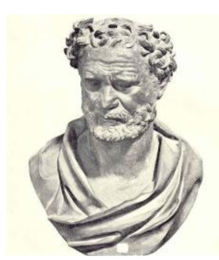
Democritus Atom

by Jerry Coffey on March 22, 2010

Democritus was an ancient Greek philosopher who lived from 460 BC to 370 BC. He was an influential pre-Socratic philosopher and pupil of Leucippus, who formulated what is thought to be the first atomic theory. Some people consider him to be the father of modern science. It is hard to separate his theories from those of Leucippus, since they are always mentioned in the same texts, but their theories have very different basis.

Democritus claimed that everything is made up of atoms. These atoms are physically, but not geometrically, indivisible; between atoms lies empty space; atoms are indestructible; have always been, and always will be, in motion; there are an infinite number of atoms and kinds of atoms, which differ in shape, and size. He said, about the mass of atoms,"The more any indivisible exceeds, the heavier it is.". He helped to propose the earliest views on the shapes and connectivity of atoms. He reasoned that the solidness of the material corresponded to the shape of the atoms involved. Thus, iron atoms are solid and strong with hooks that lock them into a solid; water atoms are smooth and slippery; salt atoms, because of their taste, are sharp and pointed; and air atoms are light and whirling. Using analogies from our senses, he gave an image of an atom that distinguished them from each other by their shape, size, and the arrangement of their parts. These connections were explained by material links in which single atoms were supplied with attachments: some with hooks and eyes others with balls and sockets. The Democritean atom is an inert solid that interacts with other atoms mechanically. In contrast, modern, quantum-mechanical atoms interact via electric and magnetic force fields and are far from inert.

He was criticized by many of his contemporaries, including Aristole, because he did not explain the initial cause of the motion of atoms.



Dalton's Atomic Theory

It was in the early 1800s that **John Dalton**, an observer of weather and discoverer of color blindness among other things, came up with his atomic theory. Let's set the stage for Dalton's work. Less than twenty years earlier, in the 1780's, **Lavoisier** ushered in a new chemical era by making **careful quantitative measurements** which allowed the compositions of compounds to be determined with accuracy. By 1799 enough data had been accumulated for Proust to establish the **Law of Constant Composition** (also called the Law of Definite Proportions). In 1803 Dalton noted that oxygen and carbon combined to make two compounds. Of course, each had its own particular weight ratio of oxygen to carbon (1.33:1 and 2.66:1), but also, for the same amount of carbon, one had exactly twice as much oxygen as the other. This led him to propose the **Law of Simple Multiple Proportions**, which was later verified by the Swedish chemist Berzelius. **In an attempt to explain how and why elements would combine with one another in fixed ratios and sometimes also in multiples of those ratios, Dalton formulated his atomic theory.**

The idea of atoms had been proposed much earlier. The ancient Greek philosophers had talked about atoms, but Dalton's theory was different in that it had the weight of careful chemical measurements behind it. It wasn't just a philosophical statement that there are atoms because there must be atoms. His atomic theory, stated that **elements consisted of tiny particles called atoms**. He said that the reason an element is pure is because **all atoms of an element were identical** and that in particular **they had the same mass**. He also said that the reason elements differed from one another was that **atoms of each element were different from one another**; in particular, **they had different masses**. He also said that **compounds consisted of atoms of different elements combined together**. Compounds are pure substances (remember they cannot be separated into elements by phase changes) because the atoms of different elements are bonded to one another somehow, perhaps by hooks, and are not easily separated from one another. **Compounds have constant composition because they contain a fixed ratio of atoms** and each atom has its own characteristic weight, thus fixing the weight ratio of one element to the other. In addition he said that **chemical reactions involved the rearrangement of combinations of those atoms**.

So that, briefly, is Dalton's theory. With modifications, it has stood up pretty well to the criteria that we talked about earlier. It did not convince everyone right away however. Although a number of chemists were quickly convinced of the truth of the theory, it took about a half century for the opposition to die down, or perhaps I should say die off.

Let me point out again the difference between a model of atoms and a theory of atoms. A model focuses on describing what the atoms are like, whereas the theory not only talks about what the atoms are like but how they interact with one another and so forth. **Dalton's model** was that the atoms were **tiny, indivisible, indestructible particles** and that each one had a **certain mass, size, and chemical behavior** that was determined by what kind of element they were. We will use that model of an atom for now, but we will modify it considerably in a later lesson.

JJ Thomson

Synopsis

J.J. Thomson was born on December 18, 1856, in Cheetham Hill, England, and went on to attend Trinity College at Cambridge, where he would come to head the Cavendish Laboratory. His research in cathode rays led to the discovery of the electron, and he pursued further innovations in atomic structure exploration. Thomson won the 1906 Nobel Prize in Physics, among many accolades. He died on August 30, 1940.

Early Life and Education

Joseph John Thomson, who was always called J.J., was born in Cheetham Hill, England, near Manchester, in 1856. His father was a bookseller who planned for Thomson to be an engineer. When an apprenticeship at an engineering firm couldn't be found, Thomson was sent to bide his time at Owens College at the age of 14. In 1876, he received a small scholarship to attend Trinity College at Cambridge to study mathematics.

Thomson worked in the Cavendish Laboratory after graduation, under the tutelage of Lord Rayleigh. He quickly earned a membership in the prestigious Royal Society and was appointed Rayleigh's successor as the Cavendish Professor of Physics at the age of 28. He was both respected and well-liked, and students came from around the world to study with him.

Research

In 1894, Thomson began studying cathode rays, which are glowing beams of light that follow an electrical discharge in a high-vacuum tube. It was a popular research topic among physicists at the time because the nature of cathode rays was unclear.

Thomson devised better equipment and methods than had been used before. When he passed the rays through the vacuum, he was able to measure the angle at which they were deflected and calculate the ratio of the electrical charge to the mass of the particles. He discovered that the ratio was the same regardless of what type of gas was used, which led him to conclude that the particles that made up the gases were universal.

Thomson determined that all matter is made up of tiny particles that are much smaller than atoms. He originally called these particles 'corpuscles,' although they are now called electrons. This discovery upended the prevailing theory that the atom was the smallest fundamental unit.

In 1906, Thomson began studying positively charged ions, or positive rays. This led to one of his other famous discoveries in 1912, when he channeled a stream of ionized neon through a magnetic and an electric field and used deflection techniques to measure the charge to mass ratio. In doing so, he discovered that neon was composed of two different kinds of atoms, and proved the existence of isotopes in a stable element. This was the first use of mass spectrometry.

Personal Life and Later Years

Thomson married Rose Paget, one of his students, in 1892. They had one daughter, Joan, and one son, George Paget Thomson, who went on to become a physicist and win a Nobel Prize of his own. J.J. Thomson published 13 books and more than 200 papers in his lifetime. In addition to being awarded the Nobel Prize in 1906, he was knighted in 1908 by King Edward VII. He left research in 1918 to become Master of Trinity College. He died in Cambridge on August 30, 1940, and is buried in Westminster Abbey near two other influential scientists: Isaac Newton and Charles Darwin.

Niels Bohr 1885 - 1962

Niels Bohr was born and educated in Copenhagen, Denmark. He lived, worked, and died there, too. But his mark on science and history was worldwide. His professional work and personal convictions were part of the larger stories of the century.

At the University of Copenhagen, he studied physics and played soccer (though not as well as his brother, who helped the 1908 Danish soccer team win an Olympic silver medal). After receiving his doctorate in 1911, Bohr traveled to England on a study grant and worked under J.J. Thomson, who had discovered the electron 15 years earlier.

Bohr began to work on the problem of the atom's structure. Ernest Rutherford had recently suggested the atom had a miniature, dense nucleus surrounded by a cloud of nearly weightless electrons. There were a few problems with the model, however. For example, according to classical physics, the electrons orbiting the nucleus should lose energy until they spiral down into the center, collapsing the atom. Bohr proposed adding to the model the new idea of quanta put forth by Max Planck in 1901. That way, electrons existed at set levels of energy, that is, at fixed distances from the nucleus. If the atom absorbed energy, the electron jumped to a level further from the nucleus; if it radiated energy, it fell to a level closer to the nucleus. His model was a huge leap forward in making theory fit the experimental evidence that other physicists had found over the years. A few inaccuracies remained to be ironed out by others over the next few years, but his essential idea was proved correct. He received the Nobel Prize for this work in 1922, and it's what he's most famous for. But he was only 37 at the time, and he didn't stop there. Among other things, he put forth the theory of the nucleus as a liquid drop, and the idea of "complementarity" -- that things may have a dual nature (as the electron is both particle and wave) but we can only experience one aspect at a time.

In 1912 Bohr married Margrethe Nørlund. They had six sons, one of whom, Aage, followed his father into physics -- and into the ranks of Nobel Prize-winners. Bohr returned to Denmark as a professor at the University of Copenhagen, and in 1920 founded the Institute for Theoretical Physics -- sponsored by the Carlsberg brewery! Bohr remained director of the institute for the rest of his life, except for his absence during World War II. Bohr's personal warmth, good humor ("Never express yourself more clearly than you can think," he once said), and hospitality combined with world events to make Copenhagen a refuge for many of the century's greatest physicists.

After Hitler took power in Germany, Bohr was deeply concerned for his colleagues there, and offered a place for many escaping Jewish scientists to live and work. He later donated his gold Nobel medal to the Finnish war effort. In 1939 Bohr visited the United States with the news from Lise Meitner (who had escaped German-occupied Austria) that German scientists were working on splitting the atom. This spurred the United States to launch the Manhattan Project to develop the atomic bomb. Shortly after Bohr's return home, the German army occupied Denmark. Three years later Bohr's family fled to Sweden in a fishing boat. Then Bohr and his son Aage left Sweden traveling in the empty bomb rack of a British military plane. They ultimately went to the United States, where both joined the government's team of physicists working on atomic bomb at Los Alamos. Bohr had qualms about the consequences of the bomb. He angered Winston Churchill by wanting to share information with the Soviet Union and supporting postwar arms control. Bohr went on to organize the Atoms for Peace Conference in Geneva in 1955.

In addition to his major contributions to theoretical physics, Bohr was an excellent administrator. The institute he headed is now named for him, and he helped found CERN, Europe's great particle accelerator and research station. He died at home in 1962, following a stroke.

Ernest Rutherford

Ernest Rutherford (1871–1937) was responsible for a remarkable series of discoveries in the fields of radioactivity and nuclear physics. He discovered alpha and beta rays, set forth the laws of radioactive decay, and identified alpha particles as helium nuclei. Most important, he postulated the nuclear structure of the atom: experiments done in Rutherford's laboratory showed that when alpha particles are fired into gas atoms, a few are violently deflected, which implies a dense, positively charged central region containing most of the atomic mass.

Born on a farm in New Zealand, the fourth of 12 children, Rutherford completed a degree at the University of New Zealand and began teaching unruly schoolboys. He was released from this task by a scholarship to Cambridge University, where he became J. J. Thomson's first graduate student at the Cavendish Laboratory. There he began experimenting with the transmission of radio waves, went on to join Thomson's ongoing investigation of the conduction of electricity through gases, and then turned to the field of radioactivity just opened up by Henri Becquerel and Pierre and Marie Curie.

Throughout his career Rutherford displayed his ability to work creatively with associates, some of whom were already established at the institutions to which he was appointed and others of whom he attracted as doctoral or postgraduate students. At McGill University in Montreal, his first appointment, he worked with Frederick Soddy on radioactive decay. At Manchester University he collaborated with Hans Geiger (of Geiger counter fame), Niels Bohr (whose model of atomic structure succeeded Rutherford's), and H. G. J. Moseley (who obtained experimental evidence for atomic numbers). During World War I, this Manchester research group was largely dispersed, and Rutherford turned to solving problems connected with submarine detection. After the war he succeeded J. J. Thomson in the Cavendish Professorship at Cambridge and again gathered a vigorous research group, including James Chadwick, the discoverer of the neutron.

Like Thomson, Rutherford garnered many honors. He received the Nobel Prize in chemistry for 1908; he was made a knight, then a peer with a seat in the House of Lords; and for the ultimate honor he was buried in Westminster Abbey.

Erwin Schrödinger 1887 - 1961

Erwin Schrödinger was the only son of well-educated parents. His father owned an oil cloth factory and was an amateur painter and botanist. Erwin was taught at home, by tutors and parents, until he was 11. He then attended school to prepare for university.

He attended the University of Vienna where he was inspired by a brilliant young physicist, Friedrich Hasenhörl. Schrödinger obtained his PhD in physics and took a position with the university, where he remained until World War I. He served as an artillery officer on the Italian front. During the war Hasenhörl was killed; in his acceptance speech for the Nobel Prize in 1933, Schrödinger remarked that without the war, it would have been his teacher Hasenhörl receiving the honor. As the war neared its end and he dared think ahead, Schrödinger looked forward to a post as a professor at the University of Czernowitz, but as war ended so did the Austro-Hungarian Empire, along with Schrödinger's opportunity at Czernowitz. He went back to his somewhat secondary post in Vienna, got married, and soon was offered a new position. He changed jobs several times before being offered the chair in theoretical physics at the University of Zurich in Switzerland in 1921.

His six years in Zurich were among the most productive in his career, though he didn't begin the work for which he was best known -- wave mechanics -- until 1925. His interest was sparked by a footnote in a paper by Albert Einstein. Schrödinger began to think about explaining the movement of an electron in an atom as a wave. By 1926 he published his work, providing a theoretical basis for the atomic model that Niels Bohr had proposed based on laboratory evidence. The equation at the heart of his publication became known as Schrödinger's wave equation. This was the second theoretical explanation of electrons in an atom, following Werner Heisenberg's matrix mechanics. Many scientists preferred Schrödinger's theory since it could be visualized, while Heisenberg's was strictly mathematical. A split threatened among physicists, but Schrödinger soon showed that the two theories were identical, only expressed differently.

In 1927 Schrödinger was offered the extremely prestigious job of replacing Max Planck when he retired from the University of Berlin. Schrödinger hated to leave the Alps for the crowded city, but he accepted. It turned out to be a wonderful teaching and learning period for Schrödinger, but one brought to a nasty close by the rise of the Nazi party in Germany. He saw many esteemed colleagues hounded from their jobs and forced to leave the country. He also chose to leave in 1933, the year Hitler became Germany's chancellor. He went to Oxford University and in his first week there learned that he'd won the Nobel Prize with Paul Dirac.

After three years, he returned to a university post in Austria, but in 1938, Germany invaded and Schrödinger was dismissed. The Prime Minister of Ireland at the time, Eamon de Valera, was a mathematician and invited Schrödinger to join the newly established Institute for Advanced Studies in Dublin. Schrödinger emigrated there with few possessions and little money. He remained for 17 years, often turning his attention to philosophical questions about physics and its relationship to other fields.

In 1956, after war and foreign occupation had receded from Austria, Schrödinger returned to Vienna. He fell ill the following year and died in 1961.

Werner Heisenberg 1901 - 1976

Werner Heisenberg's high school years were interrupted by World War I, when he had to leave school to help harvest crops in Bavaria. Back in Munich after the war, he volunteered as a messenger for democratic socialist forces that fought and ousted the communist government that had taken control of the Bavarian state. He was involved in youth groups trying to rebuild German society out of the ashes of World War I, including the "New Boy Scouts".

In 1920 he entered the University of Munich to pursue a degree in math. But the math professor wouldn't allow him into an advanced seminar, so he quit. He transferred to physics. He immediately took an interest in theoretical physicists, and soon met many scientists whose work would dominate the coming decades, including Niels Bohr. One of his chief interests was working out problems involved in the Bohr-Rutherford model of the atom. He just barely received his PhD in 1923 -- nearly failing because he had neglected his laboratory work. He became a professor at the University of Gottingen at age 22. Because he suffered from severe seasonal allergies, during pollen season he left Bavaria for the island of Heligoland. While there he had time to think and work out problems with the atomic model. He realized the limitations of visual models and suggested working strictly with experimental data and mathematical results. To do this he applied a mathematical system to atomic physics, called matrix mechanics. It was a turning point for physics. Many in the field disliked it because it didn't provide a physical model to relate to. Erwin Schrödinger came up with the theory of wave mechanics about a year later. Those uncomfortable with Heisenberg's system jumped on the wave mechanics side. The conflict between the theories was resolved when Schrödinger proved that they were, in fact, identical.

In 1926 Heisenberg joined Bohr at the Institute for Theoretical Physics in Copenhagen. This turned out to be one of the most productive periods in Heisenberg's life. In 1927 he was puzzling over the basic quantum properties of electrons. He realized that the act of measuring an electron's properties by hitting it with gamma rays would alter the electron's behavior. Indeed, you could measure the position of an electron (or other particle) OR you could measure its momentum. But the more precisely you measure one property, the more you throw the other off. He tied this up in an equation using Planck's constant, and called it the uncertainty principle. While many resisted this idea, it eventually became accepted as a fundamental law of nature.

Later in 1927 Heisenberg returned to Germany and became the youngest full professor in the country. Professorship entailed a full plate of teaching and administrative duties, and his scientific output naturally dwindled. With the political turmoil in Germany and World War II, Heisenberg's life became complicated. There was a mass exodus of German scientists in the 1930s, but Heisenberg was one of the few top-notch scientists who decided to remain. But as the war began the government recognized, the importance of Heisenberg's knowledge. He was made director of the German atom bomb project. He spent five years working on it.

At war's end, Heisenberg was captured by the Allies and was imprisoned in England for six months. He was released and returned to Germany where he reestablished the Kaiser Wilhelm Institute for Physics, but renamed it the Max Planck Institute, in honor of his friend and colleague. He retired in 1970, and died in 1976 survived by his wife of 39 years and seven children.