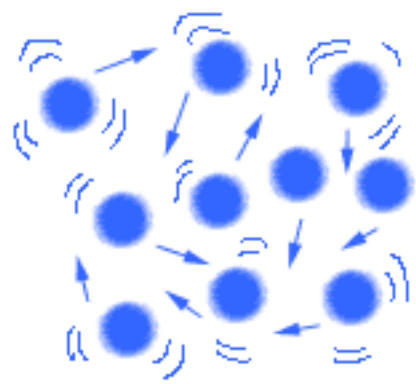
Particle Theory of Matter

By the late 1700s, scientists had adopted the **Particle Theory of Matter**. This theory states that:

- all matter is made up of very tiny particles
- each pure substance has its own kind of particle, different from the particles of other pure substances
- the particles of matter are held together by very strong electric forces
- there are empty spaces between the particles that are much larger than the particles themselves
- the particles are always moving
- the particles move faster at higher temperatures

Many models have attempted to explain what these "very tiny particles" might be. The following is a summary of the most significant models from the last 2400 years.

Democritus (~400 BC)



Around 400 BC, the Greek philosopher Democritus asked the question, "can matter be divided into smaller and smaller pieces forever, or is there a limit to the number of times a piece of matter can be divided?"

Democritus believed that matter could not be divided up endlessly. He believed that, eventually, the smallest possible piece of matter would be obtained. This piece would be indivisible.

He named the smallest piece of matter atomos, which means "not to be cut" in Greek.

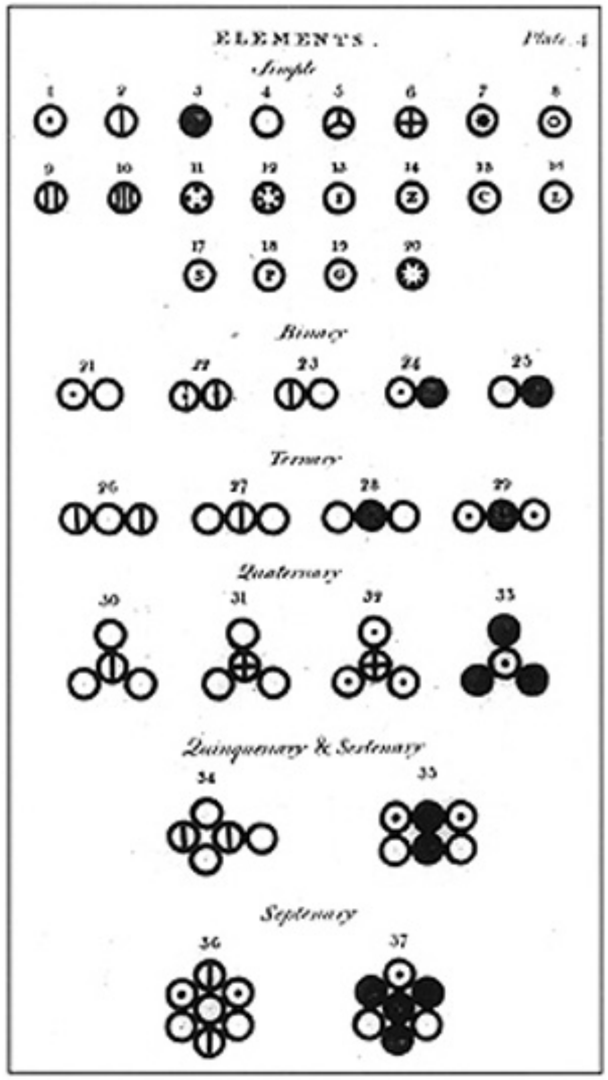
To Democritus, atomos were small, hard particles that came in a variety of shapes and sizes. They were infinite in number, constantly moving, and capable of joining together.

Note: Aristotle, one of the greatest Greek philosopher of the time, supported a different (and ultimately wrong) model, called the four element model. This model proposed that all matter was composed of some combination of four elements: earth, air, fire, and water.

Because Aristotle was so important, Democritus' theory was ignored for nearly 2000 years!

Dalton (~1800 AD)

In the early 1800s, the English chemist John Dalton performed a number of experiments that eventually led to the acceptance of the idea of atoms. Dalton's atomic theory had five main points:



1. Elements are made of extremely small particles called atoms.

2. Atoms of a given element are identical in size, mass, and other properties; atoms of different elements differ in size, mass, and other properties.

3. Atoms cannot be subdivided, created, or destroyed.

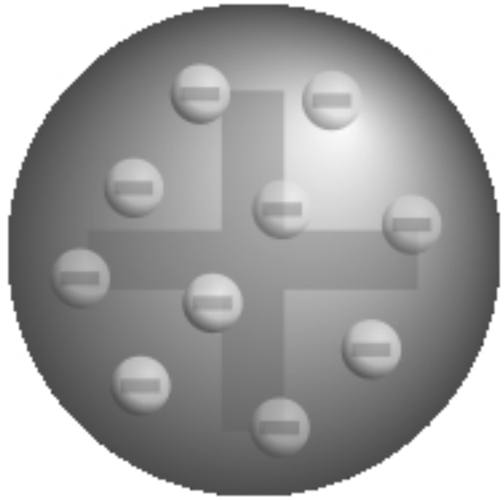
4. Atoms of different elements combine in simple whole-number ratios to form compounds.

5. In chemical reactions, atoms are combined, separated, or rearranged.

Despite being fairly similar to Democritus' theories, Dalton's ideas about how atoms combine to form compounds sets it apart. For this reason, Dalton's model is widely credited as one of the foundations of modern chemistry.

Dalton's model is often referred to as the **billiard ball model**, since he imagined that atoms would resemble tiny solid spheres (like billiard balls).

Thomson (1904 AD)



In the years following Dalton's work, several scientists suggested that atoms were built up from a more fundamental particle. In 1897, the English physicist Joseph John (J.J.) Thomson discovered these "sub-atomic" particles.

Based on his experiments, Thomson concluded that these particles were very light and negatively charged. He called the particles corpuscles, but later scientists preferred the name **electron**.

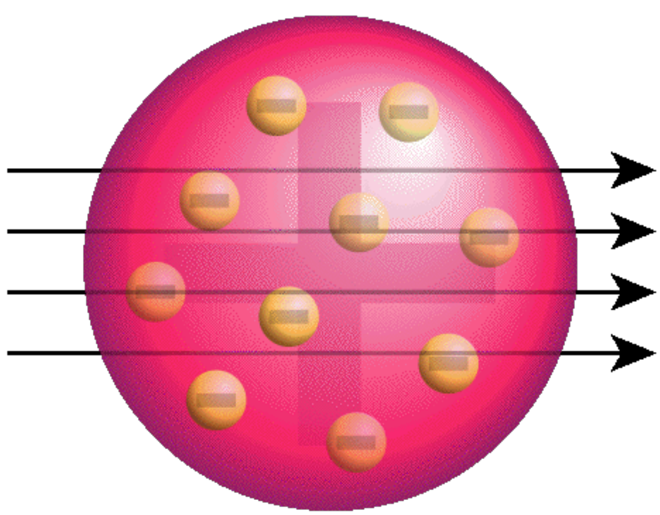
Thomson's discovery of the electron provided the first evidence that an atom is made of even smaller particles.

In 1904, following his discovery of the electron, Thomson proposed a model of the atom that is sometimes called the **plum pudding model**. According to this model, atoms were made from a positively charged substance with negatively charged electrons scattered throughout.

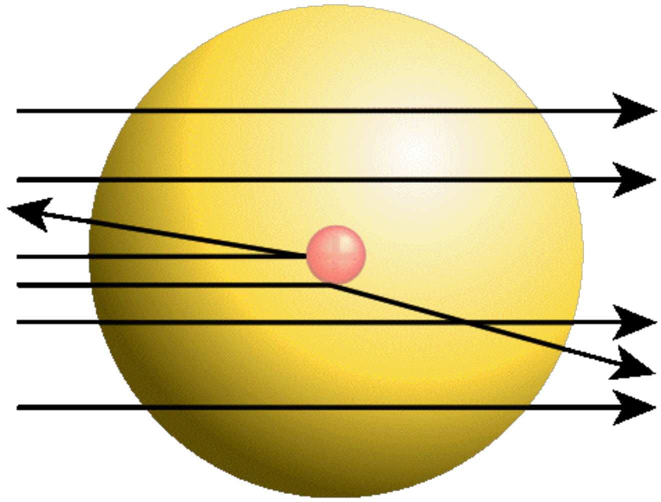
Rutherford (1911)

In 1909, Ernest Rutherford carried out an experiment to probe the structure of the atom. In this experiment, Rutherford fired a beam of positively charged particles at a thin sheet of gold foil. Because of this, it is often referred to as the gold-foil experiment.

At the time of Rutherford's experiment, the prevailing atomic model was Thomson's plum pudding model. Rutherford expected that, if Thomson's model was correct, the positive charges should either pass straight through the sea of positive charge, or be very slightly deflected from their original path (as shown below).

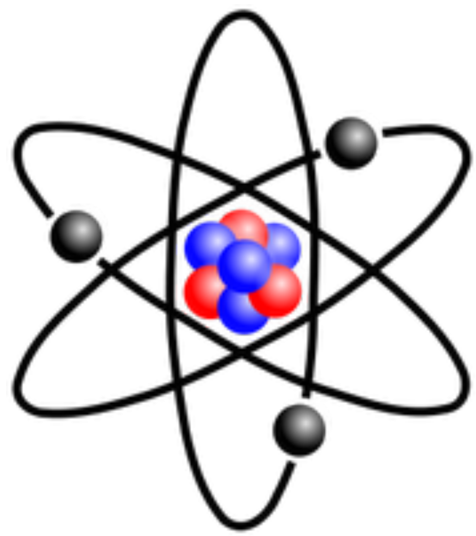


What actually happened, however, was that some of the positive particles were deflected from the gold foil at very high angles (some came straight back!). Most of the remaining particles passed straight through the foil.



The data collected in this experiment demonstrated that the plum pudding model was incorrect. The way the positive particles bounced off the thin foil indicated that most of the mass of the atom was concentrated in one location. The fact that most of the particles went straight through indicated that the atom was mostly empty space.

These observations led Rutherford to propose a new model of the atom. In Rutherford's model, the atom consists of a small, positively charged nucleus located at the center of the atom. The tiny, negatively charged electrons circle the nucleus like planets around the sun.



This is often referred to as the **planetary model** of the atom.

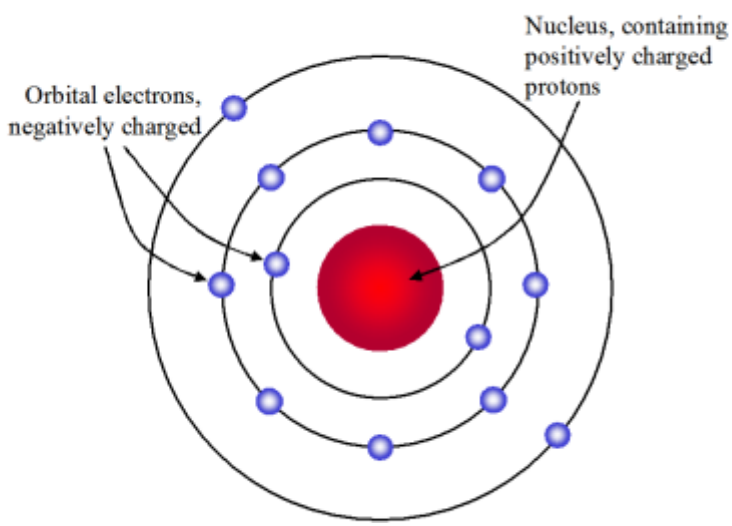
Bohr (1913)

The planetary model of the atom has a major technical problem. The laws of mechanics predict that the electrons orbiting the nucleus should lose energy over time. As a result, the electrons would spiral inwards, eventually colliding with the nucleus.

To overcome this difficulty, Danish physicist Niels Bohr proposed, in 1913, what is now called the **Bohr model** of the atom. According to the Bohr model

- the electrons can only orbit the nucleus in certain specific orbits
- each orbit is located a specific distance from the nucleus
- each orbit can hold a maximum number of electrons (2, 8, and 8 for the first three orbits)
- electrons cannot exist between orbits, but they can move from one orbit to another if excited by heat, light, or electricity

Since the Bohr model is a modification of the Rutherford model, it is often referred to as the Rutherford-Bohr model.



Quantum Mechanical Model

Bohr's model works well for simple atoms (like hydrogen), but it does not explain the behavior of larger, more complex atoms. In addition, the discovery of two more subatomic particles (protons and neutrons) suggested that the Bohr model was no longer adequate to explain atomic structure.

These, and other problems with the Bohr model led to the development of a new model of the atom: the **quantum mechanical model**.

The quantum mechanical model proposes that:

- electrons do not move about the nucleus in definite paths, but instead are grouped in **energy levels**
- energy levels are divided into four **sublevels**
- each sublevel contains several pairs of electrons, called **orbitals**
- the electrons move randomly around the nucleus in electron clouds called **orbitals**

The quantum mechanical model is the current model used to describe the atom. Despite this fact, introductory high school courses (like this one) continue to teach the Bohr model because of its simplicity.