Antoine Henri Becquerel, radioactivity, and the foundations of Nuclear Medicine

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Abstract
Henri Becquerel's discovery of natural radioactivity in 1896 marked a turning point in the history of science and laid the foundation for modern nuclear physics and nuclear medicine. This overview reviews Becquerel's life, his scientific career, and the experiments that led to the identification of spontaneous radiation emitted by uranium compounds. It also highlights the subsequent contributions of Marie and Pierre Curie, who expanded the understanding of radioactivity through the discovery of polonium and radium. Furthermore, the article discusses the early therapeutic applications of radium and the lasting impact of Becquerel's work on diagnostic imaging, radionuclide therapy, and radiation oncology. More than 130 years after his discovery, Becquerel's scientific legacy remains fundamental to contemporary medicine and is commemorated by the SI unit of radioactive activity, the becquerel (Bq).

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Introduction

The second half of the nineteenth century was one of the most transformative periods in the history of science. Rapid advances in physics, chemistry, and engineering fundamentally changed humanity's understanding of the natural world and laid the foundations for many modern technologies. It was during this intellectually vibrant era that Antoine Henri Becquerel (1852-1908) made the remarkable discovery of natural radioactivity, an achievement that profoundly influenced both science and medicine.

Today, radioactivity is indispensable in numerous medical applications, particularly in nuclear medicine and radiation oncology. Diagnostic procedures such as scintigraphy, single-photon emission computed tomography (SPECT), and positron emission tomography (PET), together with therapeutic approaches including receptor- or antibody-mediated radioimmunotherapy and radiosynoviorthesis, all rely on radioactive isotopes. Depending on the radiopharmaceutical employed, diagnostic procedures typically involve administered activities ranging from approximately 3 to 1000 MBq, whereas therapeutic applications require substantially higher activities.

In recognition of Henri Becquerel's pioneering contribution, the International System of Units (*Système international d'unités, SI*) adopted the becquerel (Bq) in 1975 as the derived unit of radioactive activity. One becquerel corresponds to one nuclear decay per second, replacing the previously used unit, the curie (Ci), where 1 mCi=37 MBq.

Biography

Antoine Henri Becquerel was born in Paris on 15 December 1852 into one of France's most distinguished scientific families. For three generations, the Becquerel family made major contributions to physics.

His grandfather, Antoine César Becquerel, and his father, Alexandre Edmond Becquerel, were both eminent physicists and professors [1]. Henri finished school at the *Lycée Louis-le-Grand* and studied at the *École Polytechnique* and the *École des Ponts et Chaussées*. He later became Professor of Physics at the *École Polytechnique* and Chief Engineer in the French Department of Roads and Bridges.

In December 1903, Becquerel shared the Nobel Prize in Physics with Marie Skłodowska Curie and Pierre Curie for their pioneering work on radioactivity.

In 1908, he became President of the *Académie des Sciences* but died later that year at the age of only 55, most likely from complications related to prolonged radiation exposure.

Becquerel´s scientific contributions

Henri Becquerel's early scientific investigations were strongly influenced by the pioneering work of his father as well as by the fundamental studies of Michael Faraday. His initial research focused primarily on the phenomenon of the magnetic rotation of the plane of polarization of light in gases, an area that contributed to the broader understanding of the interaction between electromagnetic phenomena and matter. These early investigations reflected the scientific interests of the late 19th century, when the relationship between light, magnetism, electricity, and the properties of materials was undergoing rapid development.

Following these initial studies, Becquerel expanded his research activities to a variety of physical and chemical phenomena. Among his notable investigations were studies on phosphorescence, the absorption of light by crystalline substances, and, together with Charles Brogniart, research into the green pigmentary substance observed in species of the genus *Phyllium*. Through these diverse investigations, Becquerel developed extensive expertise in optical phenomena, luminescent materials, and the behavior of matter under different forms of energy excitation. This scientific background later proved essential for his groundbreaking observations in the field of radioactivity.

The discovery of X-rays by Wilhelm Conrad Röntgen (1845-1923) in 1895 stimulated considerable interest among physicists worldwide and prompted investigations into whether other forms of penetrating radiation might exist in nature. Inspired by Röntgen's discovery, Becquerel began studying uranium-containing compounds in 1896, initially focusing on their phosphorescent properties and their possible relationship to X-ray emission. During these experiments, he made the remarkable observation that uranium salts were capable of producing a previously unknown type of radiation that could penetrate materials and induce the darkening of photographic plates, even in the absence of external stimulation.

Becquerel demonstrated that this radiation was emitted spontaneously by uranium compounds and was independent of prior exposure to sunlight or any other external energy source. This observation represented a fundamental scientific breakthrough, as it revealed the existence of a new natural phenomenon: the spontaneous emission of radiation from atomic substances. He referred to this phenomenon as "uranium rays," a term that preceded the later concept of radioactivity introduced by Marie and Pierre Curie.

Within the same year, Becquerel published seven scientific communications describing his experimental findings and progressively establishing the characteristics of this newly discovered radiation [2-8]. His systematic observations provided the first evidence that atoms were not necessarily stable, indivisible entities, as had been widely assumed at the time, but could possess intrinsic properties associated with the emission of energy. This discovery subsequently became the foundation of nuclear physics and nuclear medicine, leading to the development of radioactive tracers, diagnostic imaging techniques, and radionuclide-based therapies.

Reflecting on his discovery several years later, Becquerel described his observations in the journal Nature [9], emphasizing the unexpected nature of the phenomenon and the importance of careful experimental investigation in revealing previously unknown properties of matter:

"At the commencement of the year 1896, in carrying out some experiments with the salts of uranium, the exceptional optical properties of which I had been studying for some time, I observed that these salts emitted an invisible radiation, which traversed metals and bodies opaque to light as well as glass and other transparent substances. This radiation impressed a photographic plate… The phenomenon does not appear to be influenced by any known external cause, such as a variation of temperature or a luminous excitation; it is entirely different from phosphorescence; is not weakened in an appreciable manner by time, even at the end of several years; and is emitted spontaneously without any apparent exciting cause."

The Expansion of radioactivity research and Becquerel's contribution to Nuclear Science

Following Henri Becquerel's pioneering discovery of uranium rays, his most renowned doctoral student, Marie Curie, together with her husband Pierre Curie, continued and significantly expanded the investigation of this newly recognized phenomenon. Through systematic studies of uranium minerals and other naturally occurring substances, the Curies demonstrated that the phenomenon was not restricted to uranium alone but was also associated with other chemical elements. In 1898, they discovered two new radioactive elements, polonium and radium, and introduced the term "radioactive" to describe substances capable of spontaneously emitting penetrating radiation.

Early therapeutic applications of radium

The discovery of radium by Marie and Pierre Curie in 1898 rapidly led to investigations into its potential medical applications. Due to its intense radioactive properties and the ability of its emissions to affect biological tissues, radium was soon introduced into clinical practice, marking one of the earliest examples of therapeutic use of a radioactive substance. Initially applied in the treatment of superficial lesions and malignant diseases, radium therapy represented a pioneering step toward the development of modern radiation oncology and later radionuclide-based therapeutic approaches.

Notable historical examples can be found in two musicians of that time: One is the treatment received by the renowned French composer Claude Debussy (1862-1918), who was diagnosed with colorectal cancer. In 1915, during the final years of his life, Debussy underwent radium irradiation as an attempt to alleviate the symptoms associated with his disease. Although the treatment was not curative, it provided symptomatic relief and demonstrated the potential of radioactive substances to influence the course of severe medical conditions [10]. The other example is the Italian opera composer Giacomo Puccini (1858-1924), who suffered from an aggressively growing ("extrinsic") laryngeal carcinoma. The Belgian physician Dr. Louis Ledoux treated the maestro in

Brussels in November 1924 using the latest method available at the time, radium irradiation (which was offered only in Berlin and Brussels), initially through external radiation therapy using a radium collar worn around his neck for several hours at a time, and then surgically via a procedure known as radium implantation, in which seven radioactive needles were inserted into the tumor through the neck, followed by a tracheotomy and the insertion of a nasogastric tube—all performed under local anesthesia. Puccini found this treatment humiliating. Just a few days after this procedure, Puccini died of "heart failure": On the afternoon of November 28, Puccini collapsed unconscious in his armchair. The radioactive needles were removed immediately. A fever had developed as a symptom of tumor breakdown, leading to tachycardia and circulatory collapse. On the night of Friday, November 29, Puccini became restless, repeatedly trying to get out of bed. In the morning, he received the Last Rites from the Apostolic Nuncio, Monsignor Micara. Puccini died a few hours later, shortly before 12:00 noon [11].

The use of radium in such early clinical applications illustrates the rapid translation of fundamental discoveries in physics and chemistry into medical practice. Within only a few decades after Becquerel's discovery of natural radioactivity, radioactive materials had progressed from experimental phenomena to therapeutic agents, establishing the conceptual and technological foundations for contemporary nuclear medicine. These early experiences with radium therapy ultimately contributed to the development of more precise radionuclide-based treatments, in which radioactive emissions are selectively delivered to pathological tissues while minimizing damage to surrounding healthy structures.

The work of Marie and Pierre Curie represented a major conceptual advancement, transforming Becquerel's initial observation into a broader scientific discipline. Their research established that radioactivity was an intrinsic property of certain atoms rather than merely a consequence of external excitation, such as exposure to light or other sources of energy. This fundamental insight marked a turning point in physics and chemistry, challenging traditional concepts of atomic stability and ultimately contributing to the emergence of modern nuclear science.

In 1899, Becquerel returned, in a remarkable conceptual connection to his earlier investigations of the magnetic rotation of the plane of polarized light, to the study of the interaction between radiation and magnetic fields. Applying his expertise in electromagnetic phenomena to the newly discovered uranium radiation, he investigated whether these emissions could be influenced by magnetic forces. His experiments demonstrated that the radiation emitted by uranium-containing materials could be deflected by a magnetic field, providing important evidence that at least part of the radiation consisted of electrically charged particles.

This observation represented a crucial distinction between uranium radiation and Röntgen's recently discovered X-rays. Whereas X-rays appeared to behave as electromagnetic radiation without electric charge, Becquerel's observations indicated that uranium emitted particles carrying an electrical charge. The deflected component was subsequently identified as beta radiation, consisting of high-energy electrons (β-particles). Becquerel's work therefore provided one of the earliest experimental demonstrations that radioactive emissions could consist of material particles rather than solely electromagnetic waves, contributing significantly to the later understanding of atomic structure and radioactive decay.

As mentioned above, for their fundamental contributions to the understanding of radioactivity, Henri Becquerel and Marie and Pierre Curie were jointly awarded the Nobel Prize in Physics in 1903. This recognition acknowledged the complementary nature of their achievements: Becquerel's discovery established the existence of natural radioactivity, while the Curies' subsequent investigations expanded, characterized, and scientifically established the phenomenon through the discovery of new radioactive elements and detailed studies of radioactive properties.

From a historical perspective, Becquerel may therefore be regarded as the scientific pioneer who opened the field of radioactivity, which was subsequently developed and firmly established through the work of the Curie family and other researchers. His discovery created the foundation upon which numerous applications of nuclear science were later built, including radionuclide-based diagnostics, molecular imaging, and targeted radionuclide therapies in nuclear medicine.

It is therefore historically appropriate that the name Becquerel, rather than Curie, became associated with the modern SI-derived unit of radioactive activity [12]. The becquerel (Bq) represents a lasting acknowledgment of Becquerel's fundamental contribution to the discovery of spontaneous nuclear radiation and his role as a pioneer of the scientific field that ultimately evolved into nuclear medicine.

Conclusion

Henri Becquerel was an exceptionally productive and dedicated scientist whose contributions extended far beyond his pioneering discovery of natural radioactivity. Throughout his scientific career, he published extensively across several areas of physics, demonstrating remarkable versatility and a sustained commitment to experimental investigation. His scientific achievements were recognized internationally, and even during his lifetime he received numerous honors, prizes, and distinctions in addition to the Nobel Prize in Physics. He was widely respected not only within the European scientific community but also across the Atlantic, where his work was acknowledged as a fundamental contribution to the advancement of modern physics.

Becquerel's discovery of spontaneous radioactivity represented a milestone in the history of science and had profound consequences for the development of medicine. By revealing that certain elements could emit radiation independently of external stimulation, he opened the way for the systematic study of radioactive substances and established the scientific foundation for the subsequent development of nuclear technologies. The principles derived from his observations ultimately enabled the application of radionuclides in medicine, including diagnostic imaging with radiopharmaceuticals, molecular characterization of disease processes, and targeted radionuclide therapies.

Beyond its immediate medical relevance, Becquerel's discovery also played a decisive role in shaping modern atomic physics. His findings contributed to the gradual transformation of the classical concept of the atom as an indivisible and immutable structure into the modern understanding of atoms as dynamic systems capable of undergoing nuclear transformations. Together with the subsequent discoveries of Marie and Pierre Curie and other pioneers of nuclear science, Becquerel's work initiated a new era of research into the structure of matter, nuclear interactions, and the nature of energy.

Now 130 years after his discovery, Henri Becquerel's scientific legacy remains deeply embedded in contemporary nuclear medicine and nuclear science. The SI unit of radioactive activity bearing his name, the becquerel (Bq), serves as a permanent reminder of his fundamental contribution to the discovery of radioactivity and—as we think—his role as one of the founding figures of a field that continues to provide invaluable diagnostic and therapeutic benefits to patients worldwide [13].

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