



Marie Curie

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ARTICLE

Marie Curie

(1867–1934). Marie Curie was a French physicist who was born in Poland. Famous for her work on radioactivity, she won two Nobel Prizes. With French physicist Henri Becquerel and her husband, Pierre Curie, she was awarded the 1903 Nobel Prize for Physics. She was the sole winner of the 1911 Nobel Prize for Chemistry. She was the first woman to win a Nobel Prize, and she is the only woman to win the award in two different fields.



Marie Curie, 1910.

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Early Life and Education



Maria Skłodowska, later known as Marie Curie, stands next to her sister Bronisława Skłodowska, in 1886.

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Her name at birth was Maria Salomea Skłodowska. She was born on November 7, 1867, in Warsaw, in what was then the Congress Kingdom of Poland, Russian Empire. From childhood she was noted for her remarkable memory, and at the age of 16 she won a gold medal on completion of her secondary education at a Russian-controlled school. Because her father, a teacher of mathematics and physics, lost his savings through bad investment, she began to work as a tutor.

Skłodowska could not attend the University of Warsaw because at that time women were not allowed. Instead, in the evenings she took part in the “floating university,” a network of underground classes that Polish citizens attended without the Russian government’s knowledge. At the age of 18 she took a post as a governess, where she suffered an unhappy love affair. However, from her earnings she was able to finance her sister Bronisława’s medical studies in Paris, France. The sisters had an understanding that Bronisława would in turn later help Maria get an education.

In 1891 Skłodowska went to Paris and began taking classes at the Sorbonne, one of the colleges at the University of Paris (now the Universities of Paris I–XIII). She enrolled under the name Marie. She was particularly interested in the lectures of mathematician Paul Appell and physicists Gabriel Lippmann and Edmond Bouty. Skłodowska worked hard and within three years had completed degrees in physics and mathematics. In the spring of 1894 she met Pierre Curie, a physicist teaching at a technical college in Paris.

First Nobel Prize



Marie Curie poses in her laboratory in Paris, France.

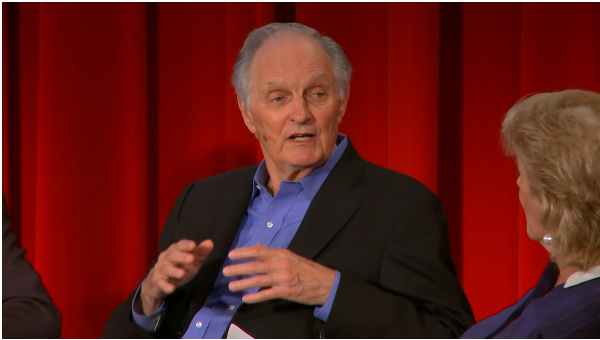
Associated Newspapers/Shutterstock.com

Marie and Pierre married on July 25, 1895. Their partnership soon achieved results of world significance. In 1896 Henri Becquerel discovered a new phenomenon in which uranium gave off invisible rays of energy, or radiations, that could pass through solid matter. Marie later called this phenomenon “radioactivity”). Marie, looking for a subject for a thesis, decided to find out if the property discovered in uranium was found in other matter. In 1898 both she and German chemist Gerhard Carl Schmidt independently discovered that the element thorium was also radioactive.



French chemist Gustave Bémont (left) visits Pierre and Marie Curie in the Curies' laboratory in 1898.

Photos.com/Getty Images



Alan Alda talks about the work of Marie Curie, the subject of his 2011 play *Radiance: The Passion of Marie Curie*.

© World Science Festival

Turning her attention to minerals, Marie became interested in pitchblende. Pitchblende is a mineral whose radioactivity is superior to that of pure uranium. She figured that this fact could be explained only by the presence in the ore of small quantities of an unknown substance of very high radioactivity. Pierre then joined Marie in trying to identify the substance. As a result, in the summer of 1898, they discovered the new element polonium (named in honor of Poland, Marie's native land) and a few months later the element radium. While Pierre devoted himself chiefly to the physical study of the new radiations, Marie struggled to obtain pure radium in the metallic state. She would eventually achieve success with the help of the chemist André-Louis Debierne, one of Pierre's pupils. On the results of this research Marie received her doctorate of science in June 1903. That same year the Royal Society awarded Marie and Pierre the Davy Medal. The Curies also shared with Becquerel the Nobel Prize for Physics for the discovery of radioactivity.



Marie Curie poses with her daughters, Ève (left) and Irène (right).

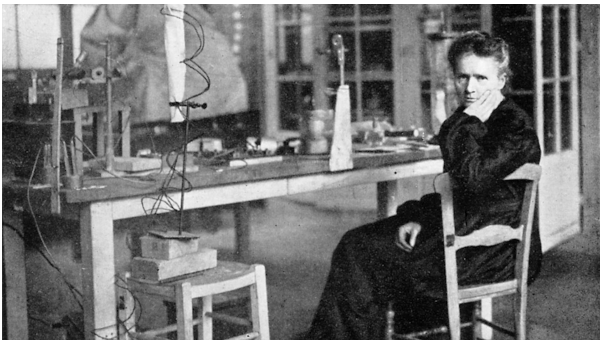
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The birth of the Curies' two daughters, Irène and Ève, in 1897 and 1904 did not interrupt Marie's intensive scientific work. In 1900 Marie was appointed lecturer in physics at the École Normale Supérieure for girls in

Sèvres, France. While there she introduced a method of teaching based on experimental demonstrations. In December 1904 she was appointed chief assistant in the laboratory at the Sorbonne where Pierre was director.

Second Nobel Prize

Pierre died in an accident on April 19, 1906. After his death Marie devoted all her energy to completing the scientific work that they had undertaken. On May 13 she was appointed to the professorship that had been left vacant on her husband's death, making her the first woman to teach in the Sorbonne. In 1908 she became titular professor, and in 1910 her fundamental treatise on radioactivity was published. In 1911 she was awarded the Nobel Prize for Chemistry, for the isolation of pure radium. In 1914 she saw the completion of the building of the laboratories of the Radium Institute (Institut du Radium) in Paris.



During World War I (1914–18) Marie Curie developed a fleet of mobile radiological labs to bring X-ray equipment to doctors treating wounded soldiers at the front.

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Throughout World War I (1914–18) Marie devoted herself to the development of the use of X-radiography—the taking of radiographs, or X-ray images. She was assisted by her daughter Irène. In 1918 the Radium Institute, the staff of which Irène had joined, began to operate in earnest, and it was to become a universal center for nuclear physics and chemistry. Marie spent her time researching the chemistry of radioactive substances and the medical applications of these substances.

Later Work



Marie Curie works in her laboratory at the University of Paris (now the Universities of Paris I–XIII) in 1925.

Historia/REX/Shutterstock.com

In 1921, accompanied by her two daughters, Marie traveled to the United States. U.S. President Warren G. Harding presented her with a gram of radium that had been bought using donations from American women. (Curie needed the radium for her research, but it was difficult to obtain and very expensive.) Curie gave lectures, especially in Belgium, Brazil, Spain, and Czechoslovakia. She was made a member of the International Committee on Intellectual Cooperation by the Council of the League of Nations. In addition, she saw the development of the Curie Foundation in Paris. In 1932 the Radium Institute of Warsaw, Poland, was inaugurated. Marie's sister Bronislawa became director of the institute.

One of Marie's outstanding achievements was understanding the need to accumulate intense radioactive sources, not only to treat illness but also to maintain an abundant supply for research in nuclear physics. In the late 1920s and early '30s Irène performed successful experiments using the stockpile. (Irène had married Marie's assistant Frédéric Joliot in 1926 and had changed her name to Irène Joliot-Curie.) Irène's work prepared the way for the discovery of the neutron by British physicist James Chadwick in 1932 and for the discovery of artificial radioactivity by the Joliot-Curies in 1934.

Marie Curie died on July 4, 1934, near Sallanches, France, as a result of a blood disease caused by exposure to radiation. In 1995 her ashes were enshrined in the Panthéon in Paris. She was the first woman to receive this honor for her own achievements. Her office and laboratory in the Curie Pavilion of the Radium Institute are preserved as the Curie Museum.

Citation (MLA style):

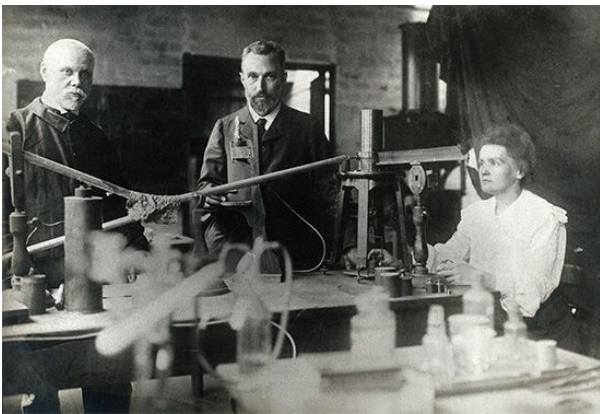
"Marie Curie." *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 19 Oct. 2023. packs.eb.com. Accessed 4 May. 2025.

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ARTICLE

Curie family

It is an unusual distinction for four members of one family to win Nobel Prizes in science. The family to whom those honors came was that of the Curies, four individuals whose lives and work form a significant part of the history of nuclear physics in the 20th century.



Pierre and Marie Curie were the first members of their illustrious scientific family to win the Nobel Prize.

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Pierre Curie completed distinguished work in the study of crystals and magnetism, and he discovered piezoelectricity with his brother Jacques. In 1894 Pierre met Maria (later Marie) Salomea Sklodowska, and the two were married the next year. In 1898 Pierre and Marie Curie announced the discovery of the chemical elements polonium and radium. In 1903 the Curies and Henri Becquerel shared the Nobel Prize for Physics for their discovery of radioactivity. After Pierre's death, Marie carried on with her scientific work and in 1911 was awarded the Nobel Prize for Chemistry for isolating pure radium.



Marie Curie (right) and her daughter Irène Joliot-Curie, 1925.

Universal Images Group/Getty Images

Irène Curie was the elder daughter of Pierre and Marie. In 1925 she met Frédéric Joliot while working in her mother's laboratory. They married in 1926, and for the next 30 years the Joliot-Curies continued to add to the work of the elder Curies. Their first efforts were directed at the study of atomic nuclei. Together they synthesized new artificial radioactive material. For their work they were awarded the Nobel Prize for Chemistry in 1935. During the late 1930s they did experiments that led to the development of nuclear fission.

Ève Curie, the younger daughter of Pierre and Marie, was a concert pianist, journalist, and diplomat. She is best known for writing a biography of her mother, *Madame Curie* (1937), which was an instant international best seller. It was later made into a Hollywood film (1943).

Citation (MLA style):

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ARTICLE

radioactivity

Late in the 19th century, scientists discovered an amazing activity in certain kinds of matter. Through the ages, atoms of these substances have been shooting off particles and emitting radiations (together called rays) without anyone suspecting that this was happening. Scientists also found that nothing could be done to change the emissions. The application of heat, electricity, or any other force made no difference whatsoever. Emission seemed to be an unchangeable property of the substances.



Nuclear radiation cannot be sensed, so people who are regularly exposed to it rely on measuring devices to avoid harmful doses. Radiation dosage is measured in millisieverts.

Contunico © ZDF Studios GmbH, Mainz; Thumbnail © Eevlva/Dreamstime.com

Many vital uses have come from this discovery. A special use of the element uranium led to the development of nuclear weapons and nuclear energy. Doctors also have found that the rays can penetrate living tissues for short distances and affect the tissue cells. Like X rays, they can disrupt chemical bonds in the molecules of important chemicals within cells, and so they help in treating cancers and other diseases.

In time, scientists learned how to make all other elements give off these rays. These include the major elements that make up our bodies. If such radioactive elements are placed in the body through food or by other methods, the rays can be traced through the body. This use of tracer elements is extremely helpful in expanding knowledge of our life processes.

Geologists have learned how to use radioactivity to determine the age of rocks. From this they obtain new checks on the ages of mountain ranges and even the age of the Earth itself. The study of radioactivity continues to contribute to the understanding of the nature of atoms, and from this, scientists are learning how energy and matter interact to bring about everything that happens in the physical universe.

Learning the Nature of Radioactivity

At first, scientists did not know the nature of these strange emissions, and they could only call them rays. This gave rise to the term radioactivity, from the Latin word *radiare*, meaning “to give off rays.” Modern knowledge of radioactivity can best be traced by seeing how it was discovered and how with further experiments and study scientists gradually learned its nature.

The first development came as a result of Wilhelm Roentgen's discovery of X rays in 1895 (see Roentgen; X rays). The French physicist Henri Becquerel became interested in the fact that the glass of an X-ray tube glows with a greenish light while the invisible radiation is being given off. He wondered whether other materials when made to glow, or fluoresce, might also emit invisible radiation like X rays.

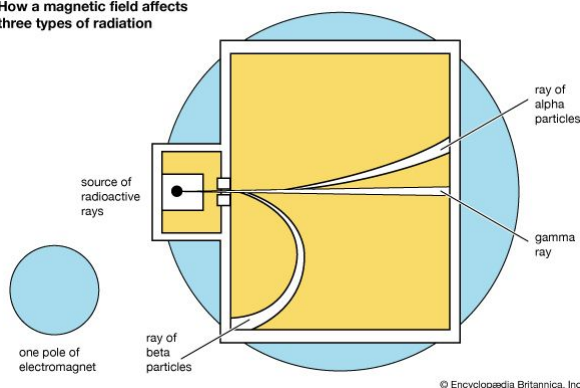
To find out, he placed phosphorescent crystals upon a photographic plate that had been wrapped in opaque paper so that only penetrating radiation could reach the photographic emulsion. Among the substances he tested was a salt of uranium. None of the other compounds affected the film. The uranium salt, however, made a fairly clear imprint. He experimented for several months and found that fluorescence had nothing to do with the result. All compounds of uranium affected the film, whether or not they had been made fluorescent. The invisible radiation seemed to be a natural property of uranium.

Becquerel also found that when he placed uranium near a charged electroscope, the charge leaked away. It was apparent that the radiation made the air in the electroscope a conductor of electricity. Shortly afterward the Polish-born French physicist Marie Curie and her husband, Pierre, made another amazing discovery. She started to test samples of different metals and ores to note the length of time it took for samples to discharge an electroscope.

Strangely enough, pitchblende, a uranium ore, proved to be four to five times as radioactive as was pure uranium, even after the uranium had been removed from the pitchblende. Madame Curie concluded that the ore must contain some other radioactive substance. She later isolated this substance and found it to be a hitherto unknown chemical element. It was 4 million times as radioactive as uranium, so she gave it the name radium. (*See also* Becquerel; Curie, family; radium.)

Meanwhile other scientists were discovering the nature of radioactivity. In 1899 Ernest Rutherford found that uranium gave off two different kinds of rays. One kind was stopped by a sheet of paper or a few inches of air. Rutherford named it the alpha ray. A second type, the beta ray, could go through about $\frac{1}{5}$ inch (5 millimeters) of aluminum. A year later it was discovered that a third kind, the gamma ray, could pass through about 8 inches (20 centimeters) of iron. (The names alpha, beta, and gamma are often written with the Greek letters, α , β , and γ , respectively.)

How a magnetic field affects three types of radiation



A magnetic field (only one pole is shown) affects radioactive rays differently depending on the type of ray. Alpha rays (heavy, positively charged particles) are deflected slightly in one direction. Beta rays (light, negatively charged electrons) are deflected strongly in the opposite direction. Electromagnetic gamma rays are not deflected.

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Each of these three rays responds differently to magnetic and electric fields. When they are directed through a detector placed in a strong magnetic field, alpha rays always curve in one direction, beta rays curve strongly in

the opposite direction, and gamma rays are unaffected. These motions are explained by differences in electric charge, in mass, or both. Experiments made by shooting the rays between electrically charged plates give similar results. Alpha rays are deflected slightly away from a positive charge and toward a negative charge. Beta rays are deflected strongly in the opposite direction, and gamma rays not at all. It is well known that like electrical charges repel each other, while unlike charges attract. The deflections were also what was to be expected if the charges are carried by particles having certain masses. Alpha rays must therefore consist of particles carrying a positive charge. Beta rays are particles having negative charge. Gamma rays apparently did not carry a charge at all.

Radioactivity and Atoms

Since the particles and the gamma rays came from within atoms, plainly the particles had somehow been parts of atoms. Atoms therefore were not the smallest units of matter, as scientists had thought they were. Atoms must consist of still smaller units, such as the particles given off by radioactivity.

By that time, scientists had already discovered the electron, a particle with negative electric charge but only $\frac{1}{1840}$ the mass of a hydrogen atom, the lightest in existence. Soon it was proved that beta rays (${}_{-1}\beta^0$) are streams of electrons. Proof was also found that particles in alpha rays (${}_2\alpha^4$) are the nuclei of helium atoms, the next lightest after hydrogen.

As additional radioactive elements were found, it was learned that the same kinds of alpha, beta, and gamma rays were given off during their transformations, regardless of the kind of element. This suggested that both radioactive and other kinds of atoms must all contain the same kinds of subatomic particles. From this and other discoveries, scientists rapidly built up the theory that every kind of atom is made up of the same subatomic particles (seenuclear energy). Later, gamma rays were proved to be electromagnetic radiation, like radio, light, and X rays, with shorter wavelengths than any X ray then known (seeradiation).

Transmutation of Elements

Before the discovery of radioactivity, scientists thought that the atoms of matter were indestructible. Atoms might combine and recombine in endless chemical compounds; but each atom always remained the same through all the changes. The discovery of radioactivity forced a change in this theory. If atoms of uranium and radium lose particles as heavy as nuclei of helium, they could hardly remain the same elements. They must become atoms of something else. Experiments and study revealed the truth of this view. These elements do change—that is, transmute—into other elements.

Radium offers a good example. When one atom of radium disintegrates, two gaseous products result—radon and the helium nucleus (the alpha particle). Each charged alpha particle captures a stray electron and becomes a stable helium atom. The unstable radon atom, in turn, changes into an atom of another element. Other disintegrations follow each other until the series ends with the stable element lead.

The successive changes of one radioactive element into another create a kind of “family” for each series, from the parent element to lead. Scientists have found four principal families, or decay series, of radioactive substances—the uranium-radium family; the actinium family; the thorium family; and the neptunium family.

Development of Artificial Radioactivity

In the early 1900s scientists tried to produce radioactivity in ordinary substances but without success. No method then available could apply enough energy to disturb the tightly bound nuclei of atoms. In 1919, however, Ernest Rutherford used the tremendous energy (for their size) of alpha particles to bombard the nuclei of nitrogen. Tests showed that this bombardment changed some of the nitrogen atoms into atoms of oxygen and hydrogen.

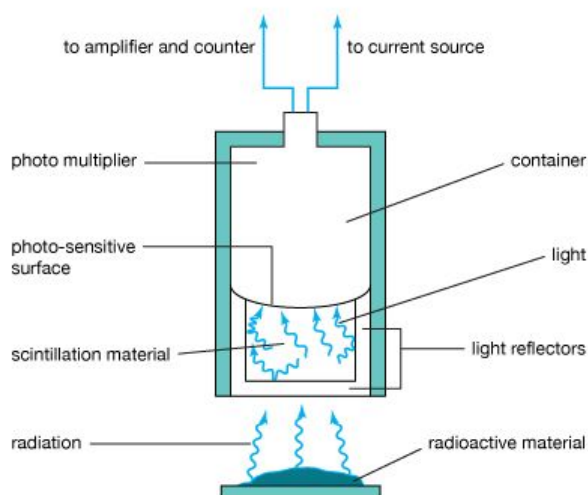
In 1934 Frederic Joliot-Curie and his wife, Irene (daughter of Marie Curie), bombarded a piece of aluminum with alpha particles and found that the aluminum gave off radioactive particles for a measurable time after the bombardment stopped. In giving off these particles the aluminum changed into a new substance that had never been found in nature.

The new substance had the chemical and physical characteristics of the element phosphorus, but its atomic weight differed from that of the well-known form. This fact indicated that the substance was a variant form, or isotope, of phosphorus. It was also radioactive. It gave off positrons (beta particles with positive charge) and gamma rays, and as a result it changed into silicon, a stable element. The Joliot-Curies also produced radioactive forms of boron, magnesium, and other elements.

In these early experiments particles from other radioactive substances were used to bombard samples because no other controlled particle had enough energy to affect the tightly bound nuclei of atoms. Physicists gradually developed machines that produced radioactive forms of every element.

Because radioactive particles are too small to be seen by the most powerful microscope, they must be detected and measured by their effects. One of the first instruments for doing this was a spinthariscopes. Particles from a radioactive source strike a plate covered with a reactive substance that produces flashes of light in a process called scintillation. Using a microscope, these flashes can be seen and counted.

Scintillation counter



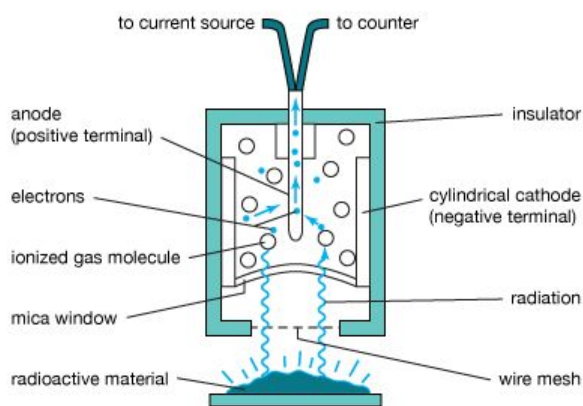
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Scintillation materials emit light flashes when radiation is absorbed. The light strikes a photosensitive surface. A photomultiplier measures the light signals and converts them into an electric signal that can be amplified and counted.

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Modern detectors record the number, and sometimes the direction, of certain kinds of particles as they pass through the detector over a given period of time. These devices include scintillation counters, Geiger counters, and Cerenkov radiation detectors. Scintillation counters and Cerenkov radiation detectors count the flashes of light emitted as particles interact with solids or fluids. The very brief flashes are detected by photomultipliers.

Geiger counter



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A Geiger counter is filled with gas, and a source of electricity supplies opposite electric charges to the container and a central tube. If radioactive particles enter and ionize some gas molecules, the electric current is able to bridge the gap between the container and central tube. The counter registers each brief spurt of current.

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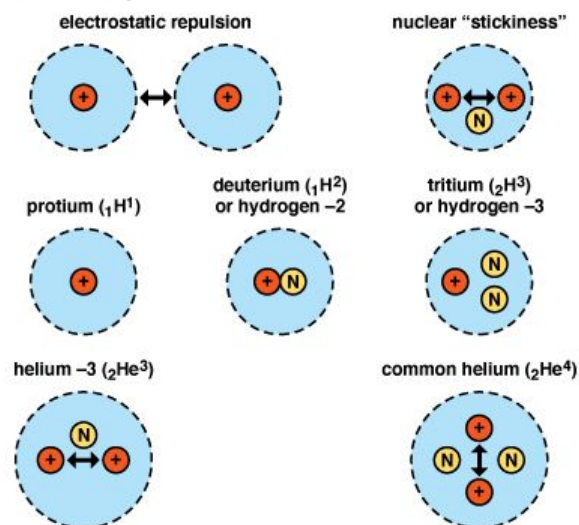
A typical Geiger counter—probably the most widely known of all the ionization chambers—consists of a gas contained between two electrodes. One electrode is a cylindrical cathode, and the other is a fine wire anode projecting into the center of the cylinder. A charged particle passing through the gas ionizes the gas molecules. The electrons and positive ions released by the ionization process are attracted to the positive and negative terminals, respectively (anode and cathode), and cause an observable pulse of current to flow through the circuit joining these elements. The flashes or electron pulses are then recorded and counted. Another kind of detector records the direction, charge, and energy of particles over a very short time span. Examples of these counters include cloud chambers and bubble chambers. Both contain molecules that are ionized by the passage of charged particles through the chambers. Gas condenses or bubbles form when the ionization occurs, leaving a visible trail.

Radioactivity and Nuclear Force

A fundamental question about radioactivity is why some elements have this property naturally while others do not. The nature of the rays and the heavy atomic weight of most naturally radioactive elements gave physicists two major clues. The answer lies in the way in which subatomic particles are held together to make up the nucleus of an atom.

The simplest nucleus in nature is that of hydrogen. It consists of a single proton, which carries one positive charge. The positive charge simply holds one negatively charged electron to form the complete atom.

Radioactivity



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Positive charges on two protons (+) tend to drive them apart (top left). If a neutron (N) is present, the protons also exert "stickiness," or nuclear force, to overcome the electrostatic repulsion (top right). When neutrons stick to the one proton of simple hydrogen, the isotopes deuterium and tritium are formed, each of which can gain another proton to form the two helium isotopes ${}_2\text{He}^3$ and ${}_2\text{He}^4$.

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For atomic nuclei having more than one proton, some kind of force is needed to overcome electrostatic repulsion between the positive charges on the protons and thus hold the nucleus together. This nuclear force can be thought of as a kind of "stickiness" that acts between subatomic particles when they are close together. Nuclear force can act at or within the "sticking distance" but not over any greater range.

The force cannot be electrical in nature, for it overcomes electrostatic repulsion without otherwise affecting the charges. Another aspect of the force is the fact that it acts only when protons are accompanied in a nucleus by another kind of particle—the neutron—discovered by James Chadwick in 1932. A neutron has about the same mass as a proton but no electric charge. Once a nucleus has one or more neutrons, various combinations can be made. One or two neutrons can stick to the one proton of hydrogen, making the heavy hydrogens deuterium (${}_1\text{H}^2$) and tritium (${}_1\text{H}^3$). Two protons also can be held with one neutron as an isotopic form of helium (${}_2\text{He}^3$).

The symbols show the make-up of the atomic nuclei. The small number to the lower left of the H in the chemical symbol for simple hydrogen (${}_1\text{H}^1$) refers to the number of protons. It is also the atomic number, which indicates where hydrogen belongs in the periodic table of the elements (see periodic table). The number to the upper right of the H refers to the total number of nucleons—protons plus neutrons. It is called the mass number, because this total determines almost entirely the mass of the atom. The symbol " H^2 " therefore means one neutron added to the proton, making the total two. The symbol ${}_1\text{H}^3$ stands for one proton and two neutrons. Helium ${}_2\text{He}^3$ has three particles, like tritium, but two of them are protons, as in common helium (${}_2\text{He}^4$). These different forms of a single element are called isotopes.

The particles in either kind of heavy hydrogen will easily hold another proton, giving two forms of helium (${}_2\text{He}^3$ and ${}_2\text{He}^4$). Helium is the next lightest element after hydrogen. After its electrons are removed, it is the alpha particle of radioactivity. With two electrons, the complete atom is one of the most satisfied and inert of all the elements (see chemistry).

The two forms of helium and the three hydrogens show why variations called isotopes can exist for every chemical element. Neutrons provide enough stickiness so that their number can vary somewhat and still hold the required number of protons. The isotopes, however, may or may not be stable—that is, able to hold together indefinitely. Deuterium (${}_1\text{H}^2$), for example, has stickiness enough to be stable. It can enter into chemical reactions normal for hydrogen, but its reaction time is slower. Tritium (${}_1\text{H}^3$) does not have such stickiness. In time it becomes an isotope (${}_2\text{He}^3$) of helium by gaining a proton. ${}_2\text{He}^3$ is stable and is found mixed in a slight amount (13 parts in 100,000) with the tightly bound “common” helium, ${}_2\text{He}^4$.

Naturally occurring radioactive isotopes

isotope	abundance* (percent)	half-life** (years)
${}^{14}\text{C}$	Trace	5.73×10^3
${}^{40}\text{K}$	0.012	1.28×10^9
${}^{48}\text{Ca}$	0.187	$>2 \times 10^{16}$
${}^{50}\text{V}$	0.25	6×10^{15}
${}^{64}\text{Zn}$	48.6	$>8 \times 10^{15}$
${}^{70}\text{Zn}$	0.62	$>1 \times 10^{15}$
${}^{76}\text{Ge}$	7.8	$>5 \times 10^{21}$
${}^{82}\text{Se}$	9.19	1.4×10^{20}
${}^{87}\text{Rb}$	27.85	5×10^{11}
${}^{96}\text{Zr}$	2.80	$>3.6 \times 10^{17}$
${}^{92}\text{Mo}$	14.8	4×10^{18}
${}^{100}\text{Mo}$	9.6	7.3×10^{18}
${}^{113}\text{Cd}$	12.26	9.3×10^{15}
${}^{116}\text{Cd}$	7.58	$>1 \times 10^{17}$
${}^{115}\text{In}$	95.72	5.1×10^{14}
${}^{124}\text{Sn}$	5.64	$>2.4 \times 10^{17}$
${}^{123}\text{Sb}$	42.75	1×10^{16}
${}^{123}\text{Te}$	0.89	1.2×10^{13}
${}^{130}\text{Te}$	34.48	2.51×10^{21}
${}^{138}\text{La}$	0.09	1.1×10^{11}
${}^{136}\text{Ce}$	0.193	3×10^{11}
${}^{142}\text{Ce}$	11.07	$>5 \times 10^{16}$
${}^{141}\text{Pr}$	100	$>2 \times 10^{16}$
${}^{144}\text{Nd}$	23.85	5×10^{15}
${}^{150}\text{Nd}$	5.62	$>5 \times 10^{18}$

¹⁴⁷ Sm	15.1	1.06×10^{11}
¹⁴⁸ Sm	11.3	1.2×10^{13}
¹⁴⁹ Sm	13.9	4×10^{14}
¹⁵² Gd	0.20	1.1×10^{14}
¹⁵⁹ Tb	100	5×10^{16}
¹⁶⁵ Ho	100	$\geq 6 \times 10^{16}$
¹⁶⁹ Tm	100	$\geq 5 \times 10^{16}$
¹⁷⁵ Lu	97.41	$\geq 1 \times 10^{17}$
¹⁷⁶ Lu	2.60	$\geq 3.0 \times 10^{10}$
¹⁷⁴ Hf	0.18	$\geq 2.0 \times 10^{15}$
¹⁸⁰ Ta	0.012	$\geq 1 \times 10^{13}$
¹⁸⁰ W	0.14	$\geq 1.1 \times 10^{15}$
¹⁸² W	26.3	$\geq 2 \times 10^{17}$
¹⁸³ W	14.3	$\geq 1.1 \times 10^{17}$
¹⁸⁶ W	28.6	$\geq 6 \times 10^{15}$
¹⁸⁷ Re	62.6	7×10^{10}
¹⁹² Os	41	$\geq 1 \times 10^{14}$
¹⁹⁰ Pt	0.013	7×10^{11}
¹⁹² Pt	0.78	1×10^{15}
¹⁹⁸ Pt	7.21	1×10^{15}
¹⁹⁶ Hg	0.146	$\geq 1 \times 10^{14}$
²⁰⁹ Bi	100	$\geq 2 \times 10^{18}$
²²² Rn	From ²²⁶ Ra	3.8 days
²²⁶ Ra	From ²³⁰ Th	1,622 years
²³⁰ Th	From ²³⁴ U	8×10^{14}
²³² Th	100	1.41×10^{10}
²³⁴ U	0.005	2.47×10^5
²³⁵ U	0.72	7.1×10^8
²³⁸ U	99.275	4.51×10^9

*The percentage of the number of atoms of one isotope to the total number of atoms of a given element.

**Approximate.

Sources: C. Michael Lederer and Virginia S. Shirley, *Table of Isotopes*, 7th ed. (1978), and Robert C. Weast, ed., *Handbook of Chemistry and Physics*, 74th ed. (1993–94).

The Neutron-Proton Ratio

In ${}_2\text{He}^4$, the protons and neutrons are exactly equal in number. In heavier elements up to and including calcium (${}_{20}\text{Ca}^{40}$), this one-to-one ratio holds closely. Only a few stable kinds of atoms depart from it by one or more particles.

Beyond calcium, neutrons are in excess of protons. Because protons electrostatically repel one another, an excess of neutrons is needed to exert a neutralizing force on the mutually-repellant protons. These neutrons, thus, help hold the nucleus together.

Up to lead (${}_{82}\text{Pb}^{208}$) and bismuth (${}_{83}\text{Bi}^{209}$), such excess of neutrons can hold nuclei permanently together in a stable state. No nucleus having more than 83 protons, however, can maintain complete stability even with an ample excess of neutrons. The combinations may hold for a time, but they are held in a state of strain, or instability. Disruptive forces tug constantly to break some part of the nucleus away, and every now and then they succeed in doing so. This constitutes a radioactive event. Thus all elements heavier than bismuth are naturally radioactive.

Families of Radioactive Decay

In only a very few cases do naturally radioactive nuclei relieve all strain and become lead or bismuth by one great change. In most situations, the nuclei have enough holding power to prevent this. Instead, relief proceeds step by step.

All the steps can be grouped in chains or families, as explained earlier in the article. Why the various steps in each chain occur as they do can only be explained in terms of energy relations.

Binding Energies of Nuclei

Whenever anything happens in nature, energy is involved. Therefore, a fundamental fact about any nucleus is the amount of the binding energy which holds it together. In general, this might be learned by determining how much work it would take to break down the nucleus into its separate particles. Physicists, however, get at the answer "the other way around"— by determining what must have gone into forming the nucleus.

This method depends upon a fact which can be described by a comparison in human affairs. Often among people, a good team gets along with less effort than is required to maintain the members separately. This same difference exists between nuclear particles existing separately and those organized as a "team" in a nucleus. The team gets along with less total energy than would be associated with the particles existing singly. (The excess is discharged, when the nucleus is formed, by radiating it away.)

A simple clue to how much less energy the nucleus needs is given by the Einstein relation between energy and mass: $E = mc^2$. This tells us that any change in the energy (E) associated with mass (m) will be matched by a corresponding change in the mass itself. (In the equation, c represents the speed of light.) Consequently, when total energy is reduced by formation of a nucleus, it should be matched by a reduction in the total mass. A simple example is afforded by helium (${}_2\text{He}^4$).

For such computations, physicists use mass units, closely related to actual masses of neutrons and protons. One unit is so tiny, it would take about 5,855 billion billion of them to weigh one ounce. The mass-unit value of a separate proton is 1.0076; and of a neutron, 1.0089. Thus the four particles in a helium nucleus, taken separately, have a mass value of 4.0330 atomic units. Experiments with the mass spectroscopy, however, prove that the value of the helium nucleus in mass units is only 4.0028. There has been a mass loss in binding of 0.0302. From this figure, the Einstein relation gives the reduction in total energy which occurs as a consequence of forming the nucleus.

Binding energies for other nuclei can be established similarly. In general, the greater the reduction of total energy (that is, the higher the binding energy) the more firmly the nucleus is held together, and the more work would be needed to break it into separate particles. The amount of binding energy for each particle in a nucleus (proton or neutron) ranges from 5.3 million electron volts for lithium (${}^6_3\text{Li}$) to about 8.7 mev. (million electron volts) in elements near iron (${}^{56}_{26}\text{Fe}$) in the Periodic Table. It decreases slowly for heavier elements to 7.94 mev. for uranium (${}^{238}_{92}\text{U}$).

Stability and Instability

Relations among binding energy, electrostatic repulsion, and the motions of the nuclear particles determine whether or not a nucleus will be stable. Older theories could not explain these relations satisfactorily, because they treated the masses, forces, and energies involved in a way that gave only one answer in a nuclear situation. This could not explain radioactivity, because under such a view, nuclei would hold together permanently or not at all. The modern theory of wave mechanics removes this difficulty with a more flexible treatment of interactions (see energy; matter).

According to wave mechanics, the outcome of any given relation between particles in a nucleus can vary millions of times a second through certain ranges. Results under older theories often turn out to be averages of the variations. (More correctly the results under the older theories are the most likely, or most probable, which occur as a given relation runs through its possible variations.)

As a rule, what happens depends upon how these averages match up. In many of the atoms in nature having 83 protons or less, the margin of holding power is sufficient to keep the atom stable, because no variations can be extreme enough to produce a breakout for some one particle. In atoms having 84 protons or more, however, electrostatic repulsion is great enough to make the margin very thin, and occasional breakouts can occur. How often this happens depends upon how often extreme variations match up in the necessary way. This explains the different half-lives of the radioactive elements.

Radioactive Half-Lives

Radioactive elements decay at different rates. Rates are measured as half-lives—that is, the time it takes for one half of any given quantity of a radioactive element to disintegrate. The longest common half-life is that of uranium 238. It is 4.5 billion years. The half-life of radium 226 is 1,602 years. Some isotopes have half-lives of minutes, seconds, or even less than millionths of a second. Isotopic half-lives are used in radioactive dating to determine the age of rocks in the Earth.

An important feature of half-lives is that the second half does not decay completely in the second half-life. Only one one half of the remainder does; and of what is left, only one half decays in the next half-life.

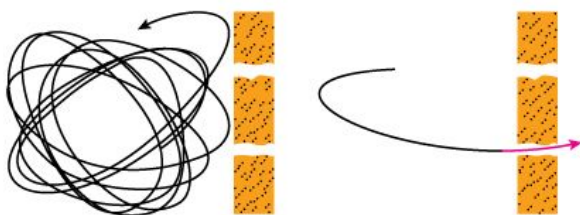
All this follows from the fact that the rate of decay is fixed by how often the favorable variations which permit escape occur. Each atom takes its chance as to when this will happen to it. If a half-life is 1,000 years, for example, and an atom has survived 1,000 years without an emission, this does not mean that it is next in turn. This still depends upon whether or not the escape combination of circumstances will occur for it in the next 1,000 years. Immense numbers of atoms must be involved before the law of averages can establish a rate of disintegration for the atoms involved. Thus in any mass of radioactive atoms, some will last almost indefinitely, even though the overall number diminishes constantly. Hence traces of any element having a fairly long half-life can be found in archaeological or rock samples today, in spite of the immense lapse of time since the universe began.

The Process of Alpha-Ray Emission

The emission of an alpha particle is a drastic radioactive change. It carries away two neutrons and two protons with their charges as well as the kinetic energy carried by the escaping particle. It may be that the emission consists of a helium nucleus instead of one or more protons, because protons and neutrons tend to group themselves firmly in this way, even in a nucleus. This, however, is by no means certain.

Kinds of radioactive decay

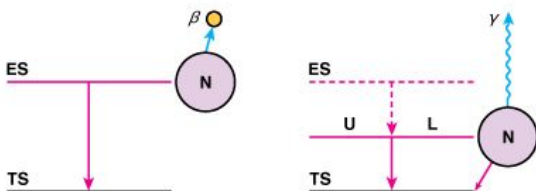
Here (left) variations in the state of an alpha particle are represented as swings of different shapes and size, while the force that holds the particle to the nucleus is a wall with holes. Swings that reach the barrier usually hit the wall; but if one of them hits a hole the particle escapes (right).



Here (below left) a radioactive nucleus is at its ground level (GL) of energy. When it emits an alpha particle, the remaining nucleus (below right) will be in an excited state (ES). The nucleus then must discharge some excess energy.



The nucleus can reach temporary stability (TS) by emitting a beta ray (below left). This might, however, just bring the nucleus to an unstable level (UL). By emitting a gamma ray photon (γ), it may then achieve temporary stability (below right).



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Shown are the ways nuclei give off the alpha, beta, and gamma rays that appear in natural radioactivity.

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The favorable combination of variations which permits the escape of an alpha particle can be explained simply by picturing the particle as whirling about within the nucleus. The restraining nuclear force may be considered as a wall, or barrier, surrounding the nucleus at a certain distance.

Under older theories, this wall would be solid and unchangeable, and the alpha particle would have enough energy to get through quickly or not at all. Modern theory considers the restraining force subject to variation; and the variation can be thought of as opening holes or tunnels in the wall.

Usually, in its whirlings about, the alpha particle strikes a solid part of the wall and is turned back. (More accurately, conditions are such that the restraining force is effective.) Every so often, however, the particle may strike a hole, get through, and escape. The difference in half-lives depends upon how often this occurs.

Emission of Beta Particles

Before an alpha emission, the nucleus had a ratio of neutrons and protons which would usually hold it together against the whirlings of the alpha particles (or the particles which make them up). As long as the nucleus remains undisturbed, its energy state under these conditions is often called its ground level.

An alpha emission carries away an equal number of neutrons and protons and reduces the restraining ratio of neutrons to protons slightly. This affects the restraining force unfavorably, and something must occur to change the nucleus to an arrangement that will be more nearly stable.

Some situations provide opportunity for doing this by emitting another alpha particle. Others favor the emission of an electron, with its negative charge, as a beta particle. The source of the electron is an outstanding feature of the modern theory. Complicated but well-established reasons tell us that it could not have existed in the nucleus before the emission. It must therefore be created at the instant of emission, by drawing it from a neutron. As a result, the neutron changes to a proton. This raises the atomic number by one and makes the neutron-proton ratio more favorable. The diagram of the uranium-radium series shows the zigzag progress of atomic numbers from 92 to 90, back to 92, and down to 90 again.

As a radioactive nucleus decays toward lead, it emits alpha particles until the neutron-proton ratio becomes too great. Then the nucleus steps up in atomic number with one or more beta emissions, before it emits an alpha particle again. Uranium I 238 drops by alpha emission to thorium 234 (formerly called uranium X_1), then comes back by two beta emissions to uranium II 234 before it transmutes to thorium 230 (ionium). Other zigzagging occurs until stability is reached in the element lead.

The Neutrino and Gamma Rays

Emission of a beta particle produces an energy change in the nucleus. The observed energy changes, however, do not add up to satisfy the principle that energy must be conserved. (Physicists believe that the law of conservation of energy must hold true in all situations.) The conservation law can be balanced if another particle, called a neutrino, is a part of the beta emission process. Proposed in 1931 by Wolfgang Pauli and first observed in 1956, neutrinos either have no mass or a negligible amount of mass. They have no electrical charge and are believed to travel at the speed of light. Neutrinos react very little with matter—only rarely do they react with protons or neutrons through a force called the weak force. Their discovery enabled scientists to work out a conservation of energy, spin, and momentum for beta decay.

There are six kinds of neutrinos, depending upon the subatomic particles (leptons) with which they are associated: electron antineutrinos with electrons, electron neutrinos with positrons, muon neutrinos and antineutrinos with muon reactions, and tau neutrinos and antineutrinos with massive tau particles.

Excess energy in a nucleus can also be relieved by emission of gamma rays. This electromagnetic radiation carries less energy than would be discharged by an alpha or beta particle emission. In natural radioactivity,

gamma rays are emitted in situations that do not require energy losses sufficient for a particle emission but offer adequate energy loss for nuclear stability. (See *also* atomic particles; matter.)

These natural radioactive processes suggest that radioactivity can be induced in naturally stable elements if means can be found to hurl particles at the nuclei with sufficient energy to bring about a transmutation. In fact, nature provides a means for doing this to light elements by using alpha particles from naturally radioactive substances. The development of particle accelerators finally made it possible for physicists to transmute every element.

Particle accelerators generally are of two types: linear and circular. In linear accelerators, stationary targets composed of elements are bombarded by alpha particles, neutrons, protons, electrons, deuterons (deuterium nuclei), and the nuclei of larger atoms such as carbon. Recent developments at circular accelerator laboratories have enabled scientists to produce antimatter particles, such as antiprotons, and accelerate them in directions opposite those of protons. When these two-particle clusters are smashed together, the energies of collision are effectively doubled.

The Electron's Opposite—the Positron

Accelerator laboratories are frequently used to produce antimatter such as positrons (identical to electrons but with a positive electrical charge). When bombarded in an accelerator, neutrons may produce a proton, a negative beta ray or electron, and an electron antineutrino.

Similarly bombarded, a proton may produce a neutron, a positron, and an electron neutrino. When an extremely high-energy gamma ray is passed through a very strong electric field, such as that found near an atomic nucleus, it may be converted into a pair—that is, an electron and a positron. Conversely, when a positron collides with a free or loosely held electron, two gamma-ray photons are produced, which fly away in opposite directions from the point of collision. The positron-electron pair ceases to exist. The results of these events have been observed experimentally and confirm the hypothesis, proposed by Einstein and others, that matter can be converted to energy, and vice versa.

Uses of Radioactive Elements

The ability to transmute any element has enabled scientists to produce radioactive forms of the common elements. Through food, these can enter into the tissues of the body. These radioactive isotopes, or radioisotopes, react chemically in the same way as do stable elements, and the body accepts them readily. Once in the body, the progress of the elements can be traced with detection devices. Thus scientists are able to use these tagged elements to trace vital processes with extreme accuracy. Elements are selected according to whether or not they have special affinity for blood, bones, brain, or other tissues. Radioactive elements also can be selected to enter diseased tissues as an aid in suppressing unwanted cells.

Industry uses radioactive analysis to determine impurities in substances. Radiographs similar to X rays that show a product's structure can reveal defects in products. Radioisotopes are the main energy source for space vehicles operating too far from the sun for the effective use of solar energy systems.

Units for Measuring Radioactivity

The unit of measurement of the radioactivity of a substance is the curie. One curie equals about 37 billion emissions per second. Matter emitting half of this amount per second would represent $\frac{1}{2}$ curie of radiation.

Another unit of measurement used in radioactivity is the radius (rho) of the nucleus. The value of rho for a particular element is approximated by multiplying 1.2×10^{-15} meter by the cube root of the element's atomic number, the number of protons in the nucleus. (1.2×10^{-15} meter would have to be multiplied by about 20 trillion to equal 1 inch.) Using this formula and the fact that a nucleus is roughly spherical, it follows that the density of particles is about the same in all nuclei. This density is incredibly high. If a cubic centimeter of matter were as dense as this, it would weigh about 250 million tons. Neutron stars, which are thought to be the result of supernovas, have densities of this magnitude, with an amount of mass roughly equal to that of the sun packed into a star about 12 miles (19 kilometers) in diameter.

L. Eric Skalinder

Additional Reading

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ARTICLE

radium

One of the most significant discoveries made in the last years of the 19th century was that of the radioactive element radium. Study of this rare element revolutionized scientific views about the nature of matter and brought fame to the young scientist Marie Curie.

Curie's interest was aroused by the discovery, made in 1896 by Henri Becquerel, that compounds of uranium exhibit radioactivity. She began experiments with different compounds of uranium and other chemical elements for possible radioactivity.

An ore of uranium, pitchblende, proved to be three or four times as radioactive as uranium oxide. Curie reasoned that some previously unknown element must be present in the mineral to produce this radioactivity. Aided by her husband, the French physicist Pierre Curie, she searched for this substance. In July 1898 the Curies announced the existence of a chemical element about 400 times as radioactive as uranium. This element was precipitated with compounds of bismuth, indicating its chemical similarity to bismuth. Curie named the new element polonium in honor of her native Poland.

In their work with pitchblende the Curies had found that another radioactive substance was separated from the ore along with barium compounds. By repeated fractional crystallization of barium chloride, the Curies formed a crystalline substance with some 900 times the radioactivity of uranium. Since the Curies knew that barium was

not radioactive, they concluded that still another element was the source of the radioactivity. They announced in December 1898 the existence of a radioactive element that they called radium.

In 1902 Marie Curie succeeded in isolating one-tenth of a gram of radium chloride that was entirely free from barium. Pure radium alone was not isolated until 1910 by Curie and André-Louis Debierne. The radioactivity of pure radium proved to be more than 1 million times as great as that of either uranium or thorium.

Properties and Uses of Radium

Radium is a brilliant white metallic element with a valence of +2 (seechemistry). In pure form it decomposes water, turns black in air, and reacts readily with acids. Radium has four naturally occurring radioactive isotopes, but others can be produced in the laboratory. The main natural isotope has a half-life of 1,620 years.

Pierre Curie deliberately burned himself with radium to study its actions on the body. At first the dangers of radium were not realized, and many workers died from radiation effects. Today workers who handle radium are protected by thick shields of lead or concrete. Scintillation counters are used to detect any escaping radiation.

The most commonly used forms of radium are such salts as radium chloride and radium bromide. Their primary use is in the treatment of cancer. Among the usual devices for applying radium are tiny glass containers called seeds. These are filled with minute amounts of radium or radon, a radioactive gaseous element formed in the disintegration of radium. Sometimes relatively large amounts of radium are used in so-called bombs—lead containers on mounts resembling those used for X-ray tubes. In many therapeutic applications, however, radium has been replaced by the less costly and more powerful artificial isotopes cobalt-60 and cesium-137.

In industry, radium sulfate may be employed in radiographic testing instruments used to detect flaws in metals. Radium compounds are also used in luminous paints. A mixture of radium and beryllium, a source of neutrons, is used in scientific research and in geophysical prospecting for petroleum. Even for these uses, less expensive substitutes are available.

The Preparation of Radium from Its Ores

Radium is present in minute quantities in all uranium ores because it is a product of the decay of uranium. The main commercial source is pitchblende, a black, heavy, noncrystalline uranium mineral. Others are uraninite, a gray-black, crystalline uranium ore; carnotite, a bright yellow, soft mineral; and autunite, a greenish to lemon yellow, fluorescent mineral.

Radium is extracted commercially from its ores by methods similar to those used by the Curies. The ore is crushed and digested in acids, with a barium salt added to act as a carrier for the radium. The precipitates are then boiled and treated with chemicals. Finally, the radium salt is separated from the barium compound to the desired purity by repeated fractional crystallization.

Citation (MLA style):

"Radium." *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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IMAGE

Pierre and Marie Curie



Pierre and Marie Curie on their honeymoon bicycle trip, 1895.

Photos.com/Jupiterimages

Citation (MLA style):

Pierre and Marie Curie. Image. *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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IMAGE

Marie, Ève, and Irène Curie



Marie Curie poses with her daughters, Ève (left) and Irène (right).

© [Photos.com/Jupiterimages](https://www.photos.com/jupiterimages)

Citation (MLA style):

Marie, Ève, and Irène Curie. Image. *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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Marie Curie driving a mobile radiological unit, 1914



Marie Curie driving a Renault automobile converted into a mobile radiological unit, 1914. Curie used these vehicles, which became known as *petites Curies*, to bring X-ray equipment to wounded soldiers at the front during World War I.

Photos.com/Getty Images

Citation (MLA style):

Marie Curie driving a mobile radiological unit, 1914. Image. *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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Curie, Marie and Pierre; medal

Britannica Note:

The discovery of radioactivity by Henri Becquerel in 1896, inspired Pierre and Marie Curie in their research, which led to the isolation of polonium and radium.



Pierre and Marie Curie depicted on the obverse of a medal from the Unio Internationalis Contra Cancrum (International Union Against Cancer) commemorating the Curies' discovery of radium in 1898.

© Photos.com/Jupiterimages

Citation (MLA style):

Curie, Marie and Pierre; medal. Image. *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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VIDEO

Marie Curie

Video Transcript

Hello, my name is Marie Curie, and I'm going to draw my life. No, that's Mariah Carey. Ah, that's much better. I was born Maria Skłodowska, in Poland, on 7 November 1867. I came from a very poor family and was the youngest of five. My parents were teachers, so made sure we appreciated the value of learning. My sister died of typhus when I was eight, and my mother died of tuberculosis when I was 10, but my dad made sure I stayed in

school. And I turned into a top student facing a world of opportunity. At least I would have if girls were allowed to go to university in Poland in the 1800s. So, my sister and I joined an illegal underground organization, a secret university which did let women in. As they say, you just have to keep calm and Curie on. I loved it there. But I knew to get a proper education, I'd need to go to a proper university. So, I spent years teaching, and saving enough money to study in Paris. [SPEAKING FRENCH] I worked really hard there and earned master's degrees in both physics and maths. On the inside, I was beaming-- honest. To continue my research, I needed to find a laboratory, which is how I met Pierre Curie, who had some space we could work in. And boy, did we work! We fell in love over our passion for science and were soon married. Talk about serious chemistry! We would have two daughters, but that's more to do with biology and physical science. When it was discovered that certain minerals gave off mysterious rays, I decided to investigate. I called this property radioactivity. Yes, that was me. I made up that word. No biggie. One of the minerals I studied was called pitchblende. Even though it contained uranium, it seemed to have unusually high levels of radioactivity. Man, I love that word. I realized this meant it must contain another, even more radioactive element, that no one had ever seen before. Pierre gave up his research to help me investigate, and together, we discovered not one, but two, new elements, radium and polonium. Then, I figured out that radium could be used to kill cancerous cells, and people got a bit carried away. Soon, they were proclaiming this dangerous glowing element to have miraculous healing properties. They put it in everything from cough syrups to lipstick, alarm clocks, and chocolate. It even went into children's toys. Oops. But that wasn't my fault. And Pierre and I won the Nobel Prize for physics in 1903 for our work in radioactivity. I was the first woman to win a Nobel Prize. That is rad science. Just when we had hit the scientific big time, Pierre was hit by a horse-drawn wagon and killed instantly. I was devastated, but determined to carry on our important work. In memory of my husband, I helped set up the Radium Institute, which aimed to use radiation to help people with cancer. And guess what, I won another Nobel Prize in chemistry. That made me the first person ever to win two Nobel Prizes. Another first! How about that for girl power? Then World War I broke out. I used my scientific knowledge to help the troops. I raised money to build a fleet of x-ray wagons that could be taken to the battlefield and used to diagnose millions of wounded soldiers. I refused to make profit from my work and I was soon too poor to buy the radium I needed for my research. When the public found out about this, they campaigned to make sure I could get all the radium I needed. Thanks folks. Even the president of the United States gave me a gram of this stuff. This might not sound like much, but its value would be equivalent to about a million pounds in today's money. Unfortunately, my work had exposed me to dangerous levels of radioactivity. Did this turn me into a superhero with radioactive powers? No, sadly not. It killed me. My papers are even radioactive today. OK, so I had some tragedies in my life, but I never gave up. My work in radioactivity has helped treat millions suffering with cancer. If you study maths and physics, then who knows? Maybe you could change the world, too.

Learn about the life of scientist Marie Curie, famous for her work on radioactivity and twice a winner of the Nobel Prize.

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Citation (MLA style):

Marie Curie. Video. *Britannica LaunchPacks: Marie Curie*, Encyclopædia Britannica, 23 Mar. 2025. packs.eb.com. Accessed 4 May. 2025.

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The Nobel Prize - Marie Curie

<https://www.nobelprize.org/prizes/physics/1903/marie-curie/facts/>

Britannica Note:

Marie Curie is the only woman in history to have won the Nobel prize in two different fields. Learn more about her research by visiting the site of the Nobel Prize organization.

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