18.1 Atomic Structure

All matter is formed from atoms. Atoms, by themselves or combined with other atoms in molecules, make up everything that we see, hear, feel, smell, and touch. An individual atom is so small that one cell in your body contains 100 trillion atoms, and a speck of dust contains many more atoms than that.

As small as they are, atoms and molecules are the building blocks of every type of matter. A few hundred incredibly tiny atoms of gold have the same density as a bar of gold. A few hundred very tiny molecules of water have the same density as a cup of water. (We would not, of course, be able to see or notice in any way those atomic clumps of gold nor those molecular masses of water!)

Why are atoms the smallest piece that is still recognizably matter? What do you find when you break apart an atom? How big is it? In this section you will find out what an atom looks like, and learn about the historical experiments that helped scientists understand atomic structure.

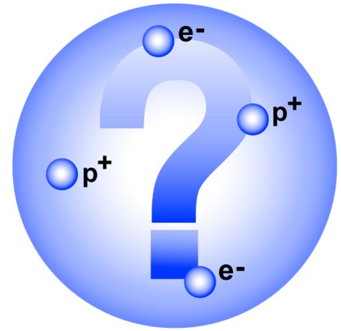


Figure 18.1: *What do atoms look like? What are they made out of? These questions have been asked by scientists ever since 400 BC, when Democritus proposed the existence of atoms.*

Inside an atom

Protons, neutrons, and electrons

Atoms and molecules are called the building blocks of matter because if you attempt to break down an atom, you no longer have gold or water or any other recognizable substance. If broken apart, almost all atoms contain three smaller particles called **protons**, **neutrons**, and **electrons**. Because these particles are even smaller than an atom, they are called **subatomic particles**. These three types of particles are arranged in an atom as shown in figure 18.2.

How are protons, neutrons, and electrons arranged within an atom?

Protons and neutrons cluster together in the atom's center, called the **nucleus**. The electrons move in the space around the nucleus. No one is able to say exactly where an electron is at any one time. A useful analogy is that electrons buzz around the nucleus much like bees around a hive. Some people describe each electron as a wave; just as the vibration of a guitar string exists all along the string, the electrons exist at all the shaded points in figure 18.2.

Subatomic particles have charge and mass

Subatomic particles have *charge* and *mass*. The proton is positive, the electron is negative, and the neutron is electrically neutral. Protons and neutrons have about the same mass. Each is about 2,000 times the mass of an electron. Since protons and neutrons exist in the nucleus, almost all the mass of an atom is concentrated there. These properties helped scientists figure out the atomic structure.

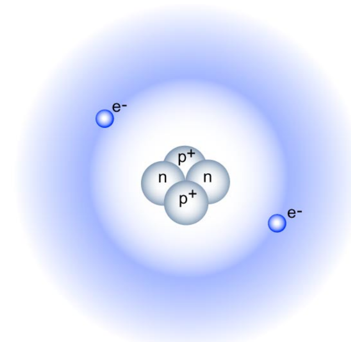


Figure 18.2: *An atom has a nucleus with one or more protons and neutrons and one or more energy levels occupied by electrons. The shaded area around the outside of the atom represents the places the electrons might be. A good analogy is that electrons "buzz" around the nucleus in energy levels like bees around a hive.*

How big are atoms?

Atoms are very small

An atom and its parts are much smaller than a meter. The diameter of an atom is 10^{-10} (0.0000000001) meter, whereas an electron is smaller than 10^{-18} (0.000000000000000001) meter. Comparatively, this means that an electron is 10 million times smaller than an atom! The diameter of a nucleon (a proton or neutron) is a distance that is equal to one fermi. This unit (equal to 10^{-15} meter) is named for Enrico Fermi, an Italian-born physicist who studied the nucleus of the atom. For his work with neutrons, he received the Nobel Prize for physics in 1938.

Most of the atom is empty space

You may be surprised to learn that most of the atom is actually empty space: If the atom was the size of your classroom, then the nucleus would be the size of a grain of sand in the center of the room.

Particle	Diameter (meters)
atom	10^{-10}
nucleus	10^{-14}
proton	10^{-15}
neutron	10^{-15}
electron	10^{-18}

Figure 18.3: *Diameters of an atom and its subatomic particles.*

John Dalton and the atomic theory

As early as 400 BC, Greek philosophers proposed the **atomic theory**. This theory states that all matter is composed of tiny particles called atoms. Many centuries later, English chemist and physicist John Dalton (1766-1844) was one of the first scientists to set out to gather evidence for the idea. Dalton was a remarkable person. Born into a family too poor to send him to school, young John educated himself and, at age 12, became a schoolteacher. He grew to be one of the leading scientists of his time.

In 1808, Dalton published a detailed atomic theory that contained the following important points:

1 Each element is composed of extremely small particles called atoms.

2 All atoms of a given element are identical.

3 Atoms of different elements have different properties, including mass and chemical reactivity.

4 Atoms are not changed by chemical reactions, but merely rearranged into different compounds.

5 Compounds are formed when atoms of more than one element combine.

6 A compound is defined by the number, type (element), and proportion of the constituent atoms.

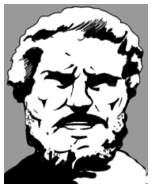
Dalton's atomic theory laid the groundwork for later atomic models, and over time, his original theory has been expanded and updated.

Weather & atomic theory

One of John Dalton's interests was weather (he kept detailed records for 57 years), and that led him to study gases. He studied the evaporation of water into the air and was able to understand that the process increased gas pressure. From these observations of pressure, and from other experiments, he gathered evidence about the structure of matter.

The changing model of the atom

The current model of the atom represents our current understanding of atomic structure. This model is one of a series of models constructed by people as they learned new information about atoms. New information enabled people to update and change their ideas about how the atom is constructed.



The name *atom* comes from Democritus, a Greek philosopher (circa 460-370 BC) who proposed that matter is made up of small particles, which he called atoms, from the Greek word *atomos,* or indivisible. His model describes atoms as small particles that differ in size and shape, that combine in different configurations, and that are constantly in motion. Many of Democritus' ideas were based on logical thinking.

Figure 18.4: *Dalton's model of the atom. He thought atoms were tiny, hard spheres.*

The idea that theories need to be supported by evidence—often gathered in carefully controlled experiments—became important in the 1600s. Then scientists began to design experiments to support or disprove ideas proposed by earlier thinkers such as Democritus. John Dalton (see previous page) was a chemist who experimented with different gases. His careful measurements gave him repeatable evidence that matter is made up of atoms. His model of the atom is a tiny hard sphere (figure 18.4).

The idea that atoms might contain smaller particles came about through a series of observations of cathode ray tubes, devices that were early versions of fluorescent and neon lights. Julius Plucker (1801-1868) and William Crooks, an English physicist and chemist (1832-1919), and his countryman and fellow physicist Joseph John Thomson (1856-1940) conducted many of these experiments. They showed that different gases placed in the tubes generated streams of particles and conducted current.

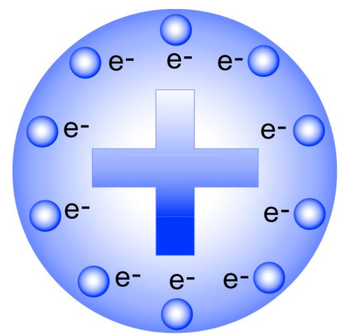
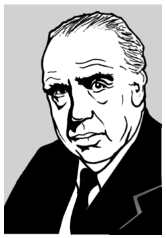


Figure 18.5: *The Thomson model of the atom. The atom is a positive sphere with negative electrons embedded in it. Thomson discovered the electron.*

From these experiments Thomson identified the electron, which carries a negative charge. Thomson knew that atoms were electrically neutral, so he proposed that the atom was a positive sphere with negative electrons embedded in it like raisins in a roll or bun (figure 18.5). The positive sphere and the negative electrons had an equal and opposite amount of charge, so the atom was neutral.

In 1911 in England, physicists Ernest Rutherford (1871-1937), Hans Geiger (1882-1945), and Ernest Marsden (1889-1970), used high-speed, lightweight atoms called alpha particles (generated by radioactive material), to bombard very thin pieces of gold foil. Most of the alpha particles passed through the foil and hit a screen behind it. But surprisingly, some of them bounced back. They must have hit areas of the foil with greater density!

Rutherford hypothesized that an atom must be made up of mostly empty space, allowing most of the alpha particles to pass through the foil. In the center of the atom, he suggested, was a tiny core called a nucleus, which contained positively-charged protons. This is where most of the mass must be found. The lighter electrons occupied the area between the nucleus and the edge of the atom. However, Rutherford did not have enough information to describe the electrons' location more fully.



Danish physicist Niels Bohr (1885-1962) used information about the nature of the emission of light by heated objects to update Rutherford's model. He described electrons as moving around the nucleus in fixed orbits that have a set amount of energy (figure 18.6). Bohr's model of the electron orbits is still used in many analyses of the atom. However, other 20th century experiments have shown that radiating waves can behave like particles in motion, and particles in motion can behave like waves.

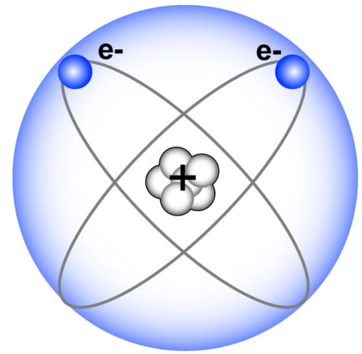


Figure 18.6: *The Bohr model of the atom. Electrons move around the nucleus in fixed orbits.*

In 1923, Louis de Broglie (1892-1987), a French physicist, showed how to analyze a moving particle as a wave. In 1926, Austrian physicist Erwin Schrödinger (1887-1961) built on de Broglie's work and treated electrons as three-dimensional waves. He developed a mathematical description of electrons in atoms that is called the quantum mechanical model of the atom. It is also called the electron cloud model, because his mathematical description cannot be described easily either in words or pictures, so a cloud represents the probability of electron position.

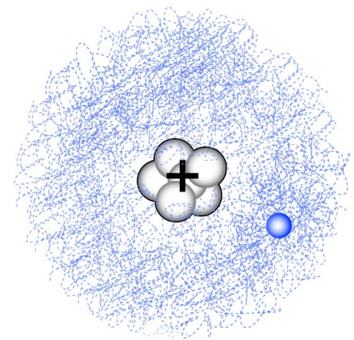


Figure 18.7: *Electrons in the Schrödinger model of the atom. This model is also called the electron cloud model. The cloud represents the probable locations of an electron.*

There still remained a serious problem with the atomic model, a problem Rutherford had identified so many years earlier: missing mass. In 1932, James Chadwick, an English physicist working in Rutherford's laboratory, finally solved the problem. He identified the third important subatomic particle, the neutron. Chadwick (1891-1974) based his work on earlier experiments by French physicists Irene and Frederic Joliot-Curie.

Understanding what is inside an atom has motivated many thousands of scientists and thinkers. What some of them discovered along the way changed the world, influencing not only theoretical spheres such as many of the sciences, philosophy, logic, and other areas, but also those subjects' practical applications. So many new technological developments of the late 20th century have been made possible by atomic research that the present era is often referred to as the "atomic age."