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.

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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.

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John Dalton, F.R.S., engraved by [William Henry Worthington](http://www.walterscott.lib.ed.ac.uk/portraits/engravers/worthington.html) after an 1814 painting by William Allen, published June 25, 1823, in Manchester and London. Note the charts with Dalton’s atomic symbols lying on the table. Fisher Collection, CHF Collections. [Request this image](http://www.chemheritage.org/discover/collections/how-to-access-the-collections/collection-image-order-form.aspx?ItemName=+John+Dalton%2C+F%2ER%2ES%2E++Image+1&ItemID=69352(FA%202000.001.069)&ItemURL=/Images/Collection-Item-Images/Fine-Art/fa-2000.001.069.jpg).

John Dalton (1766–1844) was born into a modest Quaker family in Cumberland, England, and earned his living for most of his life as a teacher and public lecturer, beginning in his village school at the age of 12. After teaching 10 years at a Quaker boarding school in Kendal, he moved on to a teaching position in the burgeoning city of Manchester. There he joined the Manchester Literary and Philosophical Society, which provided him with a stimulating intellectual environment and laboratory facilities. The first paper he delivered before the society was on color blindness, which afflicted him and is sometimes still called “Daltonism.”

Dalton arrived at his view of atomism by way of meteorology, in which he was seriously interested for a long period: he kept daily weather records from 1787 until his death, his first book was[***Meteorological Observations***](http://othmerlib.chemheritage.org/search~S6?/Ymeteorological+observations&searchscope=6&SORT=D/Ymeteorological+observations&searchscope=6&SORT=D&SUBKEY=meteorological+observations/1%2C11%2C11%2CB/frameset&FF=Ymeteorological+observations&searchscope=6&SORT=D&1%2C1%2C) (1793), and he read a series of papers on meteorological topics before the Literary and Philosophical Society between 1799 and 1801.

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Elements and their combinations as described in John Dalton’s [*New System of Chemical Philosophy*](http://othmerlib.chemheritage.org/search~S6?/Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D/Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D&SUBKEY=new+system+of+chemical+philosophy/1%2C10%2C10%2CB/frameset&FF=Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D&1%2C1%2C)(1808–1827). [Request this image](http://www.chemheritage.org/discover/collections/how-to-access-the-collections/collection-image-order-form.aspx?ItemName=+A+New+System+of+Chemical+Philosophy++Image+1&ItemID=58012(b1035253)&ItemURL=/Images/Collection-Item-Images/Rare-Books/b1035253.jpg).

The papers contained Dalton’s independent statement of [**Charles’s law**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/activities/gay-lussacs-law-of-volumes.aspx) (see [**Joseph Louis Gay-Lussac**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/early-chemistry-and-gases/gay-lussac.aspx)): “All elastic fluids expand the same quantity by heat.” He also clarified what he had pointed out in*Meteorological Observations*—that the air is not a vast chemical solvent as [**Antoine-Laurent Lavoisier**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/early-chemistry-and-gases/lavoisier.aspx) and his followers had thought, but a mechanical system, where the pressure exerted by each gas in a mixture is independent of the pressure exerted by the other gases, and where the total pressure is the sum of the pressures of each gas. In explaining the law of partial pressures to skeptical chemists of the day—including[**Humphry Davy**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/electrochemistry/davy.aspx)—Dalton claimed that the forces of repulsion thought to cause pressure acted only between atoms of the same kind and that the atoms in a mixture were indeed different in weight and “complexity.”

He proceeded to calculate atomic weights from percentage compositions of compounds, using an arbitrary system to determine the likely atomic structure of each compound. If there are two elements that can combine, their combinations will occur in a set sequence. The first compound will have one atom of A and one of B; the next, one atom of A and two atoms of B; the next, two atoms of A and one of B; and so on. Hence, water is HO. Dalton also came to believe that the particles in different gases had different volumes and surrounds of caloric, thus explaining why a mixture of gases—as in the atmosphere—would not simply layer out but was kept in constant motion. Dalton consolidated his theories in his [***New System of Chemical Philosophy***](http://othmerlib.chemheritage.org/search~S6?/Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D/Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D&SUBKEY=new+system+of+chemical+philosophy/1%2C10%2C10%2CB/frameset&FF=Ynew+system+of+chemical+philosophy&searchscope=6&SORT=D&1%2C1%2C) (1808–1827).

As a Quaker, Dalton led a modest existence, although he received many honors later in life. In Manchester more than 40,000 people marched in his funeral procession.

Ernest Rutherford



Ernest Rutherford in academic garb. Courtesy Edgar Fahs Smith Memorial Collection, Department of Special Collections, University of Pennsylvania Library.

A consummate experimentalist, 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**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/atomic-and-nuclear-structure/thomson.aspx)'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**](http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/atomic-and-nuclear-structure/curie.aspx).



Rutherford on the New Zealand 100-dollar banknote.

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.

**Niels Bohr**

Niels Bohr was a Danish physicist who made fundamental contributions to understanding the structure of atoms and to the early development of quantum mechanics. In particular, he developed the Bohr model of the atom (and later the “liquid drop” model) and the principles of correspondence and complementarity. He mentored and collaborated with many of the top physicists of the century at his institute in Copenhagen, where he and [Werner Heisenberg](http://www.physicsoftheuniverse.com/scientists_heisenberg.html) developed the “Copenhagen interpretation” of quantum theory. He is recognized as one of the most influential physicists of the 20th Century, and received the Nobel Prize in Physics in 1922 “for his services in the investigation of the structure of atoms and of the radiation emanating from them”.

Niels Henrik David Bohr was born in Copenhagen, Denmark on 7 October 1885. His father was a devout Lutheran and a respected professor of physiology at the University of Copenhagen; his mother came from a prominent and wealthy Jewish family of bankers and parliamentarians. Niels’ younger brother, Harald, became a brilliant mathematician as well as an international footballer.

Bohr enrolled as an undergraduate at Copenhagen University in 1903, initially studying philosophy and mathematics, but switching to physics in 1905 after winning an essay competition with a report on the properties of surface tension. He completed his doctorate in 1911, under the physicist Christian Christiansen. For his post-doctoral studies, Bohr moved to England, first conducting experiments at Trinity College, Cambridge under J. J. Thomson (the discoverer of the electron), and then at the University of Manchester under [Ernest Rutherford](http://www.physicsoftheuniverse.com/scientists_rutherford.html) (the discoverer of the nucleus and the structure ofatoms).

On returning to Copenhagen from Manchester in 1912, Bohr took up a position as assistant professor at the University of Copenhagen, and also married Margrethe Nørlund. The couple were to have six children: two died young, but the others went on to lead successful lives, with one, Aage Niels Bohr, also becoming a very successful physicist like his father, winning the Nobel Prize in Physics in 1975.

In 1913, on the basis of [Rutherford](http://www.physicsoftheuniverse.com/scientists_rutherford.html)'s theories, Bohr developed and published his model of atomic structure, known as the Bohr model, which depicts the atom as a small, positively-charged nucleussurrounded by negatively-charged electrons that travel in circular orbits around the nucleus, similar in structure to the Solar System, but with electromagnetic forces providing attraction, rather thangravity.

He also introduced the idea that the electrons travel in discrete orbits around the atom's nucleus, the chemical properties of the particular element being largely determined by the number of electrons in the outer orbits. In addition, he proposed that an electron could drop from a higher energy orbit to a lower one, emitting a photon of discrete energy in the process, which became part of the basis forquantum theory. It was largely for this early work that Bohr was awarded the Nobel Prize in Physics in 1922, "for his services in the investigation of the structure of atoms and of the radiation emanating from them".

In 1916, he became a full professor at the University of Copenhagen and continued his research. During this time, he postulated that an atom would not emit radiation while it was in one of its stable states but rather only when it made a transition between states, and that the atom could neither absorb nor emit radiation continuously but only in finite steps or quantum jumps. In 1920, he established the "correspondence principle", the idea that classical physics and quantum physics will give the same answers when the systems become sufficiently large.

In 1921, with the assistance of the Danish government and the Carlsberg Foundation, he founded the Institute of Theoretical Physics in Copenhagen, where he served as director for the rest of his life. The Institute soon became an international focal point for theoretical physicists in the 1920s and 1930s, and most of the world's best known theoretical physicists of that period spent at least some time there.

[Werner Heisenberg](http://www.physicsoftheuniverse.com/scientists_heisenberg.html) worked as Bohr’s assistant at the Institute from 1926 to 1927, and the two men worked closely on the mathematical foundations of quantum mechanics. It was during this fertile period in Copenhagen that [Heisenberg](http://www.physicsoftheuniverse.com/scientists_heisenberg.html) developed his famous uncertainty principle. It was also during this period that Bohr developed his principle of complementarity, the idea that that particles could be separately analyzed as having several contradictory, and apparently mutually exclusive, properties (an example being the wave-particle duality of light, where light can either behave as a particle or as wave, but not simultaneously as both).

The two physicist also grappled at this time with the philosophical implications of quantum theory, and the extent to which it reflected the reality of the everyday world. Although they were not in complete agreement, their general position was popularly referred to as the “Copenhagen interpretation”, which in broad terms stated that reality could only be ascribed to a measurement, and that quantum effects themselves were essentially characterized by indeterminacy.

Bohr, along with [John Wheeler](http://www.physicsoftheuniverse.com/scientists_wheeler.html), developed the “liquid-drop” model of the atomic nucleus (so called because it likened the nucleus to a droplet of liquid), first proposed by [George Gamow](http://www.physicsoftheuniverse.com/scientists_gamow.html). This was a key step in the understanding of many nuclear processes, and it played an essential part in 1939 in explaining the basis of nuclear fission (the splitting of a heavy nucleus into two more or less equal parts, with the consequent release of a tremendous amount of energy). He also identified that it was the rare U-235 isotope that made uranium fissionable, and which made a chain reaction theoretically possible.

During the Second World War, Denmark was occupied by the German forces, and Bohr, who was quite aware of German nuclear research (especially given his friendship with [Heisenberg](http://www.physicsoftheuniverse.com/scientists_heisenberg.html), who was intimately involved in German nuclear power research, although he was resisting involvement in the development of nuclear weapons), had to be very careful in his dealings and communications. For example, when the British intelligence services inquired about Bohr's availability for work or insights of particular value, he made it quite clear that he could not help. Eventually, in 1943, Bohr was forced to flee the German authorities, partly because of his Jewish ancestry, and partly due to the anti-Nazi views he made little effort to conceal, escaping to Sweden shortly before he was to be arrested by the German police.

From Sweden he travelled on to London, and became involved for a time with Project "Tube Alloys", the code-name for the British nuclear weapon program, and the search for a viable nuclear fissionbomb. He also worked at this time on the American equivalent, the Manhattan Project, at the top-secret Los Alamos laboratory in New Mexico, United States, where he was apparently known by the assumed name of Nicholas Baker for security reasons.

He gradually assumed an important role as a senior consultant in the Manhattan Project, but he was also concerned about a potential nuclear arms race and he firmly believed that atomic secrets should be shared by the international scientific community. To this end, he had high level discussions with both the U.S. President Franklin D. Roosevelt and the British Prime Minister Winston Churchill. Churchill in particular was vehemently against sharing such secrets with Soviet Russia and considered Bohr as potentially unstable and a dangerous security risk.

After the War, Bohr returned to Copenhagen, where he was awarded the Order of the Elephant (Denmark’s highest decoration, the equivalent of a knighthood) by the Danish government in 1947. He continued to serve in many public roles, notably as president of the Royal Danish Academy, a position he held from 1939 until his death in 1962. He also continued to advocate the peaceful use of nuclear energy, and addressed an “Open Letter” to the United Nations on the subject in 1950. However, it was only later in the 1950s, after the immense surprise that the Soviets had developed nuclear weapons independently, that the International Atomic Energy Agency was created, very much along the lines of Bohr's original suggestion.

Bohr died in Copenhagen on 18 November 1962, aged 62, and is buried in the Assistens Cemetery in Copenhagen.

Bohr Atomic Model :

In 1913 Bohr proposed his quantized shell model of the atom to explain how electrons can have stable orbits around the nucleus. The motion of the electrons in the Rutherford model was unstable because, according to classical mechanics and electromagnetic theory, any charged particle moving on a curved path emits electromagnetic radiation; thus, the electrons would lose energy and spiral into the nucleus. To remedy the stability problem, Bohr modified the Rutherford model by requiring that the electrons move in orbits of fixed size and energy. The energy of an electron depends on the size of the orbit and is lower for smaller orbits. Radiation can occur only when the electron jumps from one orbit to another. The atom will be completely stable in the state with the smallest orbit, since there is no orbit of lower energy into which the electron can jump.

Plum Pudding Model



plum pudding model of the atom

The Plum Pudding Model is an[atom model](http://www.universetoday.com/56637/atom-model/) proposed by JJ Thomson, the physicist who discovered the electron. It is also known as the Chocolate Chip Cookie or Blueberry Muffin Model. You can easily picture it by imagining the said goodies. For example, you can imagine a plum pudding wherein the pudding itself is positively charged and the plums, dotting the dough, are the negatively charged electrons.

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Thus, in contrast to today’s atom that has a very dense and very small (compared to the whole atom) positively charged nucleus, Thomson’s had a more dispersed positive charge. As a whole, the plum pudding representation only strived to explain why most atoms were neutral.

It’s interesting to note that this model was sometimes visualized as having a cloud of positive charge, a striking contrast to the most recent atomic model which describes the positive nucleus to be surrounded by an electron cloud.

Introduced by Thomson in the March 1904 edition of the UK’s Philosophical Magazine, this model was invalidated 5 years after during what is now known as the Rutherford gold foil experiment, an experiment designed to probe the atom.

The basic setup of the experiment was as follows: alpha particles coming from a radioactive source were directed to a gold foil. The foil was then surrounded by a wall of zinc sulfide that exhibited scintillations (tiny flashes) when hit by the alpha particles. Patterns formed by the scintillations would provide information as to how the charges were distributed inside the atom.

With the plum pudding model in mind, Rutherford expected very minimal alpha particle deflections as they were bombarded on the foil. Hence, the scintillations were only supposed to be observed right behind the foil, exactly opposite to the source of alpha particles. Alas, although majority of the flashes were indeed observed behind the foil, a few were also seen near the source.

According to Rutherford, it was like firing a cannonball on a tissue paper and seeing it bounce against the paper right back at him on certain occasions.

Since alpha particles are just helium nuclei, they are positively charged. The only logical explanation therefore was that the positive charge in the atom were not as dispersed as you would imagine in a pudding’s soft crust. Instead, Rutherford guessed that they should be concentrated in a very small volume in the center. This specific portion of Rutherford’s model still holds even up to this day.

**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.

**Wave Mechanical Model of the Atom**

By the mid-1920s it had become apparent that the Bohr model was incorrect. Scientists needed to pursue a totally new approach. Two young physicists, Louis Victor de Broglie from France and Erwin Schrödinger from Austria, suggested that because light seems to have both wave and particle characteristics (it behaves simultaneously as a wave and as a stream of particles), the electron might also exhibit both of these characteristics.

When Schrödinger carried out a mathematical analysis based on this idea, he found that it led to a new model for the hydrogen atom that seemed to apply equally well to other atoms—something Bohr’s model failed to do. We will now explore a general picture of this model, which is called the **wave mechanical model** of the atom.

In the Bohr model, the electron was assumed to move in circular orbits. In the wave mechanical model, on the other hand, the electron states are described by orbitals. Orbitals are nothing like orbits. To approximate the idea of an orbital, picture a single male firefly in a room in the center of which an open vial of female sex-attractant hormones is suspended. The room is extremely dark and there is a camera in one corner with its shutter open. Every time the firefly “flashes,” the camera records a pinpoint of light and thus the firefly’s position in the room at that moment. The firefly senses the sex attractant, and as you can imagine, it spends a lot of time at or close to it. How-ever, now and then the insect flies randomly around the room.

When the film is taken out of the camera and developed, the picture will probably look like Figure 11.18. Because a picture is brightest where the film has been exposed to the most light, the color intensity at any given point tells us how often the firefly visited a given point in the room. Notice that, as we might expect, the firefly spent the most time near the room’s center.

According to the wave mechanical model, the electron in the hydrogen atom can be pictured as being something like this firefly. Schrödinger found that he could not precisely describe the electron’s path. His mathematics enabled him only to predict the probabilities of finding the electron at given points in space around the nucleus. In its ground state the hydrogen electron has a probability map like that shown in Figure 11.19. The more intense the color at a particular point, the more probable that the electron will be found at that point at a given instant. The model gives no information about when the electron occupies a certain point in space or how it moves. In fact, we have good reasons to believe that we can never know the details of electron mo- tion, no matter how sophisticated our models may become. But one thing we feel confident about is that the electron does not orbit the nucleus in circles as Bohr suggested.