1920s did scientists work out how the electrons arrange themselves to give the element its properties.

A Student in Paris (1891-1897)

Years of Study

MANYA BECAME MARIE when she enrolled at the Sorbonne in fall 1891. At first she lived in the home of her sister. Bronya had married another Polish patriot, Casimir Dluski, whom she had met in medical school. The Dluskis' home, however, was an hour's commute by horse-drawn bus from the university, and Marie resented the lost time, not to mention the money wasted on carfare.

Paris in 1889 (two years before Marie Sklodowska's arrival), with the Eiffel Tower newly erected for a world's fair--a celebration of modern technology

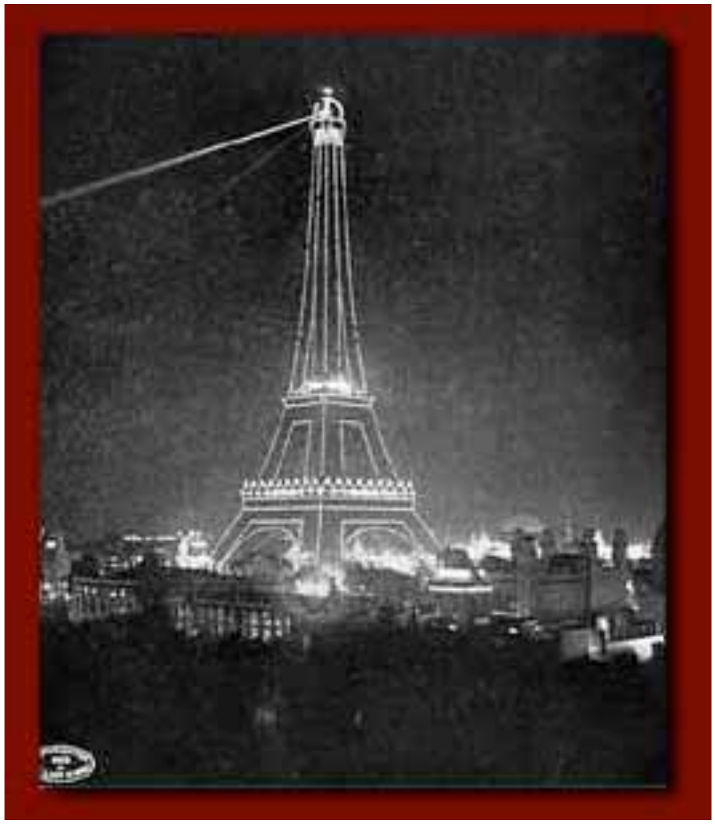
In addition, remaining with the Dluskis meant participating regularly in the active Polish exile community in Paris. Marie's father warned her that doing so might jeopardize her career prospects at home or even the lives of relatives there. Thus after a few months Marie moved to the Latin Quarter, the artists' and students' neighborhood close to the university.

Her living arrangements were basic. Stories from these years tell how she kept herself warm during the winter months by wearing every piece of clothing she owned, and how she fainted from hunger because she was too absorbed in study to eat. But even if Bronya had to come to her aid from time to time, living alone enabled Marie to focus seriously on her studies.

> **“...my situation was not exceptional; it was the familiar experience of many of the Polish students whom I knew....”**

Paris rooftops, painting by Gustave Caillebotte

A Poor Student In Paris



"**It would be impossible** to tell of all the good these years brought to me. Undistracted by any outside occupation, I was entirely absorbed in the joy of learning and understanding. Yet, all the while, my living conditions were far from easy, my own funds being small and my family not having the means to aid me as they would have liked to do. However, my situation was not exceptional; it was the familiar experience of many of the Polish students whom I knew. The room I lived in was in a garret, very cold in winter, for it was insufficiently heated by a small stove which often lacked coal. During a particularly rigorous winter, it was not unusual for the water to freeze in the basin in the night; to be able to sleep I was obliged to pile all my clothes on the bedcovers. In the same room I prepared my meals with the aid of an alcohol lamp and a few kitchen utensils. These meals were often reduced to bread with a cup of chocolate, eggs or fruit. I had no help in housekeeping and I myself carried the little coal I used up the six flights.

This life, painful from certain points of view, had, for all that, a real charm for me. It gave me a very precious sense of liberty and independence. Unknown in Paris, I was lost in the great city, but the feeling of living there alone, taking care of myself without any aid, did not at all depress me. If sometimes I felt lonesome, my usual state of mind was one of calm and great moral satisfaction.

All my mind was centered on my studies, which, especially at the beginning, were difficult. In fact, I was insufficiently prepared to follow the physical science course at the Sorbonne, for, despite all my efforts, I had not succeeded in acquiring in Poland a preparation as complete as that of the French students following the same course. So I was obliged to supply this deficiency, especially in mathematics. I divided my time between courses, experimental work, and study in the library. In the evening I worked in my room, sometimes very late into the night. All that I saw and learned that was new delighted me. It was like a new world opened to me, the world of science, which I was at last permitted to know in all liberty."

—from Autobiographical Notes pp. 170-171.

SHE HAD A LOT OF CATCHING UP to do. Marie realized quickly that her fears of being insufficiently prepared were accurate. Neither her math and science background nor her proficiency in technical French equaled that of her fellow students. Refusing to lose heart, she determined to overcome these shortcomings through diligent work.

The diligence paid off. Marie finished first in her master's degree physics course in the summer of 1893 and second in math the following year. Lack of money had stood in the way of her undertaking the math degree, but senior French scientists recognized her abilities and pulled some strings. She was awarded a scholarship earmarked for an outstanding Polish student. Before completing the math degree she was also commissioned by the Society for the Encouragement of National Industry to do a study, relating magnetic properties of different steels to their chemical composition. She needed to find a lab where she could do the work.

Love and Marriage

Another Polish student in Paris drew this portrait of Marie in 1892, after she had been enrolled at the Sorbonne for some months. Although at first she spent some time with other Polish students to help overcome homesickness, she soon had to devote all her time to her studies. (Photo ACJC)

THE SEARCH FOR LAB SPACE led to a fateful introduction. In the spring of 1894, Marie Sklodowska mentioned her need for a lab to a Polish physicist of her acquaintance. It occurred to him that his colleague Pierre Curie might be able to assist her. Curie, who had done pioneering research on magnetism, was laboratory chief at the Municipal School of Industrial Physics and Chemistry in Paris. Unaware of how inadequate Pierre's own lab facilities were, the professor suggested that perhaps Pierre could find room there for Marie to work. The meeting between Curie and Sklodowska would change not only their individual lives but also the course of science.

"I noticed the grave and gentle expression of his face, as well as a certain abandon in his attitude, suggesting the dreamer absorbed in his reflections."

Marie would eventually find rudimentary lab space at the Municipal School. Meanwhile her relationship with Curie was growing from mutual respect to love. Her senior by about a decade, Pierre had all but given up on love after the death of a close woman companion some 15 years earlier. The women he had met since had shown no interest in science, his life's passion. In Marie, however, he found an equal with a comparable devotion to science.


Marie hesitated before agreeing to marry Pierre Curie, because such a decision "meant abandoning my country and my family." (Photo ACJC)

POLAND STILL BECKONED HER BACK. After her success in her math exam in the summer of 1894, Marie returned there for a vacation, uncertain whether she would return to France. Pierre's heartfelt letters helped convince her to pursue her doctorate in Paris.

Meeting Pierre Curie

"**I met Pierre Curie** for the first time in the spring of the year 1894.... A Polish physicist whom I knew, and who was a great admirer of Pierre Curie, one day invited us together to spend the evening with himself and his wife.

As I entered the room, Pierre Curie was standing in the recess of a French window opening on a balcony. He seemed to me very young, though he was at that time thirty-five years old. I was struck by the open expression of his face and by the slight suggestion of detachment in his whole attitude. His speech, rather slow and deliberate, his simplicity, and his smile, at once grave and youthful, inspired confidence. We began a conversation which soon became friendly. It first concerned certain scientific matters about which I was very glad to be able to ask his opinion. Then we discussed certain social and humanitarian subjects which interested us both. There was, between his conceptions and mine, despite the difference between our native countries, a surprising kinship, no doubt attributable to a certain likeness in the moral atmosphere in which we were both raised by our families.

We met again at the Physics Society and in the laboratory. Then he asked if he might call upon me.... Pierre Curie came to see me, and showed a simple and sincere sympathy with my student life. Soon he caught the habit of speaking to me of his dream of an existence consecrated entirely to scientific research, and he asked me to share that life. It was not, however, easy for me to make such a decision, for it meant separation from my country and my family, and the renouncement of certain social projects that were dear to me. Having grown up in an atmosphere of patriotism kept alive by the oppression of Poland, I wished, like many other young people of my country, to contribute my effort toward the conservation of our national spirit....

During the year 1894 Pierre Curie wrote me letters that seem to me admirable in their form. No one of them was very long, for he had the habit of concise expression, but all were written in a spirit of sincerity and with an evident anxiety to make the one he desired as a companion know him as he was.... It is appropriate to quote here a few lines which express how he looked on the possibility of our marriage:

"We have promised each other (is it not true?) to have, the one for the other, at least a great affection. Provided that you do not change your mind! For there are no promises which hold; these are things that do not admit of compulsion.

"It would, nevertheless, be a beautiful thing in which I hardly dare believe, to pass through life together hypnotized in our dreams: your dream for your country; our dream for humanity; our dream for science. Of all these dreams, I believe the last, alone, is legitimate. I mean to say by this that we are powerless to change the social order. Even if this were not true we should not know what to do.... From the point of view of science, on the contrary, we can pretend to accomplish something. The territory here is more solid and obvious, and however small it is, it is truly in our possession."

One can understand, from this letter, that for Pierre Curie there was only one way of looking at the future. He had dedicated his life to his dream of science: he felt the need of a companion who could live his dream with him ”

—from Pierre Curie pp. 72-77.

Gabriel Lippmann, Marie Curie's thesis advisor, did early studies in a field in which Pierre Curie and his brother were pioneers: electrical effects in crystals. A pillar of the French tradition of patronage, Lippmann let Marie use his laboratory for her thesis work and helped her find other sources of support.

"Our work drew us closer and closer, until we were both convinced that neither of us could find a better life companion."

Marie was determined not only to get her own doctorate but to see to it that Pierre received one as well. Although Pierre had done important scientific research in more than one field over the past 15 years, he had never completed a doctorate (in France the process consumed even more time than it did in the U.S. or U.K.). Marie insisted now that he write up his research on magnetism. In March 1895 he was awarded the degree. At the Municipal School Pierre was promoted to a professorship. The honor and the higher salary were offset by increased teaching duties without any improvement in lab space.

In a simple civil ceremony in July 1895, they became husband and wife. Neither wanted a religious service. Marie had lost her faith when her devout Roman Catholic mother died young, and Pierre was the son of non-practicing Protestants. Nor did they exchange rings. Instead of a bridal gown Marie wore a dark blue outfit, which for years after was a serviceable lab garment.

The Curies' honeymoon trip was a tour of France on bicycles purchased with a wedding gift. (Photo ACJC)

Working Wife and Mother

JUGGLING HOUSEHOLD AND PROFESSIONAL responsibilities was something Marie had to learn from the outset of her married life. In addition to the two master's degrees she held by the time of her marriage, she decided to earn a certificate that would permit her to teach science to young women. Meanwhile, she continued to conduct her research on the magnetic properties of steel. The director of the Municipal School of Industrial Physics and Chemistry granted her permission to complete that work on the school premises, although even Pierre had no private laboratory there. The school did not help to subsidize her studies, but she received complimentary steel samples from several metallurgical firms. For the rest of her life she would continue this three-cornered arrangement of mutual assistance among research, industry, and the government's educational system.

After submitting the results of her research to the Society for the Encouragement of National Industry in the summer of 1897, she used part of her payment to return the scholarship money she had received four years earlier. She was not expected to do so, of course, but she wanted to contribute to the education of some other worthy Polish student.

> **"Having grown up in an atmosphere of patriotism kept alive by the oppression of Poland, I wished, like many other young people of my country, to contribute my effort toward the conservation of our national spirit."**

The Curies in the laboratory in 1896. "At this time my husband was occupied with researches on crystals," she later wrote, "while I undertook an investigation of the magnetic properties of steel." (Photo ACJC)

PARENTHOOD SOON CHANGED the Curies' lives. In September 1897 their first child, Irène, was born. Pierre's father, a physician, delivered the baby. Just as she had done with the household budget from the time of their marriage, Marie now began keeping records of every stage of her daughter's development with the same meticulous care that she used to keep track of her experimental work

Irène, age 8, and Eve, age 1. Pierre Curie had so much respect for his wife's scientific career that he never contemplated her abandoning it, even in 1904 after a second daughter was born. (Photo ACJC)

Only a few weeks after Irène's birth Dr. Curie lost his wife to breast cancer, and he moved into a house at the edge of Paris with his son, daughter-in-law, and granddaughter. With their expanded family the Curies had to hire a servant to tend to chores. Marie, who remained in charge of her child's care, found in Dr. Curie an ideal babysitter. She could carry out her lab work fully confident that Irène was in excellent hands. Over the years grandfather and granddaughter would forge a very close bond.

> **"It became a serious problem how to take care of our little Irène and of our home without giving up my scientific work. Such a renunciation would have been very painful to me, and my husband would not even think of it...So the close union of our family enabled me to meet my obligations."**

Family and Professional Life

"It became a serious problem how to take care of our little Irène and of our home without giving up my scientific work. Such a renunciation would have been very painful to me, and my husband would not even think of it; he used to say that he had got a wife made expressly for him to share all his preoccupations. Neither of us would contemplate abandoning what was so precious to both.

Of course we had to have a servant, but I personally saw to all the details of the child's care. While I was in the laboratory, she was in the care of her grandfather, who loved her tenderly and whose own life was made brighter by her. So the close union of our family enabled me to meet my obligations. Things were particularly difficult only in case of more exceptional events, such as a child's illness, when sleepless nights interrupted the normal course of life.

It can be easily understood that there was no place in our life for worldly relations. We saw but a few friends, scientific workers, like ourselves, with whom we talked in our home or in our garden, while I did some sewing for my little girl. We also maintained affectionate relations with my husband's brother and his family. But I was separated from all my relatives, as my sister had left Paris with her husband to live in Poland.

It was under this mode of quiet living, organized according to our desires, that we achieved the great work of our lives, work begun about the end of 1897 and lasting for many years.”

—from Autobiographical Notes pp. 179-180.

Work and Family

AS BUSY YOUNG PARENTS the Curies had time, money, and energy for only two commitments, work and family. They maintained warm ties with the family of Pierre's older brother, Jacques, who taught mineralogy at the University of Montpellier. They socialized infrequently, and then only with other scientists who gathered at the Curie home on the rue Kellerman or in its garden -- colleagues and students who shared their liberal views and intellectual interests. Despite the satisfaction Marie took in her busy and fulfilling life, she missed the Sklodowski family, particularly after Bronya and her husband returned to Poland. (The Dluskis opened a tuberculosis sanatorium in the Carpathians of Austrian Poland.)

“It was under this mode of quiet living, organized according to our desires, that we achieved the great work of our lives, work begun about the end of 1897 and lasting for many years.”

With her household in order and the results of her first research published, it was time for Marie to choose a topic for her doctoral research. Although an unmarried German woman's doctoral research in electrochemistry was at an advanced stage, no woman anywhere in the world had yet been awarded a doctorate in science.

Pierre Curie (1859-1906)

Pierre Curie (upper right) with his brother Jacques and their parents. He called his family "exquisite" when he first talked about them with Marie Sklodowska.

HE HAD THE HAPPIEST OF CHILDHOODS, but the unorthodox nature of his education meant that Pierre Curie was never quite accepted by the French scientific establishment. His father, a physician, believed that his son's intellect and personality could be best nurtured through private tutoring.

By the age of 14 Pierre had demonstrated a passion and a gift for mathematics. At 16 he began university studies and at 18 he was awarded the equivalent of an American master's degree. But lack of money forced him to put off work toward his doctorate indefinitely. Instead he became a poorly paid laboratory instructor.

"It is easy to overlook those who have not the active support of influential persons."--*Marie Curie*

His first important scientific collaboration was with his older brother, Jacques. By the time Pierre was 21 and Jacques 24, the brothers had discovered the piezoelectric effect (from the Greek word meaning "to press"). The Curie brothers had found that when pressure is applied to certain crystals, they generate electrical voltage. Reciprocally, when placed in an electric field these same crystals become compressed. Recognizing the connection between the two phenomena helped Pierre to develop pioneering ideas about the fundamental role of symmetry in the laws of physics.

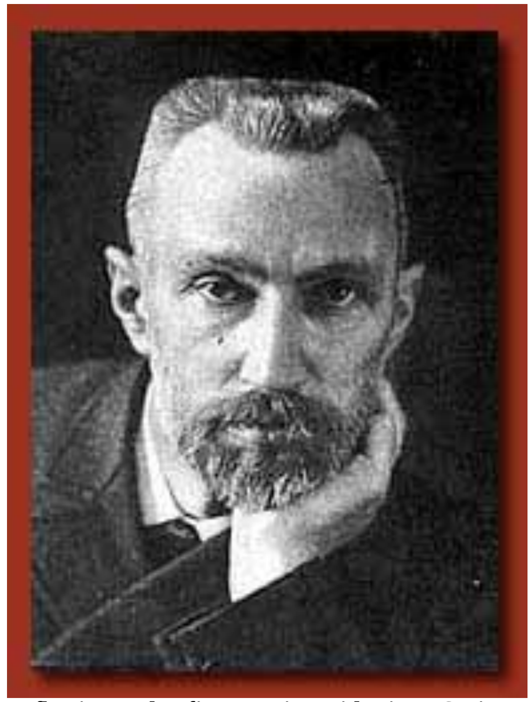
The brothers meanwhile put their discovery to immediate practical use by devising the piezoelectric quartz electrometer, which can measure faint electric currents. Nearly two decades later, the device helped Marie Curie in her early research. In the century following its discovery by the Curie brothers, the piezoelectric effect was put to use in such familiar everyday devices as microphones, quartz watches, and electronic components.

PIERRE WAS ALSO A PIONEER in the study of magnetism. He discovered a basic relationship between magnetic properties and temperature. The temperature at which certain magnetic materials undergo a marked change in their magnetic properties is today called the *Curie point* after Pierre. He also invented a highly sensitive scientific balance, similarly named in his honor, and likewise extremely useful in Marie's later work.

"[In science] we can aspire to accomplish something...every discovery, however small, is a permanent gain." -- *Pierre Curie to Marie, 1894, urging her to join him in "our scientific dream."*

Only at the urging of Marie Sklodowska, whom he met in the spring of 1894, did Pierre take the trouble of writing up his research on magnetism as a doctoral thesis. A few months before their marriage he was awarded a doctorate of science. When Marie's own thesis research led her to believe that she was on the verge of discovering a new element, he joined her in the search. After their discovery of polonium and radium, the Curies decided on a division of labor: he concentrated on investigating the properties of radium, while she did chemical experiments with a view to preparing pure compounds.

So it was Pierre (with a student) who noticed that a speck of radium spontaneously and perpetually emits heat--discovering what is now called nuclear energy. He was also, with collaborators, the first to report the decay of radioactive materials and the skin burns that radioactive substances can inflict.



Reflecting on her first meeting with Pierre Curie, Marie Curie recalled being "struck by the open expression of his face and by the slight suggestion of detachment in his whole attitude."

The Curies in their laboratory at the School for Industrial Physics and Chemistry. (Photo ACJC)

HAPPIEST WHEN WORKING in the laboratory, Pierre despised the politics and flattery that were needed to advance in the tight little world of Paris professors. Still it hurt when he was denied positions he deserved, for example in 1902 when he tried and failed to enter the French Academy of Sciences and in 1903 when he was rejected for a professorship of mineralogy.

> **"My husband and I were so closely united by our affection and our common work that we passed nearly all of our time together."**--*Marie Curie*

Marie Curie never forgave France for what she considered its rude treatment of her husband--the failure to give him either the honors or the laboratory facilities he merited. After his untimely death in a traffic accident in 1906, she devoted the rest of her life to erecting a laboratory in Paris that would be worthy of Pierre's memory. In a short, eloquent biography of him, she helped perpetuate an image of the struggling scientist that encouraged the public to give researchers the support she had wanted for Pierre.

Radioactivity: The Unstable Nucleus and its Uses

WHEN THE FRENCH PHYSICIST Henri Becquerel (1852-1908) discovered "his" uranium rays in 1896 and when Marie Curie began to study them, one of the givens of physical science was that the atom was indivisible and unchangeable. The work of Becquerel and Curie soon led other scientists to suspect that this theory of the atom was untenable.

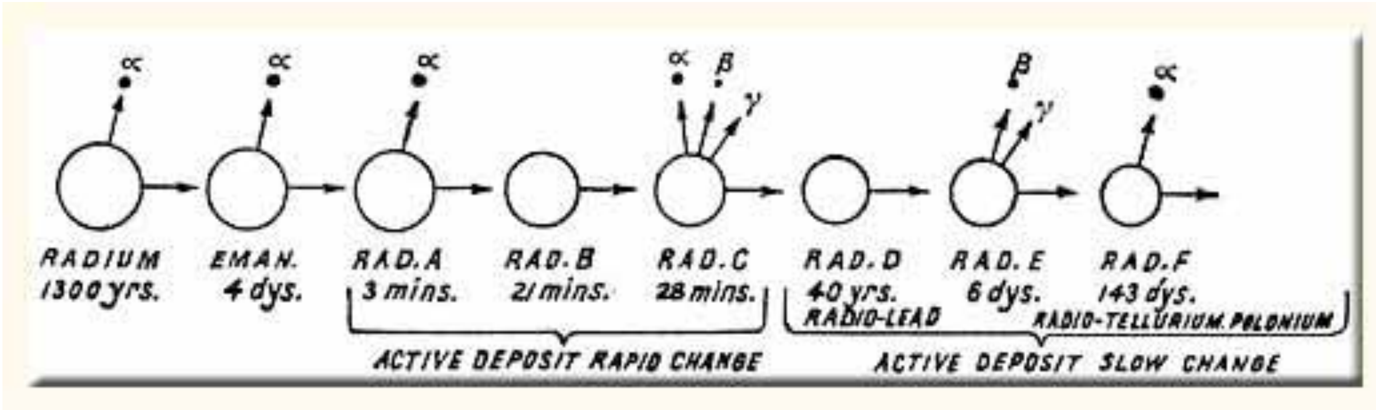
Scientists soon learned that some of the mysterious "rays" emanating from radioactive substances were not rays at all, but tiny particles. Radioactive atoms emit three different kinds of radiation. One kind of radiation is a particle of matter, called the alpha particle. It has a positive electric charge and about four times the mass of a hydrogen atom. (We now know that it consists of two protons and two neutrons, the same as the nucleus of the helium atom.) Alpha particles exit radioactive atoms with high energies, but they lose this energy as they move though matter. An alpha particle can pass through a thin sheet of aluminum foil, but it is stopped by anything thicker. Beta "rays," a second form of radiation, turned out to be electrons, very light particles with a negative electric charge. The beta particles travel at nearly the speed of light and can make their way through half a centimeter of aluminum. Gamma rays, a third type of radiation, are true rays, electromagnetic waves--the same kind of thing as radio waves and light, with no mass and no electrical charge. They are similar to, but more energetic than, the X-rays, an energetic form of electromagnetic radiation discovered by the German physicist Wilhelm Conrad Roentgen (1845-1923) in 1895. Gamma rays emitted by radioactive atoms can penetrate deeper into matter than alpha or beta particles. A small fraction of gamma rays can pass through even a meter of concrete.

The point was that radioactivity was no more nor less than the emission of tiny particles and energetic waves from the atom. Building on the research of Marie Curie and others, scientists soon realized that if atoms emitted such things they could not be indivisible and unchangeable. Atoms are made up of smaller particles, and these can be rearranged.

Rutherford

It began with a vexing puzzle--in any laboratory where people worked with radium or other radioactive minerals, radioactivity tended to spread around, turning up in unexpected corners. In fact the labs were being contaminated by a radioactive gas. In 1900 Ernest Rutherford (1871-1937) found that the radioactivity of the "emanation" (as he called it) from thorium diminished with time. This decay of radioactivity was a vital clue.

Rutherford, working in Canada with the chemist Frederick Soddy (1877-1956), developed a revolutionary hypothesis to explain the process. They realized that radioactive elements can spontaneously change into other elements. As they do so, they emit radiation of one type or another. The spontaneous decay process continues in a chain of emissions until a stable atom is formed. It was, as Rutherford and Soddy boasted, the transmutation of elements that had eluded alchemists for thousands of years. They recognized at once that the ceaseless emissions pointed to a vast store of energy within atoms--energy that might someday be released for useful power or terrible weapons, however people chose.



Rutherford's picture of transmutation. A radium atom emits an alpha particle, turning into "Emanation" (in fact the gas radon). This atom in turn emits a particle to become "Radium A" (now known to be a form of polonium). The chain eventually ends with stable lead. *Philosophical Transactions of the Royal Society of London,* **1905.**

TO UNDERSTAND WHAT HAPPENS when radioactive atoms emit radiation, scientists had to understand how the atom is built. As Rutherford first explained in 1911, each atom is made of a small, massive nucleus, surrounded by a swarm of light electrons. It is from the nucleus that the radioactivity, the alpha or beta or gamma rays, shoot out. By around 1932 Rutherford's colleagues had found that the nucleus is built of smaller particles, the positively charged protons and the electrically neutral neutrons. A proton or a neutron each has about the mass of one hydrogen atom. All atoms of a given element have a given number of protons in their nuclei, called the atomic number. To balance this charge they have an equal number of electrons swarming around the nucleus. It is these shells of electrons that give the element its chemical properties.

However, it turned out that atoms of a given element can have different numbers of neutrons, and thus different atomic mass. Soddy named the forms of an element with different atomic masses the *isotopes* of the element. For example, the lightest element, hydrogen, has the atomic number 1. Its nucleus normally is made of one proton and no neutrons, and thus its atomic mass is also 1. But hydrogen has isotopes with different atomic masses. "Heavy" hydrogen, called deuterium, has one proton and one neutron in its nucleus, and thus its atomic mass is 2. Hydrogen also has a radioactive isotope, tritium. Tritium has one proton and two neutrons, and thus its atomic mass is 3. The three forms of hydrogen each have one electron, and thus the same chemical properties.

When a radioactive nucleus gives off alpha or beta particles, it is in the process of changing into a different nucleus--a different element, or a different isotope of the same element. For example, radioactive thorium is formed when uranium-238--an isotope of uranium with 92 protons and 146 neutrons--emits an alpha particle. Since the alpha particle consists of two protons and two neutrons, when these are subtracted what is left is a nucleus with 90 protons and 144 neutrons. Thorium is the element of atomic number 90, and this isotope of thorium has an atomic mass of 234. The results of decay may themselves be unstable, as is the case with thorium-234. The chain of decays continues until a stable nucleus forms, in this case the element lead.

Rutherford and Soddy discovered that every radioactive isotope has a specific *half-life*. Half the nuclei in a given quantity of a radioactive isotope will decay in a specific period of time. The half-life of uranium-238 is 4.5 billion years, which means that over that immense period of time half the nuclei in a sample of uranium-238 will decay (in the next 4.5 billion years, half of what is left will decay, leaving one quarter of the original, and so forth). The isotopes produced by the decay of uranium themselves promptly decay in a long chain of radiations. Radium and polonium are links in this chain.

Radium caught Marie Curie's attention because its half-life is 1600 years. That's long enough so that there was a fair amount of radium mixed with uranium in her pitchblende. And it was short enough so that its radioactivity was quite intense. A long-lived isotope like uranium-238 emits radiation so slowly that its radioactivity is scarcely noticeable. By contrast, the half-life of the longest-lived polonium isotope, polonium-210, is only 138 days. This short half-life helps explain why Marie Curie was unable to isolate polonium. Even as she performed her meticulous fractional crystallizations, the polonium in her raw material was disappearing as a result of its rapid radioactive decay.

Uses of Radioactivity

THE EARLY WORK OF MARIE AND PIERRE CURIE led almost immediately to the use of radioactive materials in medicine. In many circumstances isotopes are more effective and safer than surgery or chemicals for attacking cancers and certain other diseases. Over the years, many other uses have been found for radioactivity. Until electrical particle accelerators were invented in the 1930s, scientists used radiation from isotopes to bombard atoms, uncovering many of the secrets of atomic structure. To this day radioactive isotopes, used as "tracers" to track chemical changes and the processes of life, are an almost indispensable tool for biologists and physiologists. Isotopes are crucial even for geology and archeology. As soon as he understood radioactive decay, Pierre Curie realized that it could be used to date materials. Soon the age of the earth was established by uranium decay at several billion years, far more than scientists had supposed. Since the 1950s radioactive carbon has been used to pin down the age of plant and animal remains, for example in ancient burials back to 50,000 years ago.

Radium and Radioactivity

By Mme. Sklodowska Curie, Discoverer of Radium
from *Century Magazine* (January 1904), pp. 461-466

The discovery of the phenomena of radioactivity adds a new group to the great number of invisible radiations now known, and once more we are forced to recognize how limited is our direct perception of the world which surrounds us, and how numerous and varied may be the phenomena which we pass without a suspicion of their existence until the day when a fortunate hazard reveals them.

The radiations longest known to us are those capable of acting directly upon our senses; such are the rays of sound and light. But it has also long been recognized that, besides light itself, warm bodies emit rays in every respect analogous to luminous rays, though they do not possess the power of directly impressing our retina. Among such radiations, some, the infra-red, announce themselves to us by producing a measurable rise of temperature in the bodies which receive them, while others, the ultra-violet, act with specially great intensity upon photographic plates. We have here a first example of rays only indirectly accessible to us.

Yet further surprises in this domain of invisible radiations were reserved for us. The researches of two great physicists, Maxwell and Hertz, showed that electric and magnetic effects are propagated in the same manner as light, and that there exist “electromagnetic radiations,” similar to luminous radiations, which are to the infra-red rays what these latter are to light. These are the electromagnetic radiations which are used for the transmission of messages in wireless telegraphy. They are present in the space around us whenever an electric phenomenon is produced, especially a lightning discharge. Their presence may be established by the use of special apparatus, and here again the testimony of our senses appears only in an indirect manner. If we consider these radiations in their entirety - the ultra-violet, the luminous, the infra-red, and the electromagnetic - we find that the radiations we see constitute but an insignificant fraction of those that exist in space. But it is human nature to believe that the phenomena we know are the only ones that exist, and whenever some chance discovery extends the limits of our knowledge we are filled with amazement. We cannot become accustomed to the idea that we live in a world that is revealed to us only in a restricted portion of its manifestations.

Among recent scientific achievements which have attracted most attention must be placed the discovery of cathode rays, and in even greater measure that of Roentgen rays. These rays are produced in vacuum-tubes when an electric discharge is passed through the rarefied gas. The prevalent opinion among physicists is that cathode rays are formed by extremely small material particles, charged with negative electricity, and thrown off with great velocity from the cathode, or negative electrode, of the tube. When the cathode rays meet the glass wall of the tube they render it vividly fluorescent. These rays can be deflected from their straight path by the action of a magnet. Whenever they encounter a solid obstacle, the emission of Roentgen rays is the result. These latter can traverse the glass and propagate themselves through the outside air. They differ from cathode rays in that they carry no electric charge and are not deflected from their course by the action of a magnet. Everyone knows the effect of Roentgen rays upon photographic plates and upon fluorescent screens, the radiographs obtainable from them, and their application in surgery.

The discovery of Becquerel rays dates from a few years after that of Roentgen rays. At first they were much less noticed. The world, attracted by the sensational discovery of Roentgen rays, was less inclined to astonishment. On all sides a search was instituted by similar processes for new rays, and announcements of phenomena were made that have not always been confirmed. It has been only gradually that the positive existence of a new radiation has been established. The merit of this discovery belongs to M. Becquerel, who succeeded in demonstrating that uranium and its compounds spontaneously emit rays that are able to traverse opaque bodies and to affect photographic plates.

It was at the close of the year 1897 that I began to study the compounds of uranium, the properties of which had greatly attracted my interest. Here was a substance emitting spontaneously and continuously radiations similar to Roentgen rays, whereas ordinarily Roentgen rays can be produced only in a vacuum-tube with the expenditure of energy. By what process can uranium furnish the same rays without expenditure of energy and without undergoing apparent modification? Is uranium the only body whose compounds emit similar rays? Such were the questions I asked myself, and it was while seeking to answer them that I entered into the researches which have led to the discovery of radium.

First of all, I studied the radiation of the compounds of uranium. Instead of making these bodies act upon photographic plates, I preferred to determine the intensity of their radiation by measuring the conductivity of the air exposed to the action of the rays. To make this measurement, one can determine the speed with which the rays discharge an electroscope, and thus obtain data for a comparison. I found in this way that the radiation of uranium is very constant, varying neither with the temperature nor with the illumination. I likewise observed that all the compounds of uranium are active, and that they are more active the greater the proportion of this metal which they contain. Thus I reached the conviction that the emission of rays by the compounds of uranium is a property of the metal itself that it is an atomic property of the element uranium independent of its chemical or physical state. I then began to investigate the different known chemical elements, to determine whether there exist others, besides uranium, that are endowed with atomic radioactivity that is to say, all the compounds of which emit Becquerel rays. It was easy for me to procure samples of all the ordinary substances the common metals and metalloids, oxides and salts. But as I desired to make a very thorough investigation, I had recourse to different chemists, who put at my disposal specimens in some cases the only ones in existence containing very rare elements. I thus was enabled to pass in review all the chemical elements and to examine them in the state of one or more of their compounds. I found but one element undoubtedly possessing atomic radioactivity in measurable degree. This element is thorium. All the compounds of thorium are radioactive, and with about the same intensity as the similar compounds of uranium. As to the other substances, they showed no appreciable radioactivity under the conditions of the test.

I likewise examined certain minerals. I found, as I expected, that the minerals of uranium and thorium are radioactive; but to my great astonishment I discovered that some are much more active than the oxides of uranium and of thorium which they contain. Thus a specimen of pitch-blende (oxide of uranium ore) was found to be four times more active than oxide of uranium itself. This observation astonished me greatly. What explanation could there be for it? How could an ore, containing many substances which I had proved inactive, be more active than the active substances of which it was formed? The answer came to me immediately: The ore must contain a substance more radioactive than uranium and thorium, and this substance must necessarily be a chemical element as yet unknown; moreover, it can exist in the pitch-blende only in small quantities, else it would not have escaped the many analyses of this ore; but, on the other hand, it must possess intense radioactivity, since, although present in small amount, it produces such remarkable effects. I tried to verify my hypothesis by treating pitch-blende by the ordinary processes of chemical analysis, thinking it probable that the new substance would be concentrated in passing through certain stages of the process. I performed several experiments of this nature, and found that the ore could in fact be separated into portions some of which were much more radioactive than others.

To try to isolate the supposed new element was a great temptation. I did not know whether this undertaking would be difficult. Of the new element I knew nothing except that it was radioactive. What were its chemical properties? In what quantity did it appear in pitch-blende? I began the analysis of pitch-blende by separating it into its constituent elements, which are very numerous. This task I undertook in conjunction with M. Curie. We expected that perhaps a few weeks would suffice to solve the problem. We did not suspect that we had begun a work which was to occupy years and which was brought to a successful issue only after considerable expenditure.

We readily proved that pitch-blende contains very radioactive substances, and that there were at least three. That which accompanies the bismuth extracted from pitch-blende we named Polonium; that which accompanies barium from the same source we named Radium; finally, M. Debierne gave the name of Actinium to a substance which is found in the rare earths obtained from the same ore.

Radium was to us from the beginning of our work a source of much satisfaction. Demarçay, who examined the spectrum of our radioactive barium, found in it new rays and confirmed us in our belief that we had indeed discovered a new element.

The question now was to separate the polonium from the bismuth, the radium from the barium. This is the task that has occupied us for years, and as yet we have succeeded only in the case of radium. The research has been a most difficult one. We found that by crystallizing out the chloride of radioactive barium from a solution we obtained crystals that were more radioactive, and consequently richer in radium, than the chloride that remained dissolved. It was only necessary to make repeated crystallizations to obtain finally a pure chloride of radium.

But although we treated as much as fifty kilograms of primary substance, and crystallized the chloride of radiferous barium thus obtained until the activity was concentrated in a few minute crystals, these crystals still contained chiefly chloride of barium; as yet radium was present only in traces, and we saw that we could not finish our experiments with the means at hand in our laboratory. At the same time the desire to succeed grew stronger; for it became evident that radium must possess most intense radioactivity, and that the isolation of this body was therefore an object of the highest interest.

Fortunately for us, the curious properties of these radium-bearing compounds had already attracted general attention and we were assisted in our search.

A chemical factory in Paris consented to undertake the extraction of radium on a large scale. We also received certain pecuniary assistance, which allowed us to treat a large quantity of ore. The most important of these grants was one of twenty thousand francs, for which we are indebted to the Institute of France.

We were thus enabled to treat successively about seven tons of a primary substance which was the residue of pitch-blende after the extraction of uranium. Today we know that a ton of this residue contains from two to three decigrams (from four to seven ten-thousandths of a pound) of radium. During this treatment, and as soon as I had in my possession a decigram of chloride of radium recognized as pure by the spectroscope, I determined the atomic weight of this new element, finding it to be 225, while that of barium is 137.

The properties of radium are extremely curious. This body emits with great intensity all of the different rays that are produced in a vacuum-tube. The radiation, measured by means of an electroscope, is at least a million times more powerful than that from an equal quantity of uranium. A charged electroscope placed at a distance of several meters can be discharged by a few centigrams of a radium salt. One can also discharge an electroscope through a screen of glass or lead five or six centimeters thick. Photographic plates placed in the vicinity of radium are also instantly affected if no screen intercepts the rays; with screens, the action is slower, but it still takes place through very thick ones if the exposure is sufficiently long. Radium can therefore be used in the production of radiographs.

The compounds of radium are spontaneously luminous. The chloride and bromide, freshly prepared and free from water, emit a light which resembles that of a glow-worm. This light diminishes rapidly in moist air; if the salt is in a sealed tube, it diminishes slowly by reason of the transformation of the white salt, which becomes colored, but the light never completely disappears. By redissolving the salt and drying it anew, its original luminosity is restored.

A glass vessel containing radium spontaneously charges itself with electricity. If the glass has a weak spot, for example, if it is scratched by a file, an electric spark is produced at that point, the vessel crumbles like a Leiden jar when overcharged, and the electric shock of the rupture is felt by the fingers holding the glass.

Radium possesses the remarkable property of liberating heat spontaneously and continuously. A solid salt of radium develops a quantity of heat such that for each gram of radium contained in the salt there is an emission of one hundred calories per hour. Expressed differently, radium can melt in an hour its weight in ice. When we reflect that radium acts in this manner continuously, we are amazed at the amount of heat produced, for it can be explained by no known chemical reaction. The radium remains apparently unchanged. If, then, we assume that it undergoes a transformation, we must therefore conclude that the change is extremely slow; in an hour it is impossible to detect a change by any known methods.

As a result of its emission of heat, radium always possesses a higher temperature than its surroundings. This fact may be established by means of a thermometer, if care is taken to prevent the radium from losing heat.

Radium has the power of communicating its radioactivity to surrounding bodies. This is a property possessed by solutions of radium salts even more than by the solid salts. When a solution of a radium salt is placed in a closed vessel, the radioactivity in part leaves the solution and distributes itself through the vessel, the walls of which become radioactive and luminous. The radiation is therefore in part exteriorized. We may assume, with Mr. Rutherford, that radium emits a radioactive gas and that this spreads through the surrounding air and over the surface of neighboring objects. This gas has received the name emanation. It differs from ordinary gas in the fact that it gradually disappears. [The modern name for this element is radon.]

Certain bodies—bismuth, for instance—may also be rendered active by keeping them in solution with the salts of radium. These bodies then become atomically active, and keep this radioactivity even after chemical transformations. Little by little, however, they lose it, while the activity of radium persists.

The nature of radium radiations is very complex. They may be divided into three distinct groups, according to their properties. One group is composed of radiations absolutely analogous to cathode rays, composed of material particles called electrons, much smaller than atoms, negatively charged, and projected from the radium with great velocity—a velocity which for some of these rays is very little inferior to that of light.

The second group is composed of radiations which are believed to be formed by material particles the mass of which is comparable to that of atoms, charged with positive electricity, and set in motion by radium with a great velocity, but one that is inferior to that of the electrons. Being larger than electrons and possessing at the same time a smaller velocity, these particles have more difficulty in traversing obstacles and form rays that are less penetrating.

Finally, the radiations of the third group are analogous to Roentgen rays and do not behave like projectiles.

The radiations of the first group are easily deflected by a magnet; those of the second group, less easily and in the opposite direction; those of the third group are not deflected. From its power of emitting these three kinds of rays, radium may be likened to a complete little Crookes tube acting spontaneously.

Radium is a body which gives out energy continuously and spontaneously. This liberation of energy is manifested in the different effects of its radiation and emanation, and especially in the development of heat. Now, according to the most fundamental principles of modern science, the universe contains a certain definite provision of energy, which can appear under various forms, but cannot be increased.

Without renouncing this conception, we cannot believe that radium creates the energy which it emits; but it can either absorb energy continuously from without, or possess in itself a reserve of energy sufficient to act during a period of years without visible modification. The first theory we may develop by supposing that space is traversed by radiations that are as yet unknown to us, and that radium is able to absorb these radiations and transform their energy into the energy of radioactivity. Thus in a vacuum-tube the electric energy is utilized to produce cathode rays, and the energy of the latter is partly transformed, by the bodies which absorb them into the energy of Roentgen rays. It is true that we have no proof of the existence of radiations which produce radioactivity; but, as indicated at the beginning of this article, there is nothing improbable in supposing that such radiations exist about us without our suspecting it.

If we assume that radium contains a supply of energy which it gives out little by little, we are led to believe that this body does not remain unchanged, as it appears to, but that it undergoes an extremely slow change. Several reasons speak in favor of this view. First, the emission of heat, which makes it seem probable that a chemical reaction is taking place in the radium. But this can be no ordinary chemical reaction, affecting the combination of atoms in the molecule. No chemical reaction can explain the emission of heat due to radium. Furthermore, radioactivity is a property of the atom of radium; if, then, it is due to a transformation this transformation must take place in the atom itself. Consequently, from this point of view, the atom of radium would be in a process of evolution, and we should be forced to abandon the theory of the invariability of atoms, which is at the foundation of modern chemistry.

Moreover, we have seen that radium acts as though it shot out into space a shower of projectiles, some of which have the dimensions of atoms, while others can only be very small fractions of atoms. If this image corresponds to a reality, it follows necessarily that the atom of radium breaks up into subatoms of different sizes, unless these projectiles come from the atoms of the surrounding gas, disintegrated by the action of radium; but this view would likewise lead us to believe that the stability of atoms is not absolute.

Radium emits continuously a radioactive emanation which, from many points of view, possesses the properties of a gas. Mr. Rutherford considers the emanation as one of the results of the disintegration of the atom of radium, and believes it to be an unstable gas which is itself slowly decomposed.

Professor Ramsay has announced that radium emits helium gas continuously. If this very important fact is confirmed, it will show that a transformation is occurring either in the atom of radium or in the neighboring atoms, and a proof will exist that the transmutation of the elements is possible. [In fact radium does emit helium, as alpha particles.]

When a body that has remained in solution with radium becomes radioactive, the chemical properties of this body are modified, and here again it seems as though we have to deal with a modification of the atom. It would be very interesting to see whether, by thus giving radioactivity to bodies, we can succeed in causing an appreciable change in their atoms. We should thus have a means of producing certain transformations of elements at will. [These observations were misleading. True artificial radioactivity was not produced until the work of Irène and Frédéric Joliot-Curie in 1934.]

It is seen that the study of the properties of radium is of great interest. This is true also of the other strongly radioactive substances, polonium and actinium, which are less known because their preparation is still more difficult. All are found in the ores of uranium and thorium, and this fact is certainly not the result of chance, but must have some connection with the manner of formation of these elements. Polonium, when it has just been extracted from pitch-blende, is as active as radium, but its radioactivity slowly disappears; actinium has a persistent activity. These two bodies differ from radium in many ways; their study should therefore be fertile in new results. Actinium lends itself readily to the study of the emanation and of the radioactivity produced in inactive bodies, since it gives out emanation in great quantity. It would also be interesting, from the chemical point of view, to prove that polonium and actinium contain new elements. Finally, one might seek out still other strongly radioactive substances and study them.

But all these investigations are exceedingly difficult because of the obstacles encountered in the preparation of strongly radioactive substances. At the present time we possess only about a gram of pure salts of radium. Research in all branches of experimental science—physics, chemistry, physiology, medicine—is impeded, and a whole evolution in science is retarded, by the lack of this precious and unique material, which can now be obtained only at great expense. We must now look to individual initiative to come to the aid of science, as it has so often done in the past, and to facilitate and expedite by generous gifts the success of researches the influence of which may be far-reaching.

On a New, Strongly Radio-active Substance Contained in Pitchblende

-- P. Curie, Mme. P. Curie and G. Bèmont

Translation of “Sur une nouvelle substance fortement radio-active, contenue dans la pechblende,” *Comptes rendus de l'AcadÈmie des Sciences,* Paris, 1898 (26 December), vol. 127, pp. 1215-1217.

Two of us have shown that by purely chemical procedures it is possible to extract from pitchblende a strongly radio-active substance. This substance is related to bismuth by its analytical properties. We have expressed the opinion that perhaps the pitchblende contained a new element, for which we have proposed the name of polonium.[1]

The investigations which we are following at present are in agreement with the first results we obtained, but in the course of these investigations we have come upon a second, strongly radioactive substance, entirely different from the first in its chemical properties. Specifically, polonium is precipitated from acid solution by hydrogen sulfide; its salts are soluble in acids and water precipitates them from solution; polonium is completely precipitated by ammonia.

The new radio-active substance which we have just found has all the chemical appearance of nearly pure barium: it is not precipitated either by hydrogen sulfide or by ammonium sulfide, nor by ammonia; its sulfate is insoluble in water and in acids; its carbonate is insoluble in water; its chloride, very soluble in water, is insoluble in concentrated hydrochloric acid and in alcohol. Finally this substance gives the easily recognized spectrum of barium.

We believe nevertheless that this substance, although constituted in its major part by barium, contains in addition a new element which gives it its radio-activity, and which, in addition, is closely related to barium in its chemical properties.

Here are the reasons which argue for this point of view:

1. Barium and its compounds are not ordinarily radio-active; and one of us has shown that radio-activity appears to be an atomic property, persisting in all the chemical and physical states of the material.[2] From this point of view, the radio-activity of our substance, not being due to barium, must be attributed to another element.

2. The first substances which we obtained had, in the form of a hydrated chloride, a radio-activity 60 times stronger than that of metallic uranium (the radio-active intensity being evaluated by the magnitude of the conductivity of the air in our parallel-plate apparatus). When these chlorides are dissolved in water and partially precipitated by alcohol, the part precipitated is much more active than the part remaining in solution. Basing a procedure on this, one can carry out a series of fractionations, making it possible to obtain chlorides which are more and more active. We have obtained in this manner chlorides having an activity 900 times greater than that of uranium. We have been stopped by lack of material; and, considering the progress of our operations it is to be predicted that the activity would still have increased if we had been able to continue. These facts can be explained by the presence of a radio-active element whose chloride would be less soluble in alcohol and water than that of barium.

3. M. Demaráay has consented to examine the spectrum of our substance with a kindness which we cannot acknowledge too much. The results of his examinations are given in a special Note at the end of ours. Demaráay has found one line in the spectrum which does not seem due to any known element. This line, hardly visible with the chloride 60 times more active than uranium, has become prominent with the chloride enriched by fractionation to an activity 900 times that of uranium. The intensity of this line increases, then, at the same time as the radio-activity; that, we think, is a very serious reason for attributing it to the radio-active part of our substance.

The various reasons which we have enumerated lead us to believe that the new radio-active substance contains a new element to which we propose to give the name of radium.

We have measured the atomic weight of our active barium, determining the chlorine in its anhydrous chloride. We have found numbers which differ very little from those obtained in parallel measurements on inactive barium chloride; the numbers for the active barium are always a little larger, but the difference is of the order of magnitude of the experimental errors.

The new radio-active substance certainly includes a very large portion of barium; in spite of that, the radio-activity is considerable. The radio-activity of radium then must be enormous.

Uranium, thorium, polonium, radium, and their compounds make the air a conductor of electricity and act photographically on sensitive plates. In these respects, polonium and radium are considerably more active than uranium and thorium. On photographic plates one obtains good impressions with radium and polonium in a half-minute's exposure; several hours are needed to obtain the same result with uranium and thorium.

The rays emitted by the components of polonium and radium make barium platinocyanide fluorescent; their action in this regard is analogous to that of the Rântgen rays, but considerably weaker. To perform the experiment, one lays over the active substance a very thin aluminum foil on which is spread a thin layer of barium platinocyanide; in the darkness the platinocyanide appears faintly luminous above the active substance.

In this manner a source of light is obtained, which is very feeble to tell the truth, but which operates without a source of energy. Here is at least an apparent contradiction to Carnot's Principle.

Uranium and thorium give no light under these conditions, their action being probably too weak.[3]

1 P. Curie and Mme. P. Curie, *Comptes rendus,* vol. 127, p. 175.

2 Mme. P. Curie, *Comptes rendus,* vol. 126, p. 1101.

3 May we be permitted to thank here M. Suess, Correspondent of the Institute and Professor at the University of Vienna? Thanks to his benevolent intervention, we have obtained from the Austrian government the free gift of 100 kg of a residue from the treatment of the Joachimsthal pitchblende, containing no uranium, but containing polonium and radium. This gift will greatly facilitate our researches.

X-rays and Uranium Rays

MARIE CURIE'S CHOICE of a thesis topic was influenced by two recent discoveries by other scientists. In December 1895, about six months after the Curies married, German physicist Wilhelm Roentgen discovered a kind of ray that could travel through solid wood or flesh and yield photographs of living people's bones. Roentgen dubbed these mysterious rays X-rays, with X standing for unknown. In recognition of his discovery, Roentgen in 1901 became the first Nobel laureate in physics.

One of Roentgen's first X-ray photographs -- a colleague's hand (note the wedding ring). The revelation of X-rays fascinated the public and deeply puzzled scientists

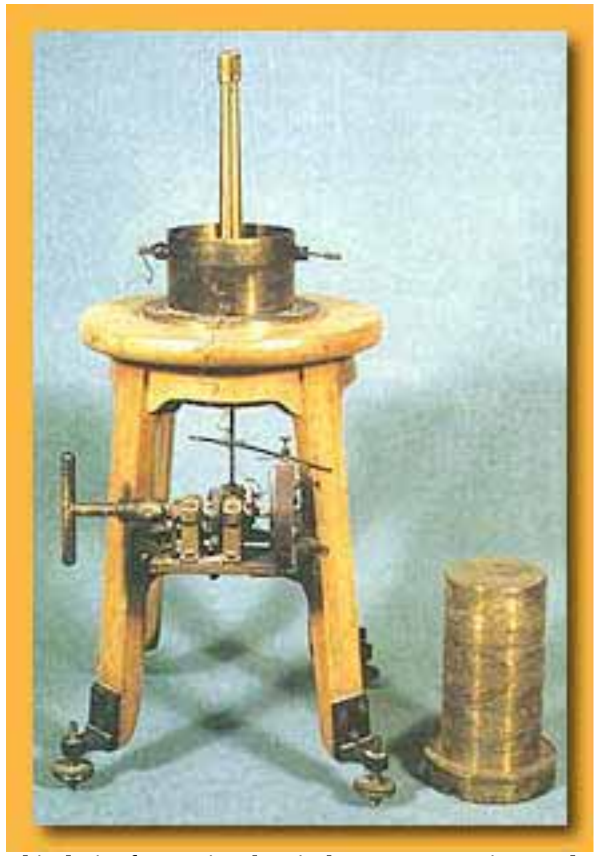
Henri Becquerel, discoverer of uranium radiation. Although he tried to help the Curies solve their financial problems and advance their careers, the relationship eventually soured--as sometimes happens with scientists touchy about sharing credit for discoveries.

In early 1896, only a few of months after Roentgen's discovery, French physicist Henri Becquerel reported to the French Academy of Sciences that uranium compounds, even if they were kept in the dark, emitted rays that would fog a photographic plate. He had come upon this discovery accidentally. Despite Becquerel's intriguing finding, the scientific community continued to focus its attention on Roentgen's X-rays, neglecting the much weaker Becquerel rays or uranium rays.

THE IGNORED URANIUM RAYS appealed to Marie Curie. Since she would not have a long bibliography of published papers to read, she could begin experimental work on them immediately. The director of the Paris Municipal School of Industrial Physics and Chemistry, where Pierre was professor of physics, permitted her to use a crowded, damp storeroom there as a lab.

A clever technique was her key to success. About 15 years earlier, Pierre and his older brother, Jacques, had invented a new kind of electrometer, a device for measuring extremely low electrical currents. Marie now put the Curie electrometer to use in measuring the faint currents that can pass through air that has been bombarded with uranium rays. The moist air in the storeroom tended to dissipate the electric charge, but she managed to make reproducible measurements.

> **"Instead of making these bodies act upon photographic plates, I preferred to determine the intensity of their radiation by measuring the conductivity of the air exposed to the action of the rays."**



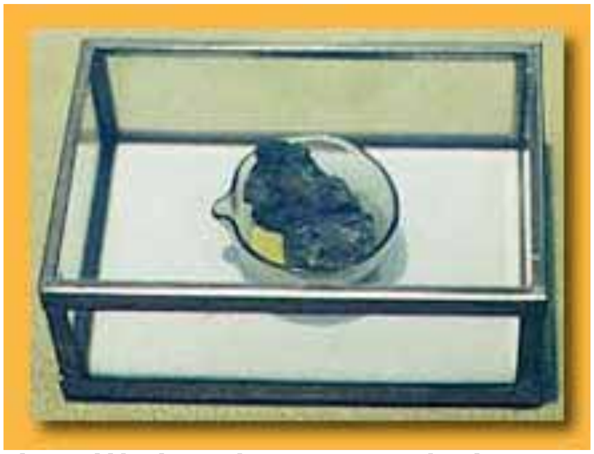
This device for precise electrical measurement, invented by Pierre Curie and his brother Jacques, was essential for Marie's work. (Photo ACJC)

With numerous experiments Marie confirmed Becquerel's observations that the electrical effects of uranium rays are constant, regardless of whether the uranium was solid or pulverized, pure or in a compound, wet or dry, or whether exposed to light or heat. Likewise, her study of the rays emitted by different uranium compounds validated Becquerel's conclusion that the minerals with a higher proportion of uranium emitted the most intense rays. She went beyond Becquerel's work, however, in forming a crucial hypothesis: the emission of rays by uranium compounds could be an atomic property of the element uranium--something built into the very structure of its atoms.

MARIE'S SIMPLE HYPOTHESIS would prove revolutionary. It would ultimately contribute to a fundamental shift in scientific understanding. At the time scientists regarded the atom--a word meaning *undivided* or *indivisible* -- as the most elementary particle. A hint that this ancient idea was false came from the discovery of the electron by other scientists around this same time. But nobody grasped the complex inner structure or the immense energy stored in atoms. Marie and Pierre Curie themselves were not convinced that radioactive energy came from within atoms--maybe, for example, the earth was bathed in cosmic rays, whose energy certain atoms somehow caught and radiated? Marie's real achievement was to cut through the complicated and obscure observations with a crystal-clear analysis of the set of conclusions that, however unexpected, were logically possible.

Marie tested all the known elements in order to determine if other elements or minerals would make air conduct electricity better, or if uranium alone could do this. In this task she was assisted by a number of chemists who donated a variety of mineral samples, including some containing very rare elements. In April 1898 her research revealed that thorium compounds, like those of uranium, emit Becquerel rays. Again the emission appeared to be an atomic property. To describe the behavior of uranium and thorium she invented the word "radioactivity" --based on the Latin word for ray.

The Discovery of Polonium and Radium



This pitchblende sample was instrumental in the discovery of radium and polonium.

PIERRE WAS SO INTRIGUED by Marie's work that he joined forces with her. Her research had revealed that two uranium ores, pitchblende and chalcolite, were much more radioactive than pure uranium itself.

She concluded that the highly radioactive nature of these ores might be due to one or more additional, as yet undiscovered, radioactive elements. Pierre put aside his research on crystals to help expedite Marie's discovery of the possible new elements. They worked as a team, each taking on specific scientific tasks.

Discovering Radium

"**My experiments proved** that the radiation of uranium compounds can be measured with precision under determined conditions, and that this radiation is an atomic property of the element of uranium. Its intensity is proportional to the quantity of uranium contained in the compound, and depends neither on conditions of chemical combination, nor on external circumstances, such as light or temperature.

I undertook next to discover if there were other elements possessing the same property, and with this aim I examined all the elements then known, either in their pure state or in compounds. I found that among these bodies, thorium compounds are the only ones which emit rays similar to those of uranium. The radiation of thorium has an intensity of the same order as that of uranium, and is, as in the case of uranium, an atomic property of the element....

During the course of my research, I had had occasion to examine not only simple compounds, salts and oxides, but also a great number of minerals. Certain ones proved radioactive; these were those containing uranium and thorium; but their radioactivity seemed abnormal, for it was much greater than the amount I had found in uranium and thorium had led me to expect.

This abnormality greatly surprised us. When I had assured myself that it was not due to an error in the experiment, it became necessary to find an explanation. I then made the hypothesis that the ores uranium and thorium contain in small quantity a substance much more strongly radioactive than either uranium or thorium. This substance could not be one of the known elements, because these had already been examined; it must, therefore, be a new chemical element.

I had a passionate desire to verify this hypothesis as rapidly as possible. And Pierre Curie, keenly interested in the question, abandoned his work on crystals (provisionally, he thought) to join me in the search for this unknown substance.

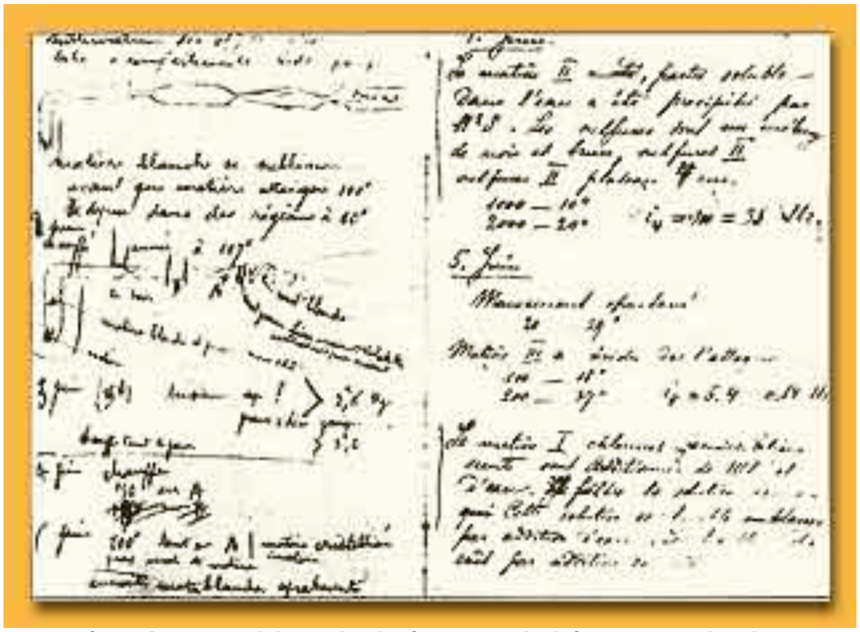
We chose, for our work, the ore pitchblende, a uranium ore, which in its pure state is about four times more active than oxide of uranium. Since the composition of this ore was known through very careful chemical analysis, we could expect to find, at a maximum, 1 per cent of new substance. The result of our experiment proved that there were in reality new radioactive elements in pitchblende, but that their proportion did not reach even a millionth per cent!”

—*from Pierre Curie pp. 96-98.*

“Neither of us could foresee that in beginning this work we were to enter the path of a new science which we should follow for all our future.”

It was far from easy to track down the new radioactive elements. Pitchblende is a highly complex mineral, made of combinations of up to 30 different elements. To isolate the unknown substances, of which only tiny amounts were present, the Curies were the first to use a new method of chemical analysis. They employed various standard (but sometimes demanding) chemical procedures to separate the different substances in pitchblende. For example, a particular element might dissolve in an acid, which they could pour off, leaving other elements behind in a sludge at the bottom of the pot. After the materials were separated into different types of compounds, the Curies used radiation measurements to trace the minute amount of unknown, radioactive element among the fractions that resulted.

Making repeated separations of the various substances in the pitchblende, Marie and Pierre used the Curie electrometer to identify the most radioactive fractions. They thus discovered that two fractions, one containing mostly bismuth and the other containing mostly barium, were strongly radioactive. In July 1898 the Curies published their conclusion: the bismuth fraction contained a new element. Chemically it acted almost exactly like bismuth, but since it was radioactive, it had to be something new. They named it "polonium" in honor of the country of Marie's birth. A second publication, in December 1898, explained their discovery in the barium fraction of another new element, which they named "radium" from the Latin word for ray. The Curies were close to reaching one of the highest goals that a scientist of the time could hope to achieve--placing new elements in the Periodic Table. While the chemical properties of the two new elements were completely dissimilar, they both had strong radioactivity.



A page from the Curies' lab notebook of 1898. On the left, in Pierre's hand, a sublimation procedure. On the right, in Marie's hand, chemical processing. (Photo ACJC).

TO CONVINCE THE SCIENTIFIC COMMUNITY of the existence of polonium and radium, and to complete the identification and establish the nature of the new elements, Marie set out to isolate them from the bismuth and barium with which they were mixed. Since the Municipal School storeroom would be inadequate to the task, the Curies moved their lab to an abandoned shed across the school courtyard. The shed, formerly a medical school dissecting room, was poorly outfitted and ventilated. It was not weathertight. She succeeded in separating the radium from the barium only with tremendous difficulty -- which would become central in the romantic legend of her life. She had to treat very large quantities of pitchblende, a ton of which the Curies received as a donation from the Austrian government. (The Austrians hoped she would find a use for a mineral their mines yielded as a waste byproduct.)

Luckily some help was available for the tedious labor of treating the pitchblende. They were able to collaborate with the Central Chemical Products Company, the firm that marketed Pierre's scientific instruments. Their colleague Andrè Debierne cleverly adapted their standard lab techniques into larger-scale industrial processes. These processes isolated from the pitchblende materials with high concentrations of radium and polonium, which the Curies studied in detail in what she called the “miserable old shed.” In exchange for supplying chemical products and paying staff wages, the Central Chemical Products Company took a share of the radium salts extracted on its premises. The firm would later make a handsome profit by marketing these radium salts for medical and other uses.

Despite the industrial assistance the Curies received, it took Marie over three years to isolate one tenth of a gram of pure radium chloride. For reasons that would not be fully understood until the concept of radioactive decay was developed, Marie never succeeded in isolating polonium, which has a half-life of only 138 days.

The "miserable old shed" where radium was isolated.

The Struggle to Isolate Radium

"**The School of Physics** could give us no suitable premises, but for lack of anything better, the Director permitted us to use an abandoned shed which had been in service as a dissecting room of the School of Medicine. Its glass roof did not afford complete shelter against rain; the heat was suffocating in summer, and the bitter cold of winter was only a little lessened by the iron stove, except in its immediate vicinity. There was no question of obtaining the needed proper apparatus in common use by chemists. We simply had some old pine-wood tables with furnaces and gas burners. We had to use the adjoining yard for those of our chemical operations that involved producing irritating gases; even then the gas often filled our shed. With this equipment we entered on our exhausting work.

Yet it was in this miserable old shed that we passed the best and happiest years of our life, devoting our entire days to our work. Often I had to prepare our lunch in the shed, so as not to interrupt some particularly important operation. Sometimes I had to spend a whole day mixing a boiling mass with a heavy iron rod nearly as large as myself. I would be broken with fatigue at the day's end. Other days, on the contrary, the work would be a most minute and delicate fractional crystallization, in the effort to concentrate the radium. I was then annoyed by the floating dust of iron and coal from which I could not protect my precious products. But I shall never be able to express the joy of the untroubled quietness of this atmosphere of research and the excitement of actual progress with the confident hope of still better results. The feeling of discouragement that sometimes came after some unsuccessful toil did not last long and gave way to renewed activity. We had happy moments devoted to a quiet discussion of our work, walking around our shed.

One of our joys was to go into our workroom at night; we then perceived on all sides the feebly luminous silhouettes of the bottles or capsules containing our products. It was really a lovely sight and one always new to us. The glowing tubes looked like faint, fairy lights."

—from Autobiographical Notes pp. 186-187.

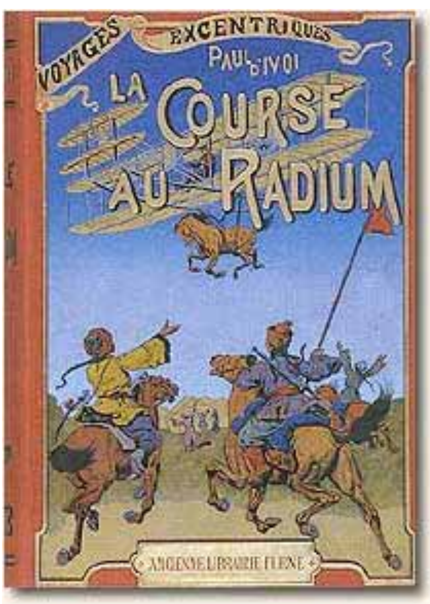
Founding the Radium Industry

THEIR NEW SUBSTANCES GLOWED! The fact that material containing radium spontaneously emitted light was among the results the Curies presented at the first international physics conference, held in Paris in 1900. Other scientists were intrigued by the implications of the idea that processes within the atom were responsible for radioactive phenomena.

"One of our joys was to go into our workroom at night.... The glowing tubes looked like faint, fairy lights."

Dish containing 2.7 gr. of radium bromide, photographed (along with the card placed above it) by the light it emitted.

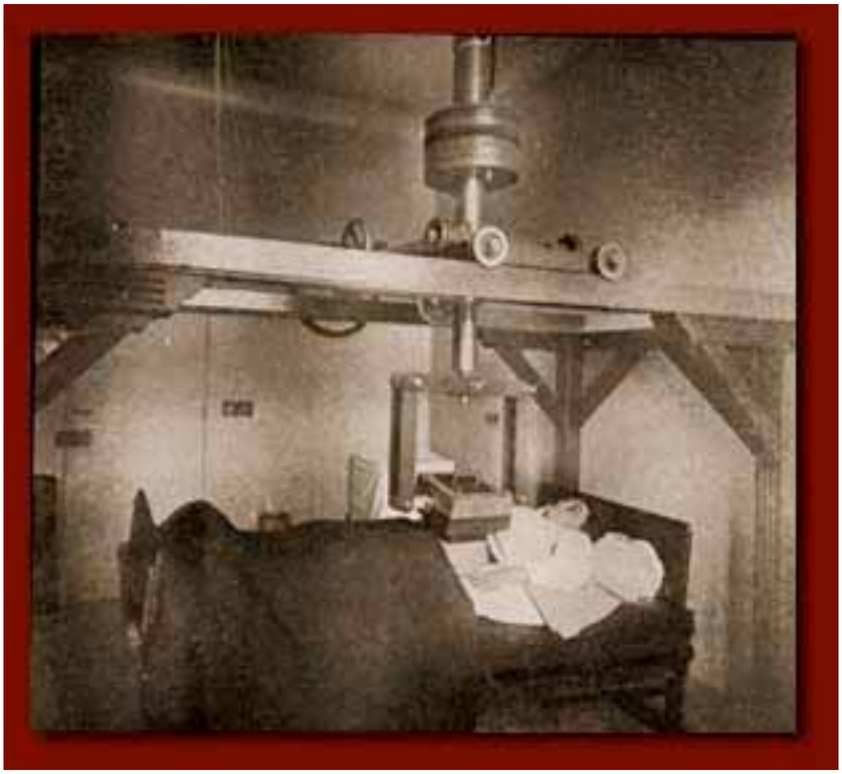
The Curies published in detail all the processes they used to isolate radium, without patenting any of them. Registering and defending patents would use up money and time they could scarcely spare. Like many of their colleagues in Paris, they believed scientists should spend as little energy as possible on personal financial matters, devoting their lives to pure scientific research for the benefit of all humanity. In any case, they had no reason to expect that radium would be a big money-maker.



"The Race for Radium." The public was fascinated by radium. In cheap science fiction novels--and sometimes in sober newspaper articles--it was touted as a magical substance whose rays could cure all ills, power wondrous machines, or destroy a city at one blow. (Photo ACJC)

"Radium Salts/Polonium - Actinium/and other radioactive substances." An announcement and price list for materials produced by Armet de Lisle's factory. Although fabulously expensive, the materials were much in demand for attacking cancer, skin diseases and other ailments. (Photo ACJC)

Radium Therapy



The first experiments on the biological properties of radium were successfully made in France with samples from our laboratory, while my husband was living. The results were, at once, encouraging, so that the new branch of medical science, called radiumtherapy (in France, Curietherapy), developed rapidly, first in France and later in other countries. To supply the radium wanted for this purpose, a radium-producing industry was established. The first plant was created in France and worked very successfully, but afterwards manufactures were founded in other countries, the most important of which are now in America, where great quantities of radium ore, named "carnotite," are available. The radiumtherapy and the radium production developed conjointly, and the results were more and more important for the treatment of several diseases, and particularly of cancer. As a consequence of this, several institutes have been founded, in the large cities, for the application of the new therapy. Some of these institutes own several grams of radium, the commercial price of the gram being now about $70,000, the cost of production depending on the very small proportion of radium in the ore.

It may be easily understood how deeply I appreciated 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.

—from Autobiographical Notes pp. 199-200.

A THRIVING INDUSTRY based on the "miracle" drug radium soon grew up, however, and it was tightly linked with the Curies. Pierre's pioneering work on the effects of radium on living organisms showed it could damage tissue, and this discovery was put to use against cancer and other ills. In 1904 French industrialist Armet de Lisle, whose factory would soon provide radium to the medical profession, began to collaborate with the Curies. De Lisle benefited from the Curies' technical suggestions on the best treatments for pitchblende. In return the Curies were able to accumulate larger samples of radioactive material than they would have been able to prepare on their own. At a time when few research posts were available in France, de Lisle also provided jobs in the new radium industry for a number of scientists who had trained with the Curies.

Although their collaboration with industry advanced their scientific endeavors, the Curies did not grow wealthy as a result. With a child and a parent to support, household help to pay for, and an expensive research project to carry out, Pierre sought a job with better pay. The product of an unorthodox educational background, he found no welcome at French universities.

> **"...we were forced to recognize, toward 1900, that some increase in our income was indispensable."**

Then the University of Geneva made an offer that included not only a good salary but also an adequate private lab in which Marie would play an official role. The threat of losing Pierre to Switzerland energized the French establishment. Thanks to the intervention of French mathematician Henri Poincarè, Pierre got the chair of physics in a Sorbonne program that introduced medical students to the basics of physics, chemistry, and natural history (and thus called PCN).

Henri Poincarè was one of the senior scientists who admired the Curies' work, and steered jobs and monetary awards their way.

New Responsibilities and Concerns

Irène points to her mother's radiation-scarred fingertips (Photo ACJC)

N O LAB WAS PROVIDED with Pierre's PCN position, so the Curies maintained their lab at the shed. Although Pierre's salary rose, his teaching load doubled, since he kept his position at the Municipal School also. The Curies noted the subsequent deterioration in his health. They failed to consider a possible link between Pierre's attacks of severe pain and the intense radiation they were working with. Marie herself had lost nearly 20 pounds while doing her thesis research, and both Curies did permanent damage to their fingertips from their unprotected exposure to highly radioactive materials.

Anxious to contribute to the family income, Marie became the first woman to be appointed lecturer at France's best teachers' training institution for women. Located in the Paris suburb of Sèvres, the school had a distinguished group of professors from the Sorbonne and elsewhere. Marie was the first instructor there to include laboratory work in the physics curriculum.

"I had to give much time to the preparation of my lectures at Sèvres, and to the organization of the laboratory work there, which I found very insufficient."

HEALTH AND FINANCIAL CONCERNS were not the only problems to plague the Curies as Marie wound up her thesis research. Although in the course of her thesis work the prestigious French Academy of Sciences had recognized Marie's scientific promise by awarding her a prize on three occasions--and such prizes could be a significant source of income for researchers--the academy dealt the Curies a blow by denying membership to Pierre in 1902. At about the same time Marie's beloved father died in Poland following a difficult gall bladder operation.

A TENDENCY TO ROMANTICIZE HER OWN LIFE characterized Marie Curie from girlhood on. In letters she wrote as a teenager she sometimes presented herself as a tragic heroine. Similarly, in her 1923 biography *Pierre Curie* and in the autobiographical notes appended to it, she depicted herself and her husband as participants in a heroic struggle. According to the self-portrait she propagated, Pierre and Marie Curie, in their pursuit of scientific truth, had to overcome not only poverty but also the indifference and even hostility of the French establishment.

> **"My plans for the future? I have none....I mean to get through as well as I can, and when I can do no more, say farewell to this base world. The loss will be small, and regret for me will be short...."** *--letter of Marie Curie to her cousin Henrietta Michalowska, December 1886*

The romantic--and only partially true--legend that Curie helped create of her heroic early struggle was further spread by the 1943 film *Madame Curie*, starring Greer Garson.

The facilities in the School of Industrial Physics and Chemistry shed, a model of which is shown here, were barely adequate, but the Curies also had the use of lab space, raw materials, and personnel provided by industrialists.

While not actually false, this image of herself and Pierre as solitary laborers in search of knowledge is only part of the truth. For example, in her biography *Pierre Curie,* Marie devotes paragraphs to describing the miserable old shed in which she and Pierre made their significant discoveries. What she does not tell the reader is that from early on in their work the Curies received significant assistance from collaborators in industry. For example, the gross treatment of the first ton of pitchblende, donated to the Curies by the Austrian government, was performed in the factory of the Central Chemical Products Company, which marketed Pierre's scientific instruments. Far from laboring entirely on their own, the Curies were allied with the French radioelements industry that their research did so much to develop.

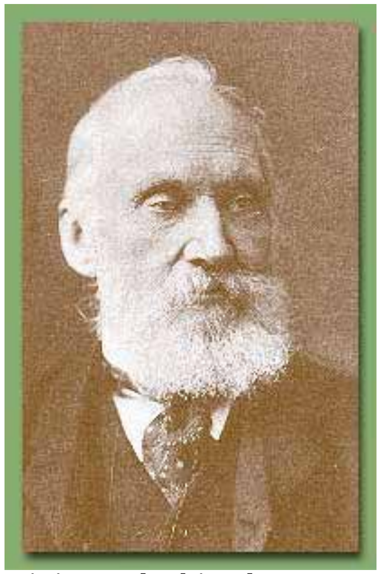
As for government research grants and salaries, Marie and Pierre were treated as well as most good scientists of their day. The real problem, Marie and her friends insisted, was that science as a whole got far too little funding.

> **“There was no question of obtaining the needed proper apparatus in common use by chemists.... Sometimes I had to spend a whole day mixing a boiling mass with a heavy iron rod nearly as large as myself. I would be broken with fatigue at the day's end.”** *--Marie Curie,* Autobiographical Notes

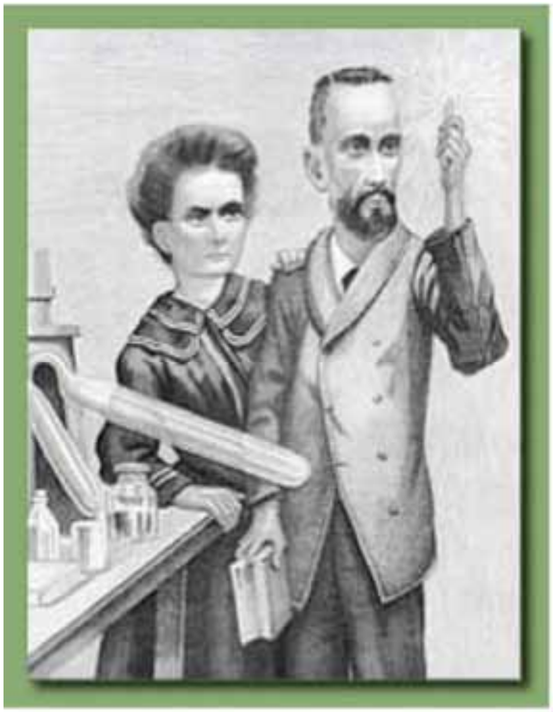
The romantic image of the struggling scientist had already been established a generation earlier by Louis Pasteur and others. While reflecting real difficulties, the image also served as a propaganda tool. At a time when Curie hoped to secure funding for her Radium Institute, her emphasis on the difficulties she faced as a scientist helped not only to arouse public sympathy but also to raise significant philanthropic donations and put pressure on the French government. If more money could be won for basic research by emphasizing certain aspects of her past and downplaying others, a larger truth would be served--scientists everywhere could do far more for humanity if they had better funding. “All civilized groups,” Marie wrote, “have an absolute duty to watch over the domain of pure science...and to provide [its workers] with the support they need.”

Honors from Abroad

FRANCE WAS LESS FORTHCOMING than other countries when it came to honoring the Curies' work. In early June 1903 both Curies were invited to London as guests of the prestigious Royal Institution. Since custom ruled out women lecturers, Pierre alone described their work in his "Friday Evening Discourse." He was careful, however, to describe Marie's crucial role in their collaboration. The audience included representatives of England's social elite and such major scientists as Lord Kelvin. Kelvin showed his respect by sitting next to Marie at the lecture and by hosting a luncheon in Pierre's honor the following day.



Britain's Lord Kelvin, whose contributions in several fields helped shape the scientific thought of his era, openly displayed his admiration for Pierre's scientific achievements.



The attention that English scientists paid to the Curies' work helped make them household names in that country, as in this famous caricature, "Radium," from the popular British periodical *Vanity Fair.*

But all was not well that weekend. Pierre was in such bad health that he had experienced difficulty in dressing himself before the talk. His fingers were so covered with sores that he spilled some radium in the hall while demonstrating its properties. Ill health, however, kept neither Curie from noting the value of the jewels worn by the members of English high society they met in the course of the weekend. They amused themselves by estimating the number of fine laboratories they could set up with the proceeds from selling those jewels.

VISITORS FROM ABROAD also helped honor Marie on the occasion of her formal thesis defense in June 1903. Her sister Bronya made the difficult trip from Poland to celebrate Marie's academic triumph.

Bronya had insisted that the first woman to receive a doctorate in France should acknowledge the special event by wearing a new dress. Characteristically, Marie chose a black dress. Like the navy wedding outfit she had chosen eight years earlier, the new dress could be worn in the lab without fear of stains.

THÈSES

A LA FACULTÉ DES SCIENCES DE PARIS

Mme SKLODOWSKA CURIE

PARIS

1903

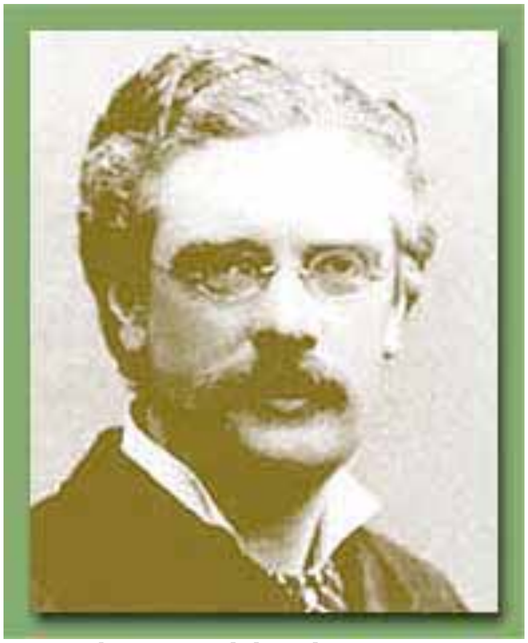
Title page of the published version of Marie Curie's doctoral thesis, "Research on Radioactive Substances." The examiners exclaimed that Curie's doctoral research contributed more to scientific knowledge than any previous thesis project.

Another foreign admirer was a last-minute guest at a dinner to celebrate Marie's achievement. New Zealand-born scientist Ernest Rutherford, who was also actively engaged in research in the new science of radioactivity, was visiting Paris. He had stopped by the Municipal School shed where Marie isolated radium, and at dinner that night he asked Marie how they managed to work in such a place. "You know," he said, "it must be dreadful not to have a laboratory to play around in."

FAMILY LOSSES UNDERCUT some of the pleasure Marie could take in her own achievements. In August 1903 she experienced a miscarriage. Some time later Bronya's second child died of tubercular meningitis. And against the backdrop of these specific losses was the fact that Pierre's health continued to deteriorate. Sometimes unbearable pain kept him awake all night, lying weakly in bed, moaning.

"I had grown so accustomed to the idea of the child that I am absolutely desperate and cannot be consoled."
--letter from Marie Curie to Bronya, August 25, 1903

The Nobel Prize and Its Aftermath

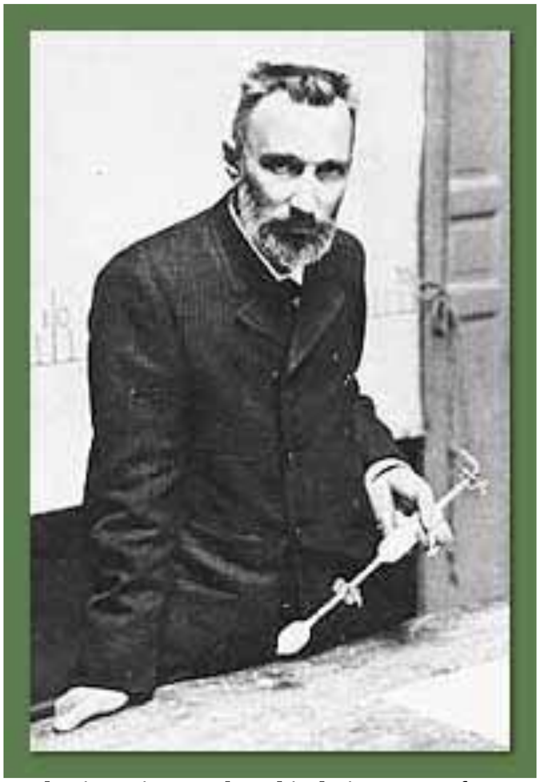


In a 1903 letter to Swedish mathematician Magnus Goesta Mittag-Leffler, Pierre wrote, "If it is true that one is seriously thinking about me [for the Nobel Prize], I very much wish to be considered together with Madame Curie with respect to our research on radioactive bodies."

MARIE WAS NOT REALLY NOMINATED for her first Nobel Prize. From the inception of the award in 1901, the Nobel Prizes have been made after a lengthy evaluation of the merits of nominees. In 1903 the French Academy of Sciences nominated Henri Becquerel and Pierre -- but not Marie -- Curie as candidates for the physics prize. If not for the intervention of a member of the nominating committee, Swedish mathematician Magnus Goesta Mittag-Leffler, Marie might have been denied recognition for her work. But Mittag-Leffler, an advocate of women scientists, wrote Pierre advising him of the situation. In his reply Pierre made clear that a Nobel Prize for research in radioactivity that failed to acknowledge Marie's pivotal role would be a travesty. Some strings were pulled, and a nomination of Marie Curie in 1902

In December 1903, Becquerel and both Curies were awarded the Nobel Prize for Physics. The Curies' citation was carefully worded to avoid specific mention of their discovery of polonium and radium. Chemists on the nominating committee had insisted that the Curies might in the future deserve a Nobel Prize for Chemistry for their discovery of those elements. And there remained some doubts about the elements, which had been isolated only in invisibly small amounts. Thus their physics prize mentioned only their collaborative work on Becquerel rays.

The certificate for the Curies' 1903 Nobel Prize for Physics cited "their joint researches on the radiation phenomena discovered by Professor Henri Becquerel." (Photo ACJC)



By the time Pierre took up his duties as a professor at the Sorbonne, where he is shown here teaching, he complained of having only "a very feeble capacity for work." (Photo ACJC)

THE CURIES FELT TOO ILL AND TOO BUSY to travel to Stockholm for the awards ceremony that December (besides, Pierre depised ceremonies and publicity). Nobel laureates, however, were required to present a lecture describing their work's importance. In June 1905 the Curies finally made the trip. Custom dictated that Pierre deliver the lecture, but he was careful to distinguish between Marie's independent work and their joint efforts. After surveying the science of radioactivity, he added a cautionary note. Radium, like other scientific and technological discoveries (such as Nobel's explosives), might prove very dangerous in the wrong hands, "and here we must ask ourselves if humanity can benefit by knowing the secrets of nature...or if this knowledge will not be harmful to the world." But he ended his talk optimistically.

> **"I am one of those who believe with Nobel that mankind will derive more good than harm from the new discoveries."**--*Pierre Curie, Award Address for 1903 Nobel Prize for Physics*

Fame and Illness

"**In 1903 I finished my doctor's thesis** and obtained the degree. At the end of the same year the Nobel prize was awarded jointly to Becquerel, my husband and me for the discovery of radioactivity and new radioactive elements.

This event greatly increased the publicity of our work. For some time there was no more peace. Visitors and demands for lectures and articles interrupted every day....

The fatigue resulting from the effort exceeding our forces, imposed by the unsatisfactory conditions of our labor, was augmented by the invasion of publicity. The overturn of our voluntary isolation was a cause of real suffering for us and had all the effect of disaster. It was serious trouble brought into the organization of our life, and I have already explained how indispensable was our freedom from external distraction, in order to maintain our family life and our scientific activity. Of course, people who contribute to that kind of trouble generally mean it kindly. It is only that they do not realize the conditions of the problem."

—from Autobiographical Notes pp. 190-191.

Letters from Pierre Curie to his friend E. Gouy

20 March 1902

As you have seen, fortune favors us at this moment; but these favors of fortune do not come without many worries. We have never been less tranquil than at this moment. There are days when we scarcely have time to breathe. And to think that we dreamed of living in the wild, quite removed from human beings!

---

22 January 1904

I have wanted to write to you for a long time; excuse me if I have not done so. The cause is the stupid life which I lead at present. You have seen this sudden infatuation for radium, which has resulted for us in all the advantages of a moment of popularity.

We have been pursued by journalists and photographers from all countries of the world; they have gone even so far as to report the conversation between my daughter and her nurse, and to describe the black- and-white cat that lives with us.... Further, we have had a great many appeals for money.... Finally, the collectors of autographs, snobs, society people, and even at times, scientists, have come to see us—in our magnificent and tranquil quarters in the laboratory—and every evening there has been a voluminous correspondence to send off. With such a state of things I feel myself invaded by a kind of stupor. And yet all this turmoil will not perhaps have been in vain, if it results in my getting a chair and a laboratory.

---

25 July 1905

We have regretted so much being deprived of your visit this year, but hope to see you in October. If we do not make an effort from time to time, we end by losing touch with our best and most congenial friends, and in keeping company with others for the simple reason that it is easy to meet them.

We continue to lead the same life of people who are extremely occupied, without being able to accomplish anything interesting. It is now more than a year since I have been able to engage in any research, and I have no moment to myself. Clearly I have not yet discovered a means to defend ourselves against this frittering away of our time which is nevertheless extremely necessary. Intellectually, it is a question of life or death.

---

7 November 1905

I am neither very well, nor very ill; but I am easily fatigued, and I have left but very little capacity for work. My wife, on the contrary, leads a very active life, between her children, the School at Sèvres, and the laboratory. She does not lose a minute, and occupies herself more regularly than I can with the direction of the laboratory in which she passes the greater part of the day.

—from Pierre Curie pp. 127-129.

Not surprisingly, the award brought changes in the Curies' lives. The prize money was very useful. They used some of it to cover the expenses of treating pitchblende, and they could hire a paid lab assistant for the first time. Pierre's scientific achievement was finally acknowledged in his native country with an appointment to a professorship at the Sorbonne. Yet it was only after Pierre rejected the first offer, which came without provisions for a lab, that the university dug up the necessary funds. Marie, for the first time in her career, would have both a title--chief of laboratory--and a university salary. “It was not without regret that we left the School of Physics,” she recalled, “where we had known such happy work days, despite their attendant difficulties.” Although Pierre began his new position in the fall of 1904, the lab was not actually completed until 1906. Marie remained sensitive to these slights against Pierre's dignity.

PUBLICITY TOOK A HEAVY TOLL on the Curies in the wake of their new international acclaim. Accustomed to working quietly and without distraction in their lab, they were now prey to journalists and photographers, who pursued them both at work and at home. Not even six-year-old Irène was safe from their prying eyes. Pierre found that the unwanted intrusions destroyed his productivity. Although he had published 25 papers between July 1898 and June 1904, he published nothing in the following two years. Even his election in July 1905 to the French Academy of Sciences, which had rejected his candidacy earlier, did little to improve his frame of mind.

The expectant mother with Irène and Pierre in their garden, 1904 (Photo ACJC)

> **“A whole year has passed since I was able to do any work, and I have not one moment to myself.”** *--letter from Pierre Curie to physicist friend Georges Gouy, July 1905*

Marie, too, complained about the loss of privacy. But having too much to do seemed to energize, not enervate, her. In December 1904, a month after their move to the Sorbonne, the Curies' younger daughter, Eve, was born. Although Marie took some time off from her professional commitments, she soon resumed both her research and her teaching at the teachers' training institute for women at S_vres. While carefully rationing the time she would spend with journalists, she attempted to explain to the public what the new discoveries meant. She even found time for museums and concerts, where Pierre joined her without enthusiasm.

A Fatal Accident

A few days before his death, Pierre was cautiously optimistic about the progress he and Marie were making in their attempt to make precise measurements of the radioactive gas that radium emitted. He also thought of returning to the studies of crystal symmetries he had set aside when their joint work began. (Photo ACJC)

LIFE WAS SEEMING A BIT ROSIER to Pierre Curie in the spring of 1906. During the family's recent Easter holiday in the country, he had enjoyed watching the efforts of 8-year-old Irène to net butterflies and of 14-month-old Eve to keep her footing on the uneven turf. More crucially, perhaps, Pierre had become involved in his work again.

Pierre Curie's agenda for Thursday, April 19, 1906, was that of a man fully engaged in both professional and social life. After a luncheon of the Association of Professors of the Science Faculties, he was scheduled to go over proofs with his publisher and to visit a nearby library. He was looking forward to entertaining a number of fellow scientists at the Curie home that evening.

PIERRE CURIE WAS NOT FATED to complete that day's activities. After working in the laboratory all morning, he braved the heavy rain, umbrella in hand, and traveled across Paris to his luncheon meeting. There he spoke forcefully on a number of issues that concerned him, including widening career options for junior faculty and drafting legal codes to help prevent laboratory accidents.

After the meeting was over he headed out toward his publisher in the rain, only to find that the doors were locked because of a strike. Hurrying to cross the street, he was run over by a horse-drawn wagon with a load of military uniforms, weighing some six tons. He was killed instantly.

When Pierre's father learned that his son had been killed crossing a Paris street in traffic on a rainy day, he said, "What was he dreaming of this time?" (Painting by Childe Hassam, 1893)

"He wasn't careful enough when he was walking in the street, or when he rode his bicycle. He was thinking of other things." *--Pierre Clerc, the Sorbonne lab assistant who identified Curie's body*

MARIE DID NOT LEARN the news that would transform her life until that evening. In shock, she began to attend to the necessary arrangements. She sent Irène next door to spend a few days with the neighbors, telegrammed the news to her family in Poland, and arranged to have the body brought to the house. Only after Pierre's older brother, Jacques, arrived the next day from Montpellier did she break down briefly. The news of Pierre Curie's death was carried in newspapers around the world, and Marie was inundated by letters and telegrams.

The day after the funeral was notable for two reasons. Encouraged by Jacques, Marie returned to her work. Also, Jacques informed Marie that the French government proposed to support her and the children with a state pension. Marie was adamant in her refusal, insisting that she was perfectly capable of supporting herself and the children.

> **"Crushed by the blow, I did not feel able to face the future. I could not forget, however, what my husband used to say, that even deprived of him, I ought to continue my work."**

If Marie was firm in rejecting the government's offer of support, she was less certain how to respond to an unexpected offer from the Sorbonne. On May 13, 1906, the university invited her to take up Pierre's academic post. By doing so, she hoped, she could one day establish, as a tribute to Pierre's memory, a state-of-the-art lab such as he had never had. It was not enough to be a teacher and researcher. She would have to learn how to create a scientific institution.

(above) Marie on the balcony of the Dluski apartment on rue d'Allemagne, Paris. In the diary Marie began 11 days after Pierre's death, she described putting a copy of this picture in Pierre's coffin: "it was the picture of the one you chose as your companion...." (Photo ACJC)

Curie family gravestone. Pierre was buried with his mother in the Curie family plot in Sceaux, on the outskirts of Paris, where eventually his father and Marie joined them. Many years later Pierre and Marie were reinterred in the Panthéon, the national sepulcher for the most eminent French citizens. (Photo ACJC)

Tragedy

"**In 1906 just as we were** definitely giving up the old shed laboratory where we had been so happy, there came the dreadful catastrophe which took my husband away from me and left me alone to bring up our children and, at the same time, to continue our work of research.

It is impossible for me to express the profoundness and importance of the crisis brought into my life by the loss of the one who had been my closest companion and best friend. Crushed by the blow, I did not feel able to face the future. I could not forget, however, what my husband used sometimes to say, that, even deprived of him, I ought to continue my work.

The death of my husband, coming immediately after the general knowledge of the discoveries with which his name is associated, was felt by the public, and especially by the scientific circles, to be a national misfortune. It was largely under the influence of this emotion that the Faculty of Sciences of Paris decided to offer me the chair, as professor, which my husband had occupied only one year and a half in the Sorbonne. It was an exceptional decision, as up to then no woman had held such a position.... The honor that now came to me was deeply painful under the cruel circumstances of its coming."

—from Autobiographical Notes pp. 191-192.

Selections from Marie Curie's diary

"**We put you into the coffin** Saturday morning, and I held your head up for this move. We kissed your cold face for the last time. Then a few periwinkles from the garden on the coffin and the little picture of me that you called "the good little student" and that you loved. It is the picture that must go with you into the grave, the picture of her who had the happiness of pleasing you enough so that you did not hesitate to offer to share your life with her, even when you had seen her only a few times. You often told me that this was the only occasion in your life when you acted without hesitation, with the absolute conviction that you were doing well. My Pierre, I think you were not wrong. We were made to live together, and our union had to be.

Your coffin was closed and I could see you no more. I didn't allow them to cover it with the horrible black cloth. I covered it with flowers and I sat beside it....

They filled the grave and put sheaves of flowers on it. Everything is over, Pierre is sleeping his last sleep beneath the earth; it is the end of everything, everything, everything.

I am working in the laboratory all day long, it is all I can do; I am better off there than anywhere else. I conceive of nothing any more that could give me personal joy, except perhaps scientific work–and even there, no, because if I succeeded with it, I would not endure you not to know it."

—from Madame Curie p. 249.

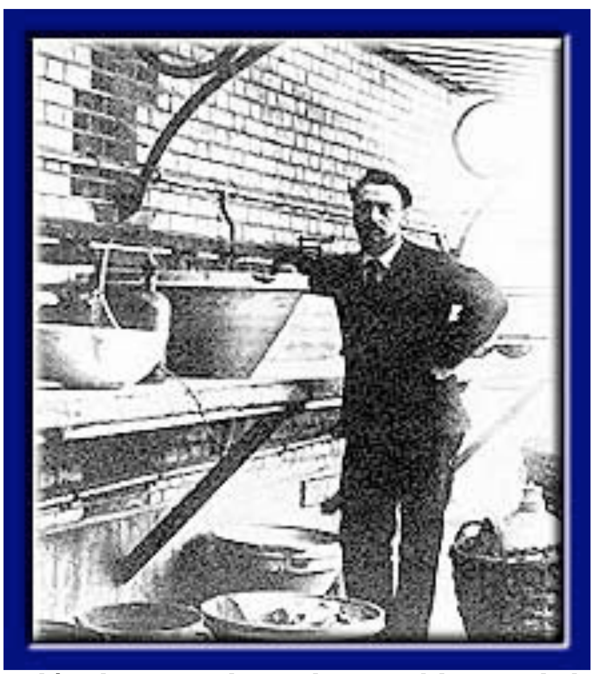
Life Goes On

MARIE CURIE FOUND A LIFELINE in her professional and family responsibilities during the summer following Pierre's death. She moved with her daughters and father-in-law to Sceaux, the suburb where Pierre's family had lived and where he and his mother were now buried. She also prepared to teach Pierre's course. On November 5, 1906, the day of her first lecture, the hall was packed. In addition to the students taking the course, a crowd had gathered of those curious to hear how the widow--the first woman professor at the Sorbonne--would fare.

The Sorbonne

The inaugural lecture of a professor was normally an occasion for lavish tributes to one's predecessor and eloquent claims for one's own field of science. But the crowd heard only a matter-of-fact lecture about developments in physics over the past decade.

> **"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, opening of first Sorbonne lecture, November 5, 1906*



Andrè Debierne, seen here in the Curies' laboratory shed, not only helped Marie confirm experimentally that radium was an element, but also remained a devoted friend and colleague over the years. (Photo ACJC)

During that summer, Marie's research program-- to identify and isolate radioactive elements--intensified. In part she was spurred on by a challenge from an unexpected quarter. In a letter to the editor on the front page of *The London Times* of August 9, 1906, Pierre's longtime fan Lord Kelvin advanced a theory that radium was no element but rather a compound of lead and five helium atoms. Since the theory threatened the entire science of radioactivity, Marie began lab work to disprove it -- and more generally to put her discovery on such a firm basis that nobody could doubt it.

Enlisting the aid of her old colleague Andrè Debierne, she eventually confirmed that radium was indeed an element. It was an effort of years to measure the atomic weight of radium beyond question and thus firmly locate the element in the Periodic Table. But the measurements left nothing in doubt.

FEW PEOPLE MANAGE TO CREATE an entirely new institution from scratch, single-handed. That is what Marie Curie set out to do--establish a lab worthy of Pierre's memory. She had her fame, her friends, and her fierce determination. A substantial grant in 1907 from an American philanthropist enabled her to assemble a research staff, but that was only a start. It helped that in the little world of the Paris elite, the professors in Curie's circle were on good terms with politicians in the left-leaning parties that controlled the French government. These politicians agreed with the professors' ideals--rational science was the vanguard of human progress. Yielding to persuasion, the government-funded University of Paris joined the private Pasteur Foundation to fund a Radium Institute. Marie Curie would supervise one of its divisions, a radioactivity laboratory, while an eminent physician would supervise the second division, a medical research laboratory.

> **"...a laboratory is not created in a few months with a wave of a magic wand..."** *--Pierre Curie in a letter to a university administrator, 1903*

American steel-manufacturer and philanthropist Andrew Carnegie established the Curie Scholarships, which enabled promising scientists to devote themselves full-time to research in Marie's lab

Marie in front of the Curie home at Sceaux with her daughters and (at far left) a friend. Irène's friendships with her classmates from the cooperative school remained close over the years. (Photo ACJC)

Her work at the Sorbonne and in the lab was so time-consuming that Marie turned over her position at the Sèvres school for women teachers-in-training to her friend and colleague Paul Langevin. She nonetheless made time to run a cooperative school with a number of other professional parents who disapproved of the rigid French school system. Each family agreed to teach one class each week in its field of expertise.

Between 1906 and 1908, Irène and a group of eight or nine other children were thus privileged to learn math, science, history, literature, and studio art from eminent figures in those fields.

ANOTHER DEATH IN THE FAMILY deeply saddened Marie and her daughters. Pierre's father died in February 1910. Now a series of Polish governesses, some more successful than others, helped raise Irène and Eve. Yet during the course of that year of mourning Marie isolated radium metal. She saw the publication of her comprehensive textbook, *A Treatise on Radioactivity.* And she secured the right to define an international standard for radium emissions. Such a standard was essential for an efficient radium industry and uniform medical applications. The measure she established was accepted by the international scientific community, which named it the Curie.

> **"Curie. A unit of radioactivity. One Curie is the quantity of a radioactive substance that undergoes 3 x 10^7 disintegrations per second."**
> *--Dictionary definition*

The Academy Debacle

The right-wing French press, including the daily *Excelsior,* attacked Curie's candidacy for the French Academy with scurrilous and racist claims based on supposedly scientific analyses of her handwriting and facial characteristics.

A SCANDAL-DRIVEN PRESS is not a recent phenomenon. Pierre and Marie had been hounded by intrusive reporters as early as 1902, when news began to circulate about the medical uses of radium. After they won the Nobel Prize, reporters redoubled their attentions. But until late 1910 most press coverage of Marie Curie focused on the heroic labors of the blonde, foreign-born mother, wife, and then widow. Some of the press changed its tune, however, in November 1910, when Curie offered herself as a candidate for the single vacant seat for a physicist in the French Academy of Sciences.

Her main rival for the seat was 66-year-old Edouard Branly, whose scientific reputation was based on his contribution to wireless telegraphy. When Italian Gugliemo Marconi was awarded the 1909 Nobel Prize for Physics for his work in that field, many French patriots felt stung by Branly's exclusion.

Branly's claim to the Academy chair was also championed by many French Catholics, who knew that he had been singled out for honor by the Pope. For generations French politics had been bitterly divided between conservative Catholics and liberal freethinkers like Marie and her friends, and the split ran through every public action.

Among the false rumors the right-wing press spread about Curie was that she was Jewish, not truly French, and thus undeserving of a seat in the French Academy. Although the liberal press came to her defense, the accusations did the intended damage. Branly won the election on January 23, 1911, by two votes. Curie responded to the snub characteristically, by throwing herself into her work.

"An academic tournament: Will a woman enter the Institute?" Marie was weighed against Edouard Branly, who taught at a leading Catholic institution.

"The struggle between you and M. Branly will arise most strongly on the clerical issue....Against him will be the forward-looking and university elements of the Academy...."
--letter from Georges Gouy to Marie Curie, November 1910

The Langevin Affair

Paul Langevin. The Langevins' 1902 marriage had deteriorated to such an extent by mid-July 1910 that Langevin left the family home for an apartment in Paris, not far from Curie's lab.

AN EVEN WORSE SCANDAL was to erupt before the end of 1911. That a woman who was left a widow at 38 should become romantically attached again is not surprising. But when Curie's relationship with fellow physicist Paul Langevin moved beyond friendly collegiality to mutual love, she could not foresee where it would lead. Langevin, a brilliant former pupil of Pierre's, was unhappily married to a woman who came from a similar working-class background but lacked his educational attainments. With four children to raise, Madame Langevin complained that Paul placed his commitment to science above the needs of his family.

"They can't comprehend at his house that he refuses magnificent situations...in private industry to dedicate himself to science," wrote a friend of Langevin's. During the summer of 1911, as rumors about a relationship between Curie and Langevin began to spread, Madame Langevin began proceedings to bring about a legal separation.

Curie was the only woman at the 1911 conference organized and subsidized by Belgian industrialist Ernest Solvay. Discussions at this gathering of the world's top physicists opened the way to a new physics that would bring together relativity, the quantum, and radioactive atoms. Langevin, at far right, stands next to the young Albert Einstein. Rutherford stands above Curie, who confers with Poincaré.

That autumn Curie, Langevin, and some 20 other top physicists attended an international conference in Brussels. While the scientists considered the challenge to modern physics presented by the discovery of radioactivity, the French press got hold of intimate letters that Curie and Langevin had exchanged (or forgeries based on them).

THE WIDOW HAD TARNISHED the good name of her deceased husband! This was only one of the accusations hurled at Curie during her absence in Belgium. Resurrecting the lie that she was Jewish, some anti-Semitic newspapers decried the devastation wrought on a good Frenchwoman by a foreign Jewish home wrecker. Other reporters spread false hints that Curie's affair with Langevin had begun while Pierre was still alive, driving him to commit suicide in despair.


Mathematician Emile Borel, scientific director of the Ecole Normale Supérieure, sheltered Curie and her daughters even when the minister of public instruction threatened to fire him for sullying French academic honor.

> **"The fires of radium which beam so mysteriously...have just lit a fire in the heart of one of the scientists who studies their action so devotedly; and the wife and the children of this scientist are in tears...."**
> --Le Journal*, November 4, 1911*

On her return to France, Curie discovered an angry mob congregated in front of her home in Sceaux, terrorizing 14-year-old Irène and 7-year-old Eve. Curie and her daughters had to take refuge in the home of friends in Paris. Meanwhile Langevin and a journalist who had reviled Marie held a duel--an emotional but bloodless "affair of honor."

Illness and Rebirth

DURING THE PRESS FRENZY Curie received a telegram informing her that she had been given an unprecedented second Nobel Prize, this time in chemistry. Although severely shaken by the scandal, she mustered the strength to attend the award ceremony, accompanied by her sister Bronya and her daughter Irène. At the ceremony on December 10, 1911, the president of the Royal Swedish Academy of Sciences explained why Curie's 1898 discovery of two new elements deserved this additional recognition. It had not only revolutionized scientific understanding of the nature of the atom but had also opened up new areas of medicine and even helped measure the age of the earth. In her lecture the following day, Curie reasserted her claim to be the first to see that radioactivity was a property built into atoms.


Svante Arrhenius, an influential Swedish physicist on the Nobel committee, at first encouraged Curie to accept the award in person, but when the scandal deepened he advised her to decline it until her name was cleared.

She gave credit, however, to Rutherford and other scientists for their contributions in explaining radioactive phenomena. Aware of accusations that she had sullied Pierre's name, she acknowledged the role their joint efforts had played in her work.

> **"...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*

Hertha Ayrton, in whose company Curie recuperated during the summer of 1912, had first met the Curies in June 1903, when Pierre addressed the Royal Institution in London. (courtesy IEE)

The stress of the past several months took its toll on Curie. Suffering from severe depression and acute kidney problems, she spent most of January 1912 in a private clinic, registered under an assumed name. In March she underwent a kidney operation. She spent months recuperating in a house near Paris, rented under the name Madame Sklodowska. Feeling unworthy of Pierre's name, she even forbade Irène to address letters to her as Madame Curie.

ELUDING THE PRESS remained her highest priority. In late July, still using the name Sklodowska, she traveled to England, where she spent the rest of the summer with her friend and colleague Hertha Ayrton. Like Curie, Ayrton was not only the widow of a distinguished physicist but also an important practicing physicist herself. The two women were joined in their rented house near the seashore by Curie's daughters and their Polish governess.

In October 1912 Curie returned to France but not to Sceaux, where the angry mob had once threatened her and her children. After further bed rest in the Paris apartment where she would live the rest of her life, she felt well enough to return to the lab. On December 3, 1912, she made her first lab notebook entry in nearly 14 months. The scandal had finally blown over: Madame Langevin had not mentioned Madame Curie by name in the separation agreement. The French academic world was ready to welcome the world's only double Nobel laureate.

> **"I have been led to think that there is a public service to be organized, which I cannot ignore, and that it could not have been properly established without myself and my laboratory's participation."** *--Marie Curie to the dean of the Sorbonne, May, 1913*

Curie in her laboratory in 1913, following the Langevin scandal. (Photo ACJC)

When Curie traveled to England in September 1913 to receive an honorary degree from the University of Birmingham, she traveled again under her married name.

NO MORE LOVE AFFAIRS lay in Curie's future. Though there would be no union between Marie Curie and Paul Langevin, her granddaughter Hélène and his grandson Michel would eventually marry. Marie Curie dedicated most of the rest of her life to the Radium Institute, which she considered both a tribute to Pierre's memory and a contribution to the betterment of human society.

Here scientists and technicians would monitor the purity and efficacy of radioactive products for medicine and industry, while conducting research to produce both pure knowledge and further beneficial uses. After long labors of design and construction, Curie saw her building completed on a street in the Latin Quarter, newly named Rue Pierre-Curie. It was August 1914.

War Duty (1914-1919)

Radiology at the Front

The Radium Institute. After Germany declared war on France in 1914, only two people remained at the Institute: Curie and "our mechanic who could not join the army because of serious heart trouble."

THREE GERMAN BOMBS fell on Paris on September 2, 1914, about a month after Germany declared war on France. By that time construction of the Radium Institute was complete, although Curie had not yet moved her lab there. Curie's researchers had been drafted, like all other able-bodied Frenchmen.

The Radium Institute's work would have to wait for peacetime. But surely there were ways in which Curie could use her scientific knowledge to advance the war effort.

> **"I am resolved to put all my strength at the service of my adopted country, since I cannot do anything for my unfortunate native country just now..."** *--letter from Marie Curie to Paul Langevin, January 1, 1915*

As the German army swept toward Paris, the government decided to move to Bordeaux. France's entire stock of radium for research was the single gram in Curie's lab. At the government's behest, Curie took a Bordeaux-bound train along with government staff, carrying the precious element in a heavy lead box. Unlike many, however, Curie felt her place was in Paris. After the radium was in a Bordeaux safe-deposit box, she returned to Paris on a military train.

X-rays could save soldiers' lives, she realized, by helping doctors see bullets, shrapnel, and broken bones. She convinced the government to empower her to set up France's first military radiology centers. Newly named Director of the Red Cross Radiology Service, she wheedled money and cars out of wealthy acquaintances.

She convinced automobile body shops to transform the cars into vans, and begged manufacturers to do their part for their country by donating equipment. By late October 1914, the first of 20 radiology vehicles she would equip was ready. French enlisted men would soon dub these mobile radiology installations, which transported X-ray apparatus to the wounded at the battle front, *petites Curies* (little Curies).

This "petite Curie," which brought X-rays to the Front in World War I, was displayed in Paris in 1998 during the commemoration of the 100th anniversary of the discovery of radium.

Marie and Irène with X-ray equipment at a military hospital. After training Irène as a radiologist for a year, Curie deemed her daughter capable of directing a battle-front radiological installation on her own.

ALTHOUGH CURIE HAD LECTURED about X-rays at the Sorbonne, she had no personal experience working with them. Intending to operate the petite Curie herself if necessary, she learned how to drive a car and gave herself cram courses in anatomy, in the use of X-ray equipment, and in auto mechanics. As her first radiological assistant she chose her daughter Irène, a very mature and scientifically well-versed 17-year-old. Accompanied by a military doctor, mother and daughter made their first trip to the battle front in the autumn of 1914.

> **"The use of the X-rays during the war saved the lives of many wounded men; it also saved many from long suffering and lasting infirmity."**--*Marie Curie*

Would Irène be traumatized by the sight of the soldiers' horrific wounds? To guard against a bad reaction, Curie was careful to display no emotion herself as she carefully recorded data about each patient.

X-rays on Wheels

"**The dominant duty** imposed on everyone at that time was to help the country in whatever way possible during the extreme crisis that it faced. No general instructions to this were given to the members of the University. It was left to each to take his own initiative and means of action....

During the rapid succession of events in August 1914, it was clearly proved that the preparation for defense was insufficient. Public feeling was especially aroused by the realization of the grave failings which appeared in the organization of the Health Service. My own attention was particularly drawn to this situation, and I soon found a field of activity which, once entered upon, absorbed the greatest part of my time and efforts until the end of the war, and even for some time thereafter....

It is well known that the X-rays offer surgeons and doctors extremely useful means for the examination of the sick and wounded....

However, at the beginning of the war, the Military Board of Health had no organization of radiology, while the civil organization was also but little developed. Radiologic installations existed in only a small number of important hospitals, and there were only a few specialists in the large cities. The numerous new hospitals that were established all over France in the first months of the war had, as a rule, no installation for the use of X-rays.

To meet this need I first gathered together all the apparatus I could find in the laboratories and stores. With this equipment I established in August and September, 1914, several stations of radiology, the operation of which was assured by volunteer helpers to whom I gave instruction. These stations rendered great service during the battle of the Marne. But as they could not satisfy the needs of all the hospitals of the Paris region, I fitted up, with the help of the Red Cross, a radiologic car. It was simply a touring motor-car, arranged for the transport of a complete radiologic apparatus, together with a dynamo that was worked by the engine of the car, and furnished the electric current necessary for the production of the rays. This car could come at the call of any of the hospitals, large or small, in the surroundings of Paris. Cases of urgent need were frequent, for these hospitals had to take care of the wounded who could not be transported to more distant places.”

—*from Autobiographical Notes pp. 208-211.*

From *Radiology in War*

“**The story of radiology** in war offers a striking example of the unsuspected amplitude that the application of purely scientific discoveries can take under certain conditions.

X rays had had only a limited usefulness up to the time of the war. The great catastrophe which was let loose upon humanity, accumulating its victims in terrifying numbers, brought up by reaction the ardent desire to save everything that could be saved and to exploit every means of sparing and protecting human life.

At once there appeared an effort to make the X ray yield its maximum of service. What had seemed difficult became easy and received an immediate solution. The material and the personnel were multiplied as if by enchantment. All those who did not understand gave in or accepted; those who did not know learned; those who had been indifferent became devoted. Thus the scientific discovery achieved the conquest of its natural field of action. A similar evolution took place in radium therapy, or the medical application of radiations emitted by the radio elements.

What are we to conclude from this unhoped-for development shared between the new radiations revealed to us by science at the end of the nineteenth century? It seems that they must make our confidence in disinterested research more alive and increase our reverence and admiration for it.”

—*from Madame Curie p. 306.*

From Marie’s letters to Irène Curie

Paris, Monday, 31 August 1914
[At this time the German Army was threatening Paris]

Dear Irène,

I’ve just received your sweet letter of Saturday and I wanted so much to hug you that I almost cried. This morning I was able to make my way to the train station where Fernand and Margaret were to leave—and I didn’t manage to see them. I wonder if they’ve left.

Things are not going very well, and we all have a heavy heart and disturbed spirit. We need great courage and I hope we will not lack it. We must keep the firm hope that after these bad days, good times will return. It's in that hope that I lock you in my heart, my beloved daughters.

Mé [Mom]

Poperinghe, 24 January 1915
[Near Dunkirk]

Dear Irène,

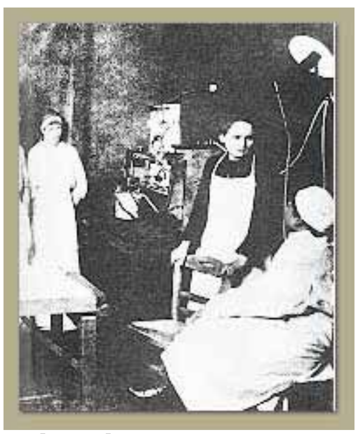
After various wanderings, we've arrived here, but we can't make an attempt at working until we've made some modifications at the hospital. They want to build a shelter for the car and a partition to create the radiology room in a big ward. That all holds up the work, but it's difficult to do otherwise. In Dunkirk, German planes dropped some bombs that killed a few people, but the populace is scarcely frightened. At Poperinghe too these accidents happen, but less often. We hear the guns grumbling almost constantly. It's not raining, a bit of frost. We were welcomed at the hospital with extreme cordiality, I have a nice room and they give me a fire in a stove at the side. I'm better off than at Furnes, I'll eat at the hospital. With a hug,

Mé

—from Correspondance pp. 129, 158.

Irène followed her mother's example. Heedless of the dangers of over-exposure to X-rays, mother and daughter were inadequately shielded from the radiation that helped save countless soldiers' lives. After the war the French government recognized Irène's hospital work by awarding her a military medal. No such official recognition came to Curie. Perhaps her role in the Langevin affair was not yet forgiven.

A Military Radiotherapy Service



At the Radium Institute, Curie trained about 150 women in X-ray technology, including these radiology assistants with her near the front lines.

CURIE KNEW SHE NEEDED more trained personnel. She and Irène could not run by themselves the 20 mobile X-ray stations she had established, nor the 200 stationary units. By 1916 Marie began to train women as radiological assistants by offering courses in the necessary techniques at the Radium Institute. She was assisted by Irène, who was also enrolled as a student at the Sorbonne.

> **"Theoretically, [the women trained at the Radium Institute] were supposed to serve as aides to physicians, but several of them proved capable of independent work."** *--Marie Curie*

Her radiological services well under way, Curie turned her attention to establishing a military radiotherapy service. By 1915 it seemed likely that the Germans could not take Paris. After retrieving the gram of radium from Bordeaux, Curie began to use a technique pioneered in Dublin to collect radon--a radioactive gas that radium steadily emits. Working alone, without protecting herself adequately from the radioactive vapors, she used an electric pump to collect the gas at 48-hour intervals. She sealed the radon in thin glass tubes about one centimeter long, which were delivered to military and civilian hospitals. There doctors encased the tubes in platinum needles and positioned them directly within patients' bodies, in the exact spot where the radiation would most effectively destroy diseased tissue.

> **"The story of radiology in war offers a striking example of the unsuspected amplitude that the application of purely scientific discoveries can take under certain conditions. X-rays had only a limited usefulness up to the time of the war...A similar evolution took place in radium therapy, the medical applications of radiations emitted by the radioelements."** *--Marie Curie,* Radiology in War

SHOULD SHE HAND OVER her medals to the government? In addition to the contributions to the war effort that Curie could make as a scientist, she was also an ordinary citizen. When the government asked people to contribute their gold and silver, Curie decided to offer her two Nobel medals, along with all the other medals bestowed on her over the years. The French National Bank turned down the offer, but Curie did her part by using most of the Nobel prize money to buy war bonds.

The war ended on November 11, 1918, but Curie's war-related work continued for nearly another whole year. During the spring of 1919 she offered radiology courses to a group of American soldiers who remained in France while awaiting passage home. That summer she summarized much of her wartime work in a book titled *Radiology in War.* By the fall of 1919 her laboratory at the Radium Institute was finally ready. She would devote most of the rest of her life to it.

Curie said that these American officers, who became her students at the Radium Institute in the spring of 1919, also "studied with much zeal the practical exercises directed by my daughter." (Photo ACJC)

The Marie Curie Radium Campaign

French philanthropist Henri de Rothschild was enthralled by science and funded many research efforts. Rothschild grants helped Curie to support her scientific staff--including the man who would become Irène's husband and collaborator.

SHE NEVER OVERCAME STAGE FRIGHT as a professor, though she taught for nearly 30 years. Yet in order to turn the Radium Institute into a world-class institution, Curie shamelessly sought out assistance, just as she had done during the war years to create the radiological service. Throughout her career Curie had benefited from the subsidies of wealthy French benefactors. Now, thanks to the interest of an American woman, U.S. citizens also became involved in filling the needs of the Radium Institute.

> **"[Curie], who handles daily a particle of radium more dangerous than lightning, was afraid when confronted by the necessity of appearing before the public."**--*Stéphane Lauzanne, editor-in-chief of* Le Matin

Despite her distrust of journalists, in May 1920 Curie agreed to give an interview to Mrs. William Brown Meloney, editor of an American women's magazine. In the interview Curie emphasized the needs of her institution, where research was just resuming following the devastating war.

Thanks to her alliance with industry, few labs in the world if any were better equipped with radium than Curie's. But Curie succeeded in shocking Meloney by emphasizing the fact that research and therapy centers in the United States together had about 50 times as much radium as the single gram she--the scientist who had discovered the element--had in her laboratory. When Meloney learned that Curie's most fervent wish was for a second gram for her laboratory, the editor organized a "Marie Curie Radium Campaign."

Meloney, Irène, Marie and Eve shortly after their arrival in the United States, where the press dubbed Eve "the girl with the radium eyes."

Led by a committee of wealthy American women and distinguished American scientists, the campaign succeeded by soliciting contributions in the United States. Meloney also arranged for Curie to write an autobiographical work for an American publisher. The book would provide royalty income over the years. Equally important, it would capture in simple and moving prose the romantic and heroic image of science that was so helpful for public support and fund-raising.

The high point of Curie's 1921 tour of the United States was the White House presentation by President Warren G. Harding, where she wore the same black dress she had worn to both Nobel ceremonies. Thanks to the Marie Curie Radium Campaign, she returned to Paris with ores, costly apparatus, and cash for her institute, in addition to the gram of radium. (Photo ACJC)

THE LANGEVIN AFFAIR could not be mentioned in print. On this condition Curie agreed to travel to the United States to drum up support for her institute. Meloney wrested from editors across the country a promise to suppress the old story. When word got out that the President of the United States himself would present Curie with the gift of radium, French officials looked for a way to make up for past oversights. Curie refused the Legion of Honor award (as Pierre had refused it nearly two decades earlier). But she agreed to attend a benefit for the Radium Institute at the Paris Opera shortly before setting sail.

> **"I pray to thank the Minister, and to inform him that I do not in the least feel the need of a decoration, but that I do feel the greatest need for a laboratory."** *--Pierre Curie refusing*

Her right hand was in a sling before she had been in the United States many days. So many people wanted to shake hands with the woman who had given humanity the gift of radium. Curie was grateful that her daughters were willing to stand in for her when she felt she could not bear another public function. Irène, for example, accepted some of the many honorary degrees granted to her mother by universities and colleges.

In 1920 Curie and a number of her colleagues created the Curie Foundation, whose mission was to provide both the scientific and the medical divisions of the Radium Institute with adequate resources. Over the next two decades the Curie Foundation became a major international force in the treatment of cancer.

Curie with President Hoover in 1929, when she made a second U.S. tour sponsored by Meloney. This time she succeeded in equipping the Warsaw Radium Institute, founded in 1925 with her sister Bronya as director.

CAMPAIGNS TO RAISE MONEY from governments as well as from individuals, were launched throughout the 1920s in many countries including France itself. Marie's scientist friends were especially active. Insisting that the quickest way to a progressive future was to foster research, they formed partnerships with liberal and socialist politicians, and they supported political parties that would increase government funding. Despite her shyness Marie helped in the work of lobbying, going with her friends from office to office. She could argue fervently, but her appearance alone was the strongest argument. A frail and aging woman dressed in black, already a legendary figure, she had--as one observer put it--the appearance and moral force of a Buddhist monk.

A World Center for the Study of Radioactivity

Poster for a campaign urging early detection of cancer. Radium and related materials had some success in destroying some types of cancers, but they have since been replaced by other radioactive materials, direct radiation treatments, and chemicals.

UNDER CURIE'S DIRECTION the Radium Institute in Paris became a world center for the study of radioactivity (there were only a few others on the same level--the Cavendish Laboratory in Cambridge, England; Berlin's Kaiser Wilhelm Institute for Chemistry; and Vienna's Radium Institute). Between 1919 and Curie's death in 1934, scientists at her Radium Institute published 483 works, including 31 papers and books by Curie herself. Until the end of her life she continued research to isolate, concentrate, and purify polonium and actinium.

She considered it important to get enough of these elements to do thorough scientific studies of them. At the same time, the work was intimately related to the commercial production of radioactive substances and many applications in science and industry as well as medicine.

Alongside the research, the Radium Institute became an international center for measuring the radium content of various products. Curie believed that providing this service, necessary for doctors and others who used radium, was a personal responsibility.

The Curie Museum in Paris keeps Marie Curie's office in the Radium Institute as she left it, as well as the chemical laboratory that she and Irène Joliot-Curie used. The laboratory (right) was reconstructed in 1981--and decontaminated, for it was too radioactive for safe occupancy. (© Rachel Paty-Musée Curie)

THE CENTRAL TASK of her life was no longer her own research, but directing the Curie Institute. Seeing that science was becoming specialized, she organized the Radium Institute in a new way--an entire major laboratory devoted to a single subject. Researchers formed small teams, each team with its own independent questions but always about radioactivity. Each team not only attacked its questions but also served as a training-ground for students. The institute housed three or four dozen researchers, and Curie kept in touch with the details of the work of every one of them. From the moment she arrived in the morning she would be surrounded by researchers. Often she stopped to sit with them on the stairs of the narrow entrance hall, briskly discussing the problems of the day.

Curie's research staff always included some foreigners, especially Poles and some women. She considered all the researchers working under her direction her "children." One of them, Salomon Rosenblum, made a major discovery in 1929, when his work with actinium (prepared by Curie herself) helped confirm quantum theory. But her own daughter Irène and son-in-law Frédéric Joliot became the stars of the Radium Institute. Curie did not live to see the Joliot-Curies receive a joint Nobel Prize for Chemistry in December 1935. But she did witness in early 1934 their triumphant discovery of artificial radioactivity, for which the prize would be awarded. Meanwhile Eve too achieved distinction--not in science but for her writing (including a popular biography of her mother).

> **"It was certainly a satisfaction for our late lamented teacher, Marie Curie, to have seen the list of radioactive elements that she had the honor to inaugurate with Pierre Curie so extended."**--
> *Frédéric Joliot-Curie, in his Nobel Prize lecture*

Receiving the 1935 Nobel Prize. Unlike Marie Curie's experience when sharing her first Nobel Prize with Pierre, Irène and Frédéric Joliot-Curie each delivered part of the Nobel lecture explaining the significance of their work. (Photo ACJC)

As all-consuming as her involvement with the Radium Institute was, Curie also found time in the last 12 years of her life to serve on the commission on Intellectual Cooperation of the League of Nations. In this capacity she worked toward establishing an international bibliography of scientific papers, developing standards for international scientific scholarships, and protecting researchers' ownership of intellectual rights for their discoveries.

When Curie learned that Einstein, like her, had been appointed to the League's Commission on Intellectual Cooperation, she sent a letter urging him to serve: "I believe your acceptance, as well as mine, is necessary if we have any hope of rendering any real service."

Physical Decline

MEDICAL PROBLEMS BEGAN TO AFFLICT Curie in 1920, when she learned that she had a double cataract. Today we know that exposure to radiation can cause this disease, in which the lens of the eye becomes clouded. Her vision became so impaired that she had to write her lecture notes in huge letters and have her daughters guide her around. Only after four operations was she able again to carry out exacting lab procedures and drive a car.

Curie, like other researchers and industrialists of the day, was unclear about the health effects of exposure to radioactivity. In 1925 she participated in a commission of the French Academy of Medicine that recommended the use of lead screens and periodic tests of the blood cells of workers in industrial labs where radioactive materials were prepared.

Advertisement for "Tho-Radia," a beauty cream containing the radioactive materials Thorium and Radium. Many such nostrums were sold world-wide. Through the 1920s most people believed that low levels of radiation were beneficial--killing germs and stimulating growth. (Photo ACJC)

Although she did not believe that researchers were exposed to the same dangers as industrial workers, she required the Radium Institute staff to have their blood counts checked regularly. She also advised staff members to get regular exercise and fresh air, as if these precautions would protect them from radiation's harmful effects.

> **"Perhaps radium has something to do with these troubles, but it cannot be affirmed with certainty."** *--letter from Curie to her sister Bronya, November 1920*

SOME DAYS SHE WAS TOO SICK TO GO TO THE LAB. On those days she worked at home on the manuscript of her book *Radioactivity*, which would be published posthumously in 1935. At first her regimen of diet and exercise worked. Yet her health continued to deteriorate. Over the Easter holiday of 1934, she took a last trip with her sister Bronya, during which she paid a final visit to her brother-in-law Jacques Curie. In May she went home sick from the lab in mid-afternoon and never returned.

> **"In the event of my death I give to the Radium Institute, of Paris, for exclusive use in the Curie laboratory, the gram of radium given to me by the Executive Committee of Women of the Marie Curie Radium Fund..."**

Today busts of Marie and Pierre Curie stand in the garden of the Radium Institute, now home to the Curie Museum.

None of the specialists who examined Curie could diagnose her problem. Suspecting tuberculosis, several advised a stay at a sanatorium in Switzerland. A medical expert from Geneva finally diagnosed a blood disorder for which there was no cure. She died on July 4, 1934. "The disease was an aplastic pernicious anemia of rapid, feverish development," the sanatorium director reported. "The bone marrow did not react, probably because it had been injured by a long accumulation of radiations."

CURIE WAS BURIED TWICE On July 6, 1934, she was interred in the same cemetery in Sceaux where her in-laws and Pierre lay. Over 60 years later the remains of Pierre and Marie Curie were re-interred in France's national mausoleum, the Panthéon, in Paris. Marie Curie thus became the first woman whose own accomplishments earned her the right to rest for eternity alongside France's most eminent men.

During the reinterment of Pierre and Marie Curie at the Panthéon, the president of France said, "As the country bows before her ashes...I form the wish, in the name of France, that everywhere in the world the equality of the rights of women and men might progress."

"By transferring these ashes of Pierre and Marie Curie into the sanctuary of our collective memory, France not only performs an act of recognition, it also affirms a faith in science, in research, and its respect for those who dedicate themselves to science, just as Pierre and Marie Curie dedicated their energies and their lives to science."

--President Fran_ois Mitterand at the Panth_on, April 1995

Jean-Frédéric Joliot (1900-1958) and Irène Curie (1897-1956)

A Second Generation of Curies

When the romantic relationship between Fred and Irène became known, cynics claimed that the gregarious "prince consort" was wooing the awkward "crown princess" of the Radium Institute only to advance his career.

MARIE CURIE'S LAST YEARS were brightened by the flourishing collaboration between her two lab assistants, her daughter Irène and young Frédéric Joliot. Just as Marie and Pierre had combined personal love with professional commitment, so did the Joliot-Curies. Irène and Fred shared not only a devotion to scientific research but also similar political outlooks as well as a love of sports.

> **"The fame and the achievement of her parents neither discouraged nor intimidated her....Her sincere love of science, her gifts, inspired in her only one ambition: to work forever in that laboratory which she had seen go up."** --*Eve Curie on her sister Irène*

Like Pierre Curie, Fred Joliot lacked impeccable academic credentials. But he had graduated first in his engineering class at the Paris Municipal School of Industrial Physics and Chemistry, where he studied under Paul Langevin, the Curies' colleague and Marie's erstwhile love. In 1925 Langevin helped place Fred at the Radium Institute as a junior assistant to Marie Curie. By that time Irène, two and a half years Fred's senior, had been awarded her doctorate for studies of the alpha rays of polonium (the first of the two elements her mother had discovered 27 years earlier). About a year after Fred's arrival in the lab, the couple married.

> **"I rediscovered in [Pierre Curie's] daughter the same purity, his good sense, his humility."** --*Frédéric Joliot*

DOUBTFUL THAT THE MARRIAGE WOULD LAST, Marie Curie not only insisted on a prenuptial agreement but also confirmed that Irène would inherit the use of the radium at the lab. The young couple struggled to make ends meet, with Fred doing some teaching on the side. Despite his many responsibilities, he was able in 1930 to complete his doctorate on properties of compounds of polonium. For a while his financial concerns led him to contemplate leaving research for a better-paying career in industry.

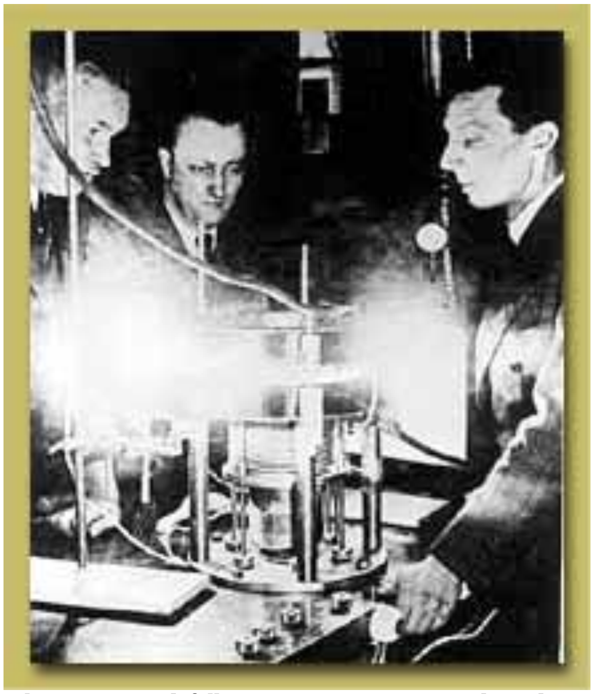
Persistent rumors about the strength of Joliot's attachment to Irène (shown above at a 1929 conference on beta and gamma rays held at the Cavendish Laboratory) led him to announce to an acquaintance, "But I do love my wife. I love her very much."

Before 1928, when they began to sign their scientific articles jointly, Irène and Fred had each published some solid work as individuals, but neither had demonstrated outstanding scientific abilities. Together they brushed greatness twice before striking pay dirt. In 1932 they noted the unusual result of an experiment they performed, but failed to understand it completely. That left the discovery of the neutron to James Chadwick. In another experiment, drawing an incorrect conclusion about the mysterious outcome, they ceded the discovery of the positron to C. D. Anderson.

A CRITICAL EXPERIMENT in their basement lab at the Radium Institute led them to a correct and very significant conclusion in mid-January 1934. By bombarding stable elements with nuclear projectiles, they were the first to discover artificial radioactivity--a normal element was changed to a radioactive one through human intervention.

Marie Curie, shown here with the Joliot-Curies and their young children, soon acknowledged her son-in-law's abilities. The young man, she said, was "a skyrocket."

"With the neutron we were too late. With the positron we were too late. Now we are in time."*--Joliot to a student, Jan. 1934*



Joliot in 1939 with fellow scientists Lew Kowarski and Hans Halban around a cloud chamber, as they began work on uranium fission. When Joliot told Irène that the cloud chamber was "the most beautiful phenomenon in the world," she--by now the mother of two children--corrected him: "Yes, my dear, it would be the most beautiful phenomenon in the world--if it were not for childbirth."

THANKS TO THEIR DISCOVERY, artificially radioactive atoms could now be prepared relatively inexpensively. The tedious labor and high cost of separating naturally occurring radioactive elements like radium from their ores would no longer impede the progress of nuclear physics and medicine. Their discovery brought the pair the 1935 Nobel Prize for Chemistry.

> **"The results of your researches are of capital importance for pure science, but in addition, physiologists, doctors, and the whole of suffering humanity hope to gain from your discoveries remedies of inestimable value."**--
> *1935 Nobel Prize for Chemistry to Irène Joliot-Curie and Frédéric Joliot*

WORKING SEPARATELY after receiving the Nobel Prize and the fame and obligations that went with it, Irène and Fred each took on administrative duties and students. Irène accepted the position of Undersecretary for Scientific Research in a Socialist-Communist coalition government, but political maneuvers were not to her taste and she soon returned to the lab. In 1938 her group did painstaking work on uranium with puzzling results, which provoked German scientists to research that led to the discovery of nuclear fission. Fred's group, recognizing a potentially immense source of energy, began pioneering work on chain reactions. When Germany invaded France in 1940, his collaborators fled and helped create the British atomic energy program, leading to the American Manhattan Project. Fred and Irène decided to remain in their homeland.

The End of the Curie Hold on French Science

For his hard and dangerous secret work during the war, Joliot, shown here just after the Occupation, was named a commander of the Legion of Honor with a military title and awarded the Croix de Guerre.

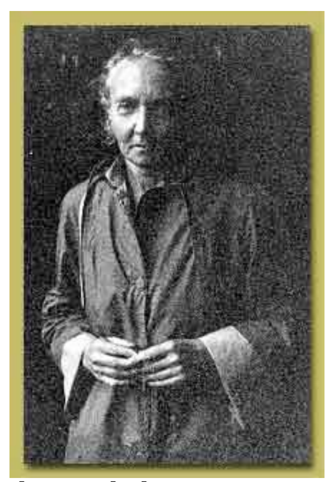
FRED WAS A HERO IN THE WAR. Pretending to be busy with theoretical atomic physics, he risked his life by using his lab to manufacture explosives and radio equipment for the Resistance. After the liberation of France, he was appointed director of the National Center for Scientific Research. Meanwhile he was elected to the French Academy of Sciences. Soon thereafter he became head of the French Atomic Energy Commission. His task was to make France a world leader in the nuclear industry. Irène became not only a commissioner but also the director of the Radium Institute.

But the Joliot-Curies' political activities led to their political downfall. In spring 1942 Fred had secretly joined the French Communist party, at that time a leading anti-Nazi force. Although Irène never became a member, she sympathized with many movements in which French Communists took a lead, including support of equal rights for French women.

At the height of the Cold War, Fred was dismissed from his position at the French Atomic Energy Commission. A few months later Irène also lost her post as commissioner.

"Progressive scientists and communist scientists shall not give a jot of their science to make war against the Soviet Union...we shall hold firm, sustained by our conviction that in so doing we serve France and all of humanity." *--Joliot's address at the French Communist Party's 12th National Congress, April 1950*

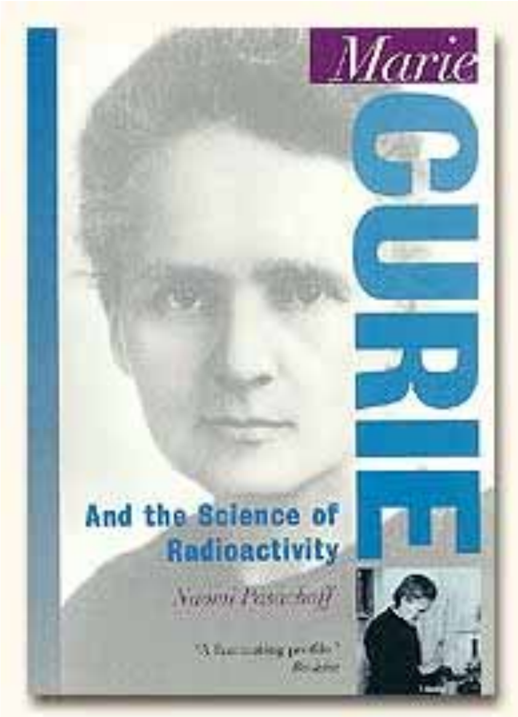
Joliot, shown here speaking in public in 1950, realized that his outspoken pro-Communist views would be his undoing. In April 1950, he told his friends, "If the government doesn't fire me after what I've said, I don't know what more they need."



Photographed at an international scientific meeting in Stockholm in July 1953, Irène was denied a hotel room by city innkeepers who disapproved of her political views.

The Curie family's domination of French nuclear physics had come to an end. The Joliot-Curies never abandoned their efforts to promote world peace. Irène continued to work in her lab until a few months before her death. But largely as a result of her efforts, a new scientific facility at Orsay, south of Paris, soon replaced the Radium Institute as France's nuclear research center. Fred kept his chair at the prestigious Collège de France, which he had held since 1937, and accepted Irène's chair at the Sorbonne after her death. He survived his wife by only two years. He succumbed to a liver disease, perhaps induced by radiation. Both Joliot-Curies were given state funerals.

Exhibit Credits



This exhibit is based on the book by Naomi Pasachoff, *Marie Curie and the Science of Radioactivity*. New York and Oxford: Oxford University Press, 1996.

The exhibit was constructed by the Center for History of Physics with support from the American Institute of Physics and the Friends of the Center.

Author:	Naomi Pasachoff
Editor:	Spencer R. Weart
Web Design:	Tom Connell
Image Research:	Jack Scott

We are also very grateful to: Lawrence Badash, Soraya Boudia, Hélène Langevin-Joliot, Pierre Radvanyi, Xavier Roquè, Bernadette Vincent-Bensaud, and Association Curie et Joliot-Curie and Musèe et Archives de l'Institute du Radium

Further reading and links: visit http://www.aip.org/history/curie/biblio.htm

Comments? Send us feedback. Email chp@aip.org

Help us make more exhibits! Visit http://www.aip.org/history/historymatters

Sign up to find out when we put more exhibits online.
Email us at chp@aip.org to be added to our email list.

Photo Credits

Images credited to ACJC are courtesy of and copyrighted © by either the Association Curie et Joliot-Curie or the Archives Curie et Joliot-Curie, Paris. Except as otherwise noted below, all other images are courtesy of and copyright © the AIP Emilio Segrè Visual Archives.

Polish girlhood: Czar Alexander II: Reproduced from N.G.O. Pereira, *Tsar-Liberator : Alexander II of Russia, 1818-1881*. Newtonville, MA : Oriental Research Partners, 1983. Cossacks parading in Warsaw: BBC Hulton Picture Library

A Student in Paris: Paris in 1889: Anonymous photo reproduced from *The Eiffel Tower : A Tour de Force*. New York : The Grolier Club, 1989. Paris Rooftops: Gustave Caillebotte, *Vue de toits (effet de neige)*, reproduced with permission of MusÈe d'Orsay, Paris

Research Breakthroughs: Pitchblende sample: Photo by Jay Pasachoff

Recognition and Disappointment: Mittag-Leffler: Reproduced with permission of The MacTutor History of Mathematics archive. Vanity fair cover from http://info.med.yale.edu/library/exhibits/curie/p-and-m-curie.html.

Tragedy and Adjustment: Childe Hassam painting: private collection

Scandal and Recovery: Branly and Curie: L'Excelsior, 23 January 1911. Langevin: Jean-Loup Charmet. Emile Borel: Reproduced with permission of The MacTutor History of Mathematics archive. Hertha Ayrton: From the Institution of Electrical Engineers Archives. Curie in Birmingham: New York Public Library, General Research Division, Astor, Lenox and Tilden Foundation

War Duty: Radium Institute: Reproduced from Curie, Eve. *Madame Curie.* New York: Doubleday, Doran & Company, 1938. Petite Curie: Photo by Jay Pasachoff. Marie and IrËne with X-ray equipment: Marie Sklodowska Curie Museum. Curie with x-ray workers: Marie Sklodowska Curie Museum

The Radium Institute: Henri de Rothschild: Bibliothèque nationale de France, Paris. Curie and Hoover: E Towpik and R. Mould. "Marie Sklodowska-Curie Memorial Issue," Nowotwory, *Polish Oncological Journal,* Warsaw, 1998. Poster for a campaign urging early detection of cancer: copyright La Ligue Nationale contre le Cancer. Curie busts: Photo by Jay M. Pasachoff. Reinterment of Pierre and Marie Curie: Photo by Jay M. Pasachoff

The Romantic Legend: Greer Garson as Curie: From the film *Madame Curie,* MGM, 1943. The facilities in the School of Industrial Physics and Chemistry shed: Photo by Jay M. Pasachoff

The End of the Curie Hold on French Science: Irène Curie photograph by William G. Myers, Ph.D., M.D., The Medical Heritage Center, The Ohio State University Prior Health Sciences Library, courtesy AIP Emilio Segrè Visual Archives

Sources

Marie Curie, Pierre Curie with Autobiographical Notes. Translated by Charlotte and Vernon Kellogg (New York: Macmillan, 1923).

Eve Curie, Madame Curie. Translated by Vincent Sheean (Garden City, NY: Doubleday, Doran, 1938), © Doubleday, Doran.

Marie and Irène Curie, Correspondence; choix de lettres, 1905-1934, edited by Gillette Ziegler. (Paris: Éditeurs français réunis, 1974), © Éditeurs français réunis. Translated by S. Weart.