

The Discovery Of Radioactivity: The Dawn of the Nuclear Age

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One hundred years ago, a group of scientists unknowingly ushered in the Atomic Age. Driven by curiosity, these men and women explored the nature and functioning of atoms. Their work initiated paths of research which changed our understanding of the building blocks of matter; their discoveries prepared the way for development of new methods and tools used to explore our origins, the functioning of our bodies both in sickness and in health, and much more. How did our conceptions of atomic properties change? How has that change affected our lives and our knowledge of the world?

Atoms and Elements: A Beginning

Elements are the building blocks of matter. The smallest particle of an element that still retains the identity of that element is the atom. All atoms of a given element are identical to one another, but differ from the atoms of other elements. Ancient Greeks first predicted the existence of the atom around 500 BC. They named the predicted particle 'atomos,' meaning "indivisible."

In 1803, John Dalton (1766-1844) proposed a systematic set of postulates to describe the atom. Dalton's work paved the way for modern day acceptance of the atom. But scientists of his day considered the atom to be merely a subordinate player in chemical reactions, an uninteresting, homogeneous, positively charged "glob" that contained scattered electrons. That premise remained unchallenged until the end of the nineteenth century, when a series of brilliant discoveries opened the door on the atomic science of the twentieth century. Working concurrently and often collaboratively, three pioneering scientists helped release the genie of the atom.

Antoine Henri Becquerel

Becquerel, a French physicist, was the son and grandson of physicists. Becquerel was familiar with the work of [Wilhelm Conrad Roentgen](#) on December 22 1895, "photographed" his wife's hand, revealing the unmistakable image of her skeleton, complete with wedding ring. Roentgen's wife had placed her hand in the path of X-rays which Roentgen created by beaming an electron ray energy source onto a cathode tube. Roentgen's discovery of these "mysterious" rays capable of producing an image on a photographic plate excited scientists of his day, including Becquerel. Becquerel chose to study the related phenomena of fluorescence and phosphorescence. In March of 1896, quite by accident, he made a remarkable discovery.

Becquerel found that, while the phenomena of fluorescence and phosphorescence had many similarities to each other and to X-rays, they also had important differences. While fluorescence and X-rays stopped when the initiating energy source was halted, phosphorescence continued to emit rays some time after the initiating energy source was removed. However, in all three cases, the energy was derived initially from an outside source.

In March of 1896, during a time of overcast weather, Becquerel found he couldn't use the sun as an initiating energy source for his experiments. He put his wrapped photographic plates away in a darkened drawer, along with some crystals containing uranium. Much to his surprise, the plates were exposed during storage by invisible emanations from the uranium. The emanations did not require the presence of an initiating energy source--the crystals emitted rays on their own! Although Becquerel did not pursue his discovery of radioactivity, others did and, in so doing, changed the face of both modern medicine and modern science.

The Curies: Lives Devoted to Research

Working in the Becquerel lab, Marie Curie and her husband, Pierre, began what became a life long study of radioactivity. It took fresh and open minds, along with much dedicated work, for these scientists to establish the properties of radioactive matter. Marie Curie wrote, "The subject seemed to us very attractive and all the more so because the question was entirely new and nothing yet had been written upon it."

Becquerel had already noted that uranium emanations could turn air into a conductor of electricity. Using sensitive instruments invented by Pierre Curie and his brother, Pierre and Marie Curie measured the ability of [emanations from various elements](#) to induce conductivity. On February 17, 1898, the Curies tested an ore of uranium, pitchblende, for its ability to turn air into a conductor of electricity. The Curies found that the pitchblende produced a current 300 times stronger than that produced by pure uranium. They tested and recalibrated their instruments, and yet they still found the same puzzling results. The Curies reasoned that a very active unknown substance in addition to the uranium must exist within the pitchblende. In the title of a paper describing this hypothesized element (which they named polonium after Marie's native Poland), they introduced the new term: "radio-active."

After much grueling work, the Curies were able to extract enough polonium and another radioactive element, radium, to establish the chemical properties of these elements. Marie Curie, with her husband and continuing after his death, established the first quantitative standards by which the rate of radioactive emission of charged particles from elements could be measured and compared. In addition, she found that there was a decrease in the rate of radioactive emissions over time and that this decrease could be calculated and predicted. But perhaps Marie Curie's greatest and most unique achievement was her realization that radiation is an atomic property of matter rather than a separate independent emanation.

Despite the giant step forward which science had now taken in its understanding of radioactivity, scientists still understood little of the structure of the atom. This understanding awaited the work of Ernest Rutherford.

Ernest Rutherford and the Atom

In 1911, Rutherford conducted a series of experiments in which he bombarded a piece of gold foil with positively charged [\(alpha\) particles](#) emitted by radioactive material. Most of the particles passed through the foil undisturbed, suggesting that the foil was made up mostly of empty space rather than of a sheet of solid atoms. Some alpha particles, however, "bounced back," indicating the presence of solid matter. Atomic particles, Rutherford's work showed, consisted primarily of empty space surrounding a well-defined central core called a nucleus.

In a long and distinguished career, Rutherford laid the groundwork for the determination of atomic structure. In addition to defining the planetary model of the atom, he showed that radioactive elements undergo a process of decay over time. And, in experiments which involved what newspapers of his day called "splitting the atom," Rutherford was the first to artificially transmute one element into another--unleashing the incredible power of the atom which would eventually be harnessed for both beneficial and destructive purposes.

Taken together, the work of Becquerel, the Curies, Rutherford and others, made modern medical and scientific research more than a dream. They made it a reality with many applications. A look at the use of isotopes reveals just some of the ways in which the pioneering work of these scientists has been utilized.

Applications: Isotopes in Research and Medicine

Scientists can now create radioactive forms of [common elements](#), called [isotopes](#). Each isotope has a fixed rate of decay which can be characterized by its half-life, or the length of time that it takes half of the radioactive atoms in a sample to decay. Because each isotope decays at a unique and predictable rate, different isotopes can be used for a variety of purposes. For example, isotopes play an important role in [modern medicine](#). They can be ingested and traced in their path through the body, revealing biochemical and metabolic processes with precision. These isotropic "tracers" are currently used for practical diagnosis of disease as well as in research.

The dating of radioactive carbon has helped to define the history of life on this planet. Any living organism takes in both radioactive and non-radioactive carbon, either through the process of photosynthesis or by eating plants or eating animals that have eaten plants. When the animal dies, however, uptake of carbon stops. As a result, radioactive carbon atoms are not replaced as they decay, and the amount of this material decreases over time. The rate of decrease is predictable and can be described with accuracy, vastly increasing our ability to date the biological events of our planet.

Conclusion: The Contradictions of Radioactivity

Radiation is a two edged sword: its usefulness in both medicine and anthropological and archaeological studies is undisputed, yet the same materials can be used for destruction. Human curiosity drove inquiring scientists to harness the power of the atom. Now humankind must accept the responsibility for the appropriate and beneficial uses of this very powerful tool.

<http://www.accessexcellence.org/AE/AEC/CC/radioactivity.php>

Radioactivity: Historical Figures

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This article will focus on the efforts of four scientists: Wilhelm Conrad Roentgen, Antoine Henri Becquerel, Marie Skłodowska Curie, and Ernest Rutherford. It emphasizes their contributions to the elucidation of radioactivity and the "key" experiments they performed pertaining to their discoveries. The biographies and photographs are adapted from The Health Physics Society Centennial Calendar by permission of the Health Physics Society.

Wilhelm Conrad Roentgen (1845-1923)

On November 8, 1895, at the University of Wurzburg, Wilhelm Roentgen's attention was drawn to a glowing fluorescent screen on a nearby table. Roentgen immediately determined that the fluorescence was caused by invisible rays originating from the partially evacuated glass Hittorf-Crookes tube he was using to study cathode rays (i.e., electrons). Surprisingly, these mysterious rays penetrated the opaque black paper wrapped around the tube. Roentgen had discovered X rays, a momentous event that instantly revolutionized the field of physics and medicine.

However, prior to his first formal correspondence to the University Physical-Medical Society, Roentgen spent two months thoroughly investigating the properties of X rays. Silvanus Thompson complained that Roentgen left "little for others to do beyond elaborating his work." For his discovery, Roentgen received the first Nobel Prize in physics in 1901. When later asked what his thoughts were at the moment of his discovery, he replied "I didn't think, I investigated. "It was the crowning achievement in a career beset by more than its share of difficulties.

As a student in Holland, Roentgen was expelled from the Utrecht Technical School for a prank committed by another student. Even after receiving a doctorate, his lack of a diploma initially prevented him from obtaining a position at the University of Wurzburg. He even was accused of having stolen the discovery of X rays by those who failed to observe them.

Nevertheless, Roentgen was a brilliant experimentalist who never sought honors or financial profit for his research. He rejected a title (i.e., von Roentgen) that would have provided entry into the German nobility, and donated the money he received from the Nobel Prize to his University. Roentgen did accept the honorary degree of Doctor of Medicine offered to him by the medical faculty of his own University of Wurzburg. However, he refused to take out any patents in order that the world could freely benefit from his work. At the time of his death, Roentgen was nearly bankrupt from the inflation that followed World War I.

Antoine Henri Becquerel (1852-1908)

Henri Becquerel was born into a family of scientists. His grandfather had made important contributions in the field of electrochemistry while his father had investigated the phenomena of fluorescence and phosphorescence. Becquerel not only inherited their interest in science, he also inherited the minerals and compounds studied by his father. And so, upon learning how Wilhelm Roentgen discovered X rays from the fluorescence they produced, Becquerel had a ready source of fluorescent materials with which to pursue his own investigations of these mysterious rays.

The material Becquerel chose to work with was potassium uranyl sulfate, $\text{K}_2\text{UO}_2(\text{SO}_4)_2$, which he exposed to sunlight and placed on photographic plates wrapped in black paper. When developed, the plates revealed an image of the uranium crystals. Becquerel concluded "that the phosphorescent substance in question emits radiation which penetrates paper opaque to light." Initially he believed that the sun's energy was being absorbed by the uranium which then emitted X rays.

Further investigation, on the 26th and 27th of February, was delayed because the skies over Paris were overcast and the uranium-covered plates Becquerel intended to expose to the sun were returned to a drawer. On the first of March, he developed the photographic plates expecting only faint images to appear. To his surprise, the images were clear and strong. This meant that the uranium emitted radiation without an external source of energy such as the sun. Becquerel had discovered radioactivity, the spontaneous emission of radiation by a material.

Later, Becquerel demonstrated that the radiation emitted by uranium shared certain characteristics with X rays but, unlike X rays, could be deflected by a magnetic field and therefore must consist of charged particles. For his discovery of radioactivity, Becquerel was awarded the 1903 Nobel Prize for physics.

Pierre Curie (1859-1906)**Marie Curie (1867-1934)**

By the time he met Marie Sklodowska, Pierre Curie had already established an impressive reputation. In 1880, he and his brother Jacques had discovered piezoelectricity whereby physical pressure applied to a crystal resulted in the creation of an electric potential. He also had made important investigations into the phenomenon of magnetism including the identification of a temperature, the Curie point, above which a material's magnetic properties disappear. However, shortly after his marriage to Marie in 1895, Pierre subjugated his research to her interests.

Together, they began investigating the phenomenon of radioactivity recently discovered in uranium ore. Although the phenomenon was discovered by Henri Becquerel, the term radioactivity was coined by Marie. After chemical extraction of uranium from the ore, Marie noted the residual material to be more "active" than the pure uranium. She concluded that the ore contained, in addition to uranium, new elements that were also radioactive. This led to their discoveries of the elements of polonium and radium, but it took four more years of processing tons of ore under oppressive conditions to isolate enough of each element to determine its chemical properties.

For their work on radioactivity, the Curies were awarded the 1903 Nobel Prize in physics. Tragically, Pierre was killed three years later in an accident while crossing a street in a rainstorm. Pierre's teaching position at the Sorbonne was given to Marie. Never before had a woman taught there in its 650 year history! Her first lecture began with the very sentence her husband had used to finish his last. In his honor, the 1910 Radiology Congress chose the Curie as the basic unit of radioactivity: the quantity of radon in equilibrium with one gram of radium (current definition: 1 Ci = 3.7×10^{10} dps). A year later, Marie was awarded the Nobel Prize in chemistry for her discoveries of radium and polonium, thus becoming the first person to receive two Nobel Prizes. For the remainder of her life she tirelessly investigated and promoted the use of radium as a treatment for cancer. Marie Curie died July 4, 1934, overtaken by pernicious anemia no doubt caused by years of overwork and radiation exposure.

Ernest Rutherford (1871-1937)

Ernest Rutherford is considered the father of nuclear physics. Indeed, it could be said that Rutherford invented the very language to describe the theoretical concepts of the atom and the phenomenon of radioactivity. Particles named and characterized by him include the alpha particle, beta particle and proton.

Even the neutron, discovered by James Chadwick, owes its name to Rutherford. The exponential equation used to calculate the decay of radioactive substances was first employed for that purpose by Rutherford and he was the first to elucidate the related concepts of the half-life and decay constant. With Frederick Soddy at McGill University, Rutherford showed that elements such as uranium and thorium became different elements (i.e., transmuted) through the process of radioactive decay. At the time, such an incredible idea was not to be mentioned in polite company: it belonged to the realm of alchemy, not science.

For this work, Rutherford won the 1908 Nobel Prize in chemistry. In 1909, now at the University of Manchester, Rutherford was bombarding a thin gold foil with alpha particles when he noticed that although almost all of them went through the gold, one in eight thousand would "bounce" (i.e., scatter) back. The amazed Rutherford commented that it was "as if you fired a 15-inch naval shell at a piece of tissue paper and the shell came right back and hit you."

From this simple observation, Rutherford concluded that the atom's mass must be concentrated in a small positively-charged nucleus while the electrons inhabit the farthest reaches of the atom. Although this planetary model of the atom has been greatly refined over the years, it remains as valid today as when it was originally formulated by Rutherford. In 1919, Rutherford returned to Cambridge to become director of the Cavendish laboratory where he had previously done his graduate work under J.J. Thomson. It was here that he made his final major achievement, the artificial alteration of nuclear and atomic structure. By bombarding nitrogen with alpha particles, Rutherford demonstrated the production of a different element, oxygen. "Playing with marbles" is what he called; the newspapers reported that Rutherford had "split the atom." After his death in 1937, Rutherford's remains were buried in Westminster Abbey near those of Sir Isaac Newton.

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