# A Postage Stamp History of the Atom, Part II: The Quantum Era

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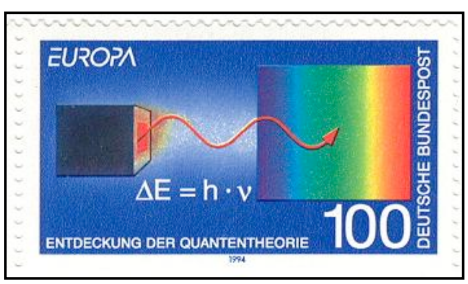
At the turn of the century some physicists were convinced that we had discovered all that there was to discover. All that was left was to get some more significant digits added to our constants and modify a few equations to better explain some phenomena. One physicist working to better explain certain experimental observations was a German named Max Planck (1858-1947) **[1]**. He was trying to understand the Ultraviolet Catastrophe (probably better called the Ultraviolet Anomaly). In the ultraviolet region the spectral energy distribution could not be explained. Rayleigh and Jeans had developed a mathematical treatment of the energy given off by such radiation. Planck was in search of an equation that would explain the energy and frequency of all electromagnetic radiation with one equation. On December 14th, 1900, Planck presented his idea in front of the German Physical Society. It was the first time that the concept of *quantized* radiation was presented to the public. He proposed that energy behaved according to the equation $E = h\nu$ **[2]**, where h is a constant **[3]**, E is the energy of a photon, and $\nu$ is the frequency of the photon. This talk is generally considered to be the birth of the quantum era.


**[1]**

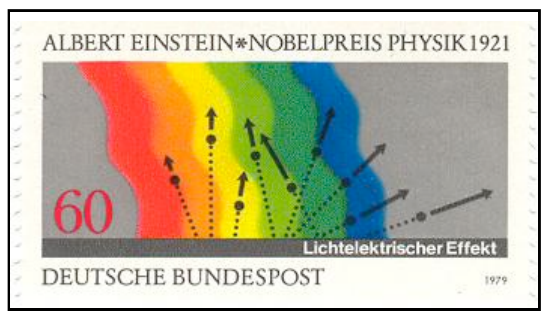



**[2]**


**[3]**

One individual very quick to support Plank's ideas was a young patent clerk in Switzerland named Albert Einstein (1879-1955) **[4]**. Unable to obtain an academic position after getting his degree, Einstein had gone to work at the patent clerks office where he was able to finish his daily duties very quickly and had time to work on his theories, one involving the Photoelectric Effect. The Photoelectric Effect **[5]** was a phenomenon first observed by Heinrich Hertz (1857-1894) **[6]** while he was working to confirm Maxwell's *Theory of the Electromagnetic Nature of Light*. When ultraviolet light strikes the surface of a metal it causes electrons to be emitted from the surface of the metal. It was later shown that visible light of certain wavelengths causes the effect, specifically the higher energy end of the spectrum, but not low energy visible light. Einstein was able to use the idea of quantized energy to show that when photons of the higher energy end of the spectrum strike the surface of a metal they cause electrons to be ejected like a billiard ball striking another billiard ball. However the lower energy light did not posses enough energy to eject the electrons. This was the work for which Einstein received the Nobel Prize.


**[4]**

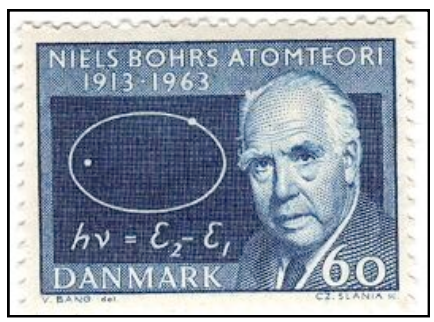



**[5]**


**[6]**

At this point our picture of the atom was still very similar to the picture given by John Dalton in 1808, a hard dense sphere of relatively uniform density. Then J. J. Thomson advanced the idea in the 1890's with his *plum pudding* model that showed some difference with electrons being disbursed throughout the atom. A truly new model of the atom came from a former student of Thomson's called Ernest Rutherford **[7]**. He took the basic idea of an atom and advanced it with his "planetary model" which had a nucleus at the center, much like the sun at the center of our solar system, and electrons orbiting the nucleus in a predictable pattern. J. J. Thomson was not an enthusiastic supporter of this theory and it became a point of debate between the two men. But a chance encounter and a love of sports helped support Rutherford's model immensely. In 1912 Rutherford was a Professor at the University of Manchester (before returning to the Cavendish Laboratory in 1919 to replace Thomson upon his retirement) when he visited Cambridge for a reunion of former Cavendish students. One of the students then in Thomson's laboratory was a young Dane named Niels Bohr (1885-1962) **[8]**.


**[7]**




**[8]**

Upon meeting Bohr, Rutherford immediately remembered the name as one of the very promising soccer players at the 1908 Olympics in London. Bohr informed Rutherford that it was not he, but his younger brother Harald, that had been on the team. Nevertheless Rutherford immediately started expounding the virtues of his planetary model of the atom to Bohr who was somewhat unhappy with Thomson's less than enthusiastic acceptance of his own new theories. Bohr was intrigued by Rutherford and moved to Manchester to finish his stay in England at

Rutherford's lab at Manchester. Upon returning to Denmark in 1912 to establish his own research group he was visited by a former classmate to whom he immediately started to explain Rutherford's ideas. The classmate was intrigued and asked how this new model of the atom might help to explain the Balmer formula for some lines in the spectrum of atomic hydrogen:

$$\bar{\nu} \equiv \frac{1}{\lambda} = 109{,}680\left(\frac{1}{2^2} - \frac{1}{n^2}\right) cm^{-1}$$

Also known was Rydberg's equation, which expanded Balmer's equation to other series of lines in the atomic spectrum of hydrogen:

$$\bar{\nu} = 109{,}680\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) cm^{-1} \left(n_2 > n_1\right)$$

Surprisingly, Bohr was not familiar with the formula, and when he saw it for the first time he was convinced he could provide the physical explanation that had been eluding physicists for years to explain why the formula worked so well.

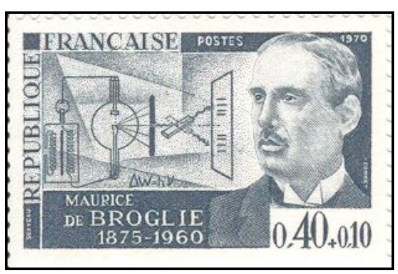
Bohr suggested that the electrons circling atoms traveled in "well-defined circular orbits" and that electrons could transition between these orbits. They would jump to higher orbits (having higher energy) when they absorbed radiation and would emit energy when dropping from a higher orbit to a lower orbit. If the electron transition ended at the second energy level the emitted energy would fall in the visible portion of the spectrum. This explained why Balmer's formula showed a $1/2^2$ as one of the terms. Bohr's theory was very well accepted, was very close to the experimental data, and gained him respect in the scientific community. Unfortunately it was also flawed.

About the same time that Bohr's model was gaining approval, World War I broke out and had a devastating impact on the scientific community. Many of Rutherford's students were drafted into wartime service and did not return from the war. Rutherford was extremely impacted by the death of Henry Moseley, whom Rutherford called the brightest student he had and whom many think would have been an equal of Einstein. It was not until after the war that the atom would come to the front of research again and the flaw in Bohr's theory would be explained.

Louis de Broglie **[9]** was serving in the French army during the war as a radio operator in Paris. He had already been trained classically at the Sorbonne but immediately became fascinated by electromagnetic radiation. After the war his older brother Maurice **[10]** encouraged him to pursue his education in physics and he submitted a Ph.D. dissertation that turned the physics community upside down. He proposed a theory whereby any particle exhibits wavelike properties no matter what its size. Paul Langevin was one of the professors on his dissertation committee. He was unsure of how to evaluate de Broglie's work and sent a copy of the research to Einstein, who read the paper and returned it with a very encouraging comment. It was only then that Louis de Broglie was awarded his doctorate in physics. His now famous equation **[11]** (where m is the mass of the particle and v is its velocity) showed that it is possible to measure the wavelength of any particle but that the wavelength is too small to be of significance for large objects. His theory combined the work of Einstein and Planck and their two famous equations.

$$\lambda = \frac{h}{mv}$$


**[9]**

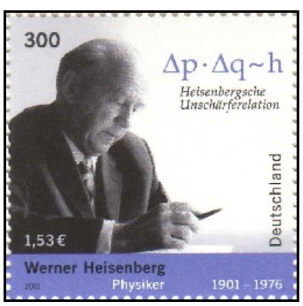



**[10]**


**[11]**

G. P. Thomson (J. J. Thomson's son) was very quick to recognize the value of the equation in explaining discrepancies in his father's research that had been attributed to experimental error. He was able to demonstrate that electrons exhibit both particle-like and wave-like behavior. The quantum revolution was now in full swing. In 1929, de Broglie received the Nobel Prize in Physics for this work.

In postwar Germany a young student named Werner Heisenberg (1901-1976) **[12]** was working toward a degree under Arnold Sommerfeld. A tenacious and brilliant student, in 1923 he would become Germany's youngest professor (at the University of Leipzig). Heisenberg was able to develop a way of describing electron behavior using a strange new mathematical technique. This turned out to be matrix mechanics invented in the 1850's. One of Heisenberg's most important collaborators was Wolfgang Pauli (1900-1958) **[13]**. Pauli had developed a mathematical way of describing an electron in an atom and helped to explain electron spin that had been observed by the Stern and Gerlach experiment. Heisenberg also put forward one of the first ideas of quantum mechanics, learned by young students as the Uncertainty Principle. He realized that by merely trying to observe a particle like the electron you are influencing it in a way that you cannot account for. The more precisely you know the objects position the less you know about its momentum. Now we state the principle as "the more precisely you know an objects' momentum, the less precisely you know its position".



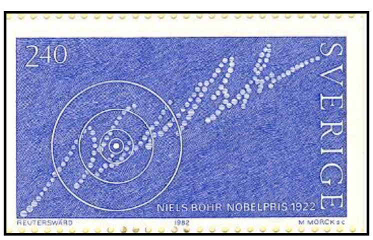

**[12]**

**[13]**


**[14]**

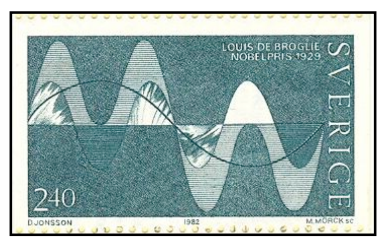
Almost simultaneously, in Austria, Erwin Schrödinger (1887-1961) **[14]** read a footnote about de Broglie's equation in a paper written by Einstein and realized that the idea of particle waves should be taken into account using Bohr's model to explain the atom (since the particles were so small the de Broglie wavelengths would be significant compared to their size). This model replaced Bohr's "Well-Defined Circular Orbits" with the idea of an orbital. The orbital is the electron density around the atom, where an electron is traveling at speeds close to the speed of light. This was to become Schrödinger's wave equation. In 1926 Max Born and P. A. M. Dirac explained the theory. Bohr and Heisenberg were at first very reluctant to accept Schrödinger's theory but it was soon shown to be equivalent to Heisenberg's matrix mechanics. In 1933 Heisenberg was awarded the 1932 Nobel Prize in Physics at the same time that Dirac and Schrodinger shared the 1933 prize.

The set of stamps issued by Sweden in 1983 present a nice pictorial representation of quantum mechanics as we know it today. The stamp honoring Bohr **[15]** shows his signature and several concentric circles illustrating his well-defined circular orbits idea. The stamp for Schrödinger **[16]** shows wave functions for two different electron orbitals representing the electron density predicted by his wave equation. The de Broglie stamp **[17]** shows a wave for his de Broglie wavelengths overlaid with amplitude graphs showing where the particle is likely to be found. The fourth stamp **[18]** is for Paul Dirac and traces electron paths. He shared the Nobel Prize with Schrödinger for this work. The fifth stamp **[19]** is for Werner Heisenberg and illustrates a molecular structure honoring his ubiquitous theory helping to explain the structure of atoms and molecules.




**[15]**


**[16]**

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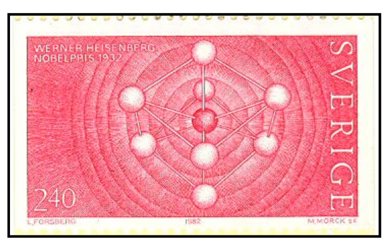


**[19]**

Some afterthoughts. While the individuals mentioned in this paper are all brilliant and they are all known to the students of quantum mechanics they are also quite human. Planck was not at all typical of the physicists you have read about. He was not a boy genius and his greatest work was not seen until he was well into his forties. His life was anything but a charmed one. He lost all four of his children prematurely. His older son died as a result of wounds suffered in World War I, and his younger son was executed by the German army because he was suspected of being part of the plot to assassinate Adolf Hitler. His older daughter died while giving birth. The child survived and was then raised by Planck's other daughter, who would go on to marry the child's father and die herself from complications during childbirth.

Werner Heisenberg led a complex life. Like many of the young Germans of his time he was often angered by the outrageous demands placed on Germany by the Treaty of Versailles. In his youth he was very involved in youth groups who spent their time hiking, camping, and enjoying the beautiful countryside in Germany and Austria. However these children would later become the Nazi youth movements. During the war years Heisenberg was in charge of Germany's nuclear program and then spent six months in British custody after the fall of Germany in 1945. Many have painted a picture of Heisenberg as misunderstood, but recent releases of audiotapes made of Heisenberg during his captivity show an individual who was sorry Germany lost the war. Most of Germany's leading scientists either supported their motherland or became refugees and relocated in the years leading to the start of the war in 1939. Niels Bohr and his Copenhagen Institute became a conduit for many of these individuals to move West, including Bohr himself who left Denmark and eventually joined the Manhattan Project.

The collegial, collaborative, and full speed ahead atmosphere of the Quantum Era that led to most of the discoveries outlined in this paper ended with World War II. The hallway blackboards and discussions late into the night in Germany's *Beer Halls* ended and the secrecy of the Manhattan Project and many similar research endeavors became much more the norm.

## References

Brennan, Richard P. *Heisenberg Probably Slept Here*, John Wiley and Sons, New York, 1997.

March, Robert *Physics for Poets*, Contemporary Books, Chicago, 1983.

# Identification of the Stamps

| # | Country | Scott | Topic |
|---|---|---|---|
| 1 | Sweden | 710 | Max Planck |
| 2 | Unified Germany | 1830 | Planck's equation |
| 3 | East Germany | 383 | Planck's constant |
| 4 | Ghana | 190 | Albert Einstein |
| 5 | West Germany | 1299 | photoelectric effect |
| 6 | Mexico | C33 | Heinrich Hertz |
| 7 | New Zealand | 487-8 | Ernest Rutherford |
| 8 | Denmark | 409 | Niels Bohr |
| 9 | Uganda | 1374k | Louis de Broglie |
| 10 | France | B439 | Maurice de Broglie |
| 11 | France | 2419 | de Broglie equation |
| 12 | Germany | 2142 | Werner Heisenberg |
| 13 | Austria | 1263 | Wolfgang Pauli |
| 14 | Austria | 1404 | Erwin Schrodinger |
| 15 | Sweden | 1425 | Niels Bohr |
| 16 | Sweden | 1426 | Erwin Schrodinger |
| 17 | Sweden | 1427 | Louis de Broglie |
| 18 | Sweden | 1428 | Paul Dirac |
| 19 | Sweden | 1429 | Werner Heisenberg |