5.1 Evolution of the Atomic Model

Key Terms

atom
electron
subatomic particle
nucleus
proton
neutron

Studying the **atom** has been a fascination of scientists for hundreds of years. Even Greek philosophers, over 2500 years ago, discussed the idea of there being a smallest piece of matter, which they called the *atomos*. Today, many studies look at particles that are much smaller than the atom. Scientists think that these particles will not only tell us more about the atom, but also help to solve many mysteries about the universe and how it formed. Researchers at the Sudbury Neutrino Observatory, shown in **Figure 5.1**, are studying one of these particles, called the *neutrino*. This particle has almost no mass and has been called the "shy particle" because it has been so difficult to detect—even though neutrinos generated by the Sun are continually bombarding us.

atom the smallest particle of an element that retains the identity of the element

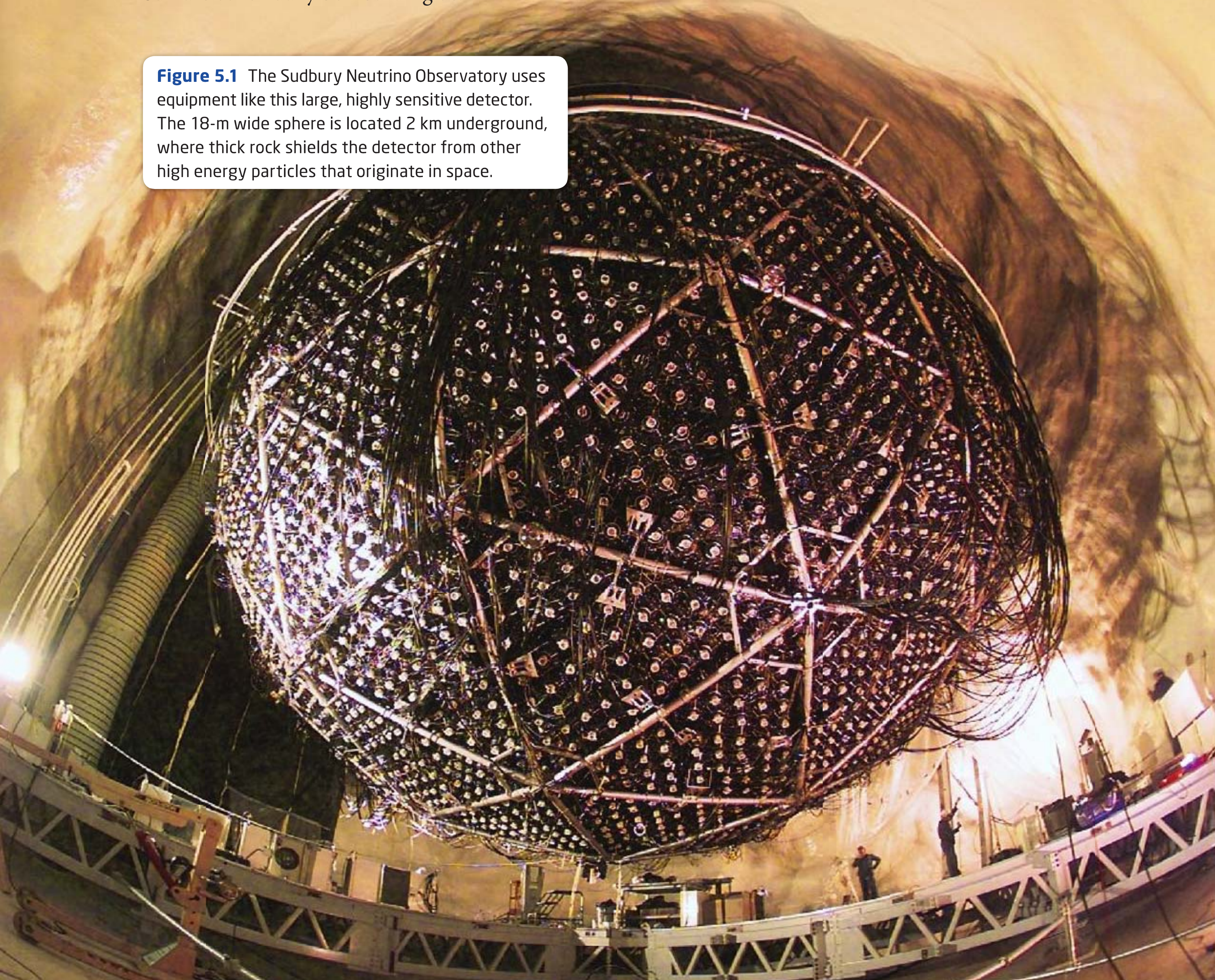

Figure 5.1 The Sudbury Neutrino Observatory uses equipment like this large, highly sensitive detector. The 18-m wide sphere is located 2 km underground, where thick rock shields the detector from other high energy particles that originate in space.

From Particle Theory to Atomic Theory

In Chapter 4, you used the particle theory of matter to describe both elements and compounds in terms of particles. As you know, however, different elements and compounds can have very different properties. In the early 1800s, a British schoolteacher named John Dalton suggested a new way to distinguish between different elements and compounds.

Dalton's Model of the Atom

In the early 1800s, John Dalton experimented with different gases and liquids to study their chemical changes. When he broke down water using an electric current, he observed that the hydrogen and oxygen formed had very different properties from the water. From experimental results like these, Dalton developed a theory that is now called Dalton's atomic theory.

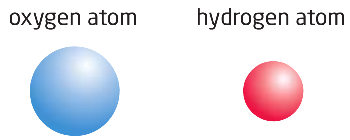

Figure 5.2 Based on his experimental evidence, Dalton stated that different elements are composed of different atoms.

Dalton's Atomic Theory

- All matter is made up of small particles called atoms.
- Atoms cannot be created, destroyed, or divided into smaller particles.
- All atoms of the same element are identical in mass and size. The atoms of one element are different in mass and size from the atoms of other elements.
- Compounds are created when atoms of different elements link together in definite proportions.

Dalton referred to the atom as a small, hard, indestructible sphere that is the smallest particle of an element. Based on his theory, Dalton developed a model of the atom, shown in **Figure 5.2**.

Dalton's work was an invaluable contribution to the understanding of atoms, elements, and matter. In time, however, new experimental evidence showed that Dalton's model of the atom had to change.

Activity 5-2

How Small Is Too Small?

Atoms are extremely small. The average width of an atom is about 10^{-10} m. Do you think you could cut a piece of paper in half enough times to end up with a piece of paper that is the same width as an atom?

Materials

- round-tipped scissors
- strip of paper (28 cm × 2.5 cm)

Procedure

1. Your teacher will give you a pair of scissors and a piece of paper.
2. Cut the piece of paper in half lengthwise, and discard one half. Then cut the remaining piece of paper in half.
3. Repeat step 2 until the remaining piece of paper can no longer be cut. Keep track of how many times you cut the paper in half.

Questions

1. How many times were you able to cut the paper in half?
2. Estimate the approximate width of the narrowest piece of paper you ended up with.
3. Use your estimate in Question 2 to determine the number of times you would need to cut the paper in half until it became 10^{-10} m wide.

Thomson's Discovery of Electrons

Throughout the 1800s, scientists used gas discharge tubes to study the effects of applying electric currents to gases at low pressure. A more modern version of a gas discharge tube is shown in **Figure 5.3**. At very low gas pressures, scientists determined that a ray was emitted from the negatively charged cathode. The ray then moved toward the positively charged anode. Because the ray began at the negative cathode, scientists inferred that the ray carried a negative charge.

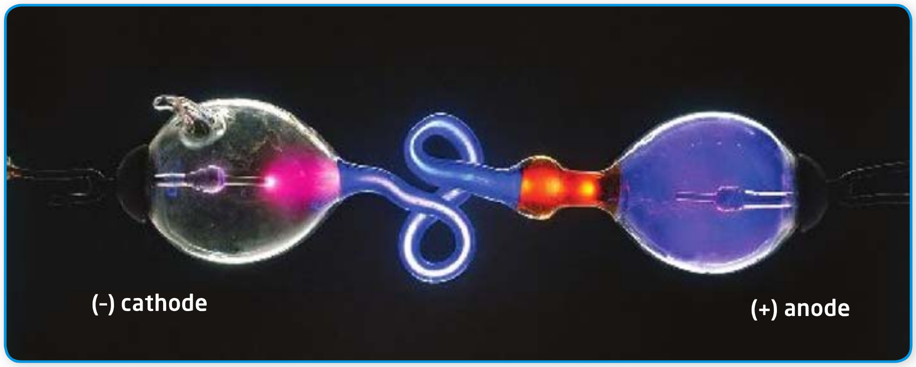

Figure 5.3 When the cathode and anode of this gas discharge tube are connected to a high-energy source of electricity, an electric current exists in the tube. This current causes the gas inside the tube to glow.

In 1897, a British physicist named Joseph John Thomson demonstrated that the rays were indeed made up of negatively charged particles that are found inside atoms. He predicted that the negative particles would be different for each element and would produce characteristically different results in the cathode ray tube. After trying different materials, Thomson was surprised to find that the same kind of ray was always emitted. Therefore, he had to conclude that the same negatively charged particles are found in all atoms. These particles, which have a very small mass, are now called **electrons**. Electrons were the first **subatomic particles** to be discovered and studied.

electron a negatively charged particle within the atom

subatomic particle a particle that is smaller than the atom

Thomson's New Atomic Model

Thomson knew that an atom did not have an overall charge. He inferred that if every atom contains negative particles, then every atom must also contain positively charged material. From this, Thomson reasoned that Dalton's model of an atom—an atom that could not be divided into smaller particles—must be wrong. Thomson proposed a new model of an atom, based on his experimental evidence. He described the atom as a lump of positively charged material, with negative electrons inserted throughout it, as shown in **Figure 5.4**. This model of the atom is also known as the raisin bun model, with the raisins representing electrons. In 1906, Thomson received the Nobel Prize in physics for his work with electric discharges in gases. Interestingly, his son, G. P. Thomson, earned a Nobel Prize in 1937 for further work on electrons.

Although Thomson's model was more accurate than Dalton's model, it was not long before Thomson's model was also revised by one of his students.

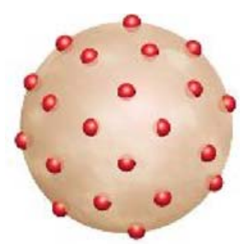

Figure 5.4 Experimental evidence led to Thomson's model of the atom, which shows negative electrons inserted throughout a mass of positively charged material.

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Rutherford's Discovery of the Nucleus

Ernest Rutherford, a scientist from New Zealand, was studying under Thomson when Thomson first proposed his atomic model. In 1898, Rutherford moved to Canada to work as a professor at McGill University in Montréal. There, he became involved in studying *radioactive* elements: elements that give off rays of energy as they break down. In 1908, Rutherford was awarded the Nobel Prize in chemistry for the work he did at McGill University.

When Rutherford returned to England in 1907, he applied his knowledge of radiation to an experiment he designed to investigate the structure of the atom. His experiment involved aiming a beam of positively charged particles, called *alpha particles,* at a very thin sheet of gold foil. The source of the alpha particles was a very small amount of the radioactive element radium. Radium was discovered and isolated by the Polish-born physicist Marie Curie. Without Curie's work, Rutherford might not have had the material he needed to perform his experiment. In fact, Marie Curie's contribution to science has been invaluable. She was awarded both a Nobel Prize in physics (1903) and a Nobel Prize in chemistry (1911).

Based on Thomson's model of the atom, Rutherford expected that the particles being shot toward the gold foil would pass through it in a straight line. He expected that only a small number of particles would be slightly deflected from a straight line. As you can see in **Figure 5.5**, his results were very different from what he expected.

Sense of scale

On average, for every 8000 alpha particles that were fired at the gold foil during Rutherford's famous experiment, only one was reflected backward.

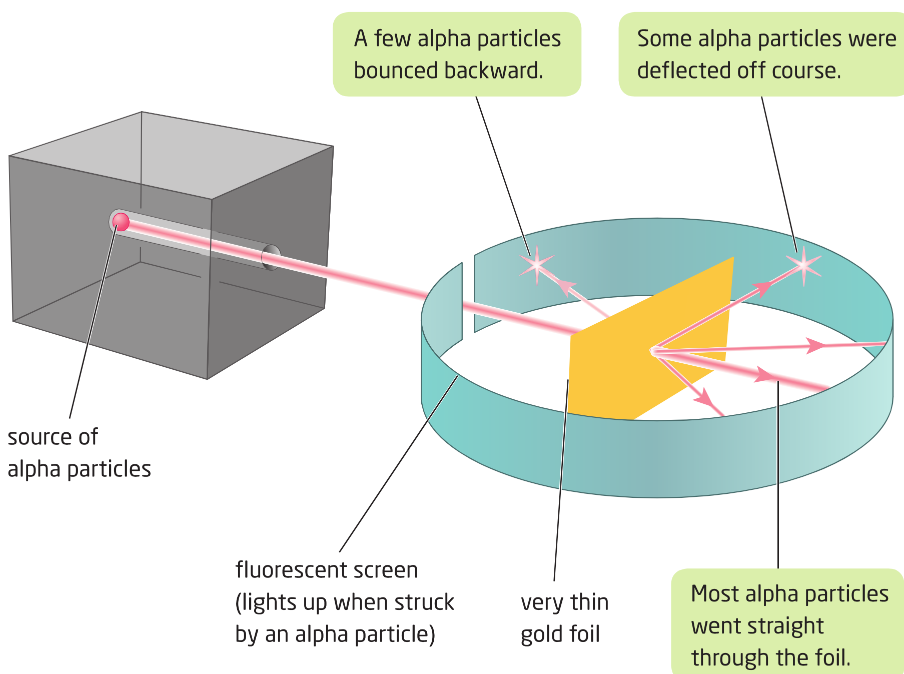


Figure 5.5 Rutherford observed that some of the particles bounced backward, instead of going straight through the foil.

Rutherford's Results

The most surprising observation in Rutherford's experiment was that some of the particles were repelled backward instead of passing right through the foil. This is like shooting a bullet at tissue paper and having it bounce back. Thomson's model of the atom could not provide an explanation for this observation. It could only predict that any particles that were travelling as fast as the alpha particles would simply pass through the spaces between the particles in the foil. As a result, Rutherford had to revise Thomson's model of the atom to fit this observation. Because alpha particles are positively charged, Rutherford inferred that a small region of positive charge in the atoms repelled them. As shown in **Figure 5.6**, he proposed that all the positively charged material in an atom formed a small dense centre, and that the electrons would have to be separated from it. He named this centre the **nucleus** of the atom. He also proposed that the negatively charged electrons revolved around the nucleus. Rutherford's model is sometimes referred to as the planetary model because the motion of the electrons around the nucleus resembles the motion of the planets around the Sun.

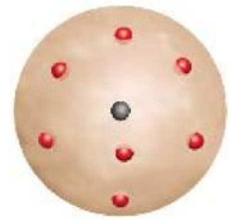


Figure 5.6 Rutherford's atomic model includes a dense, positively charged nucleus in the centre.

nucleus in chemistry, the positively charged centre of an atom

Learning Check

1. Using a diagram, explain how Dalton viewed atoms of a single element and how he viewed atoms of different elements.
2. Thomson's experimental evidence indicated that all atoms contain the same negatively charged particles. Describe Thomson's experimental evidence.
3. What was the difference between Thomson's model of the atom and Dalton's model of the atom?
4. Sketch Rutherford's model of the atom.

Bohr's Description of Energy Levels

Although Rutherford's model of the atom explained the existence of a positively charged nucleus, many scientists opposed this model. At the time, it was known that objects with opposite charges attract each other. The question posed by many scientists was, "If Rutherford's model is correct, why don't the negatively charged electrons spiral into the positive nucleus and collide with it?" In 1912, a Danish scientist named Neils Bohr arrived in England to study with Rutherford. It was Bohr who was able to provide an answer to that question.

Electron Energy Levels

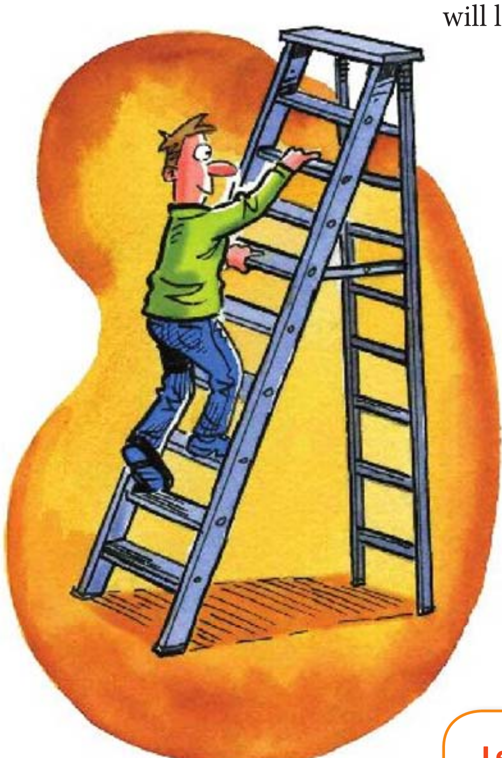
Bohr believed that Rutherford's atomic model was fundamentally correct but not quite complete. Bohr was fascinated by what happens when an electric current passes through hydrogen gas: the hydrogen atoms release bands of light in a pattern, and each band of colour corresponds to a specific amount of energy. Bohr wanted his new theory of the atom to be able to explain the evidence that unique bands of light are given off by all the elements. He proposed that electrons could only move within fixed regions or *energy levels*, rather than being able to move anywhere around the nucleus. For an electron to move from one energy level to a higher one, the electron must absorb a specific amount of energy, called a *quantum*. This can be compared to a person on a ladder, as shown in **Figure 5.7**. Someone on a ladder can be only certain distances above the ground because of the positions of the rungs of the ladder. It is not possible for someone to stand between the rungs of a ladder.

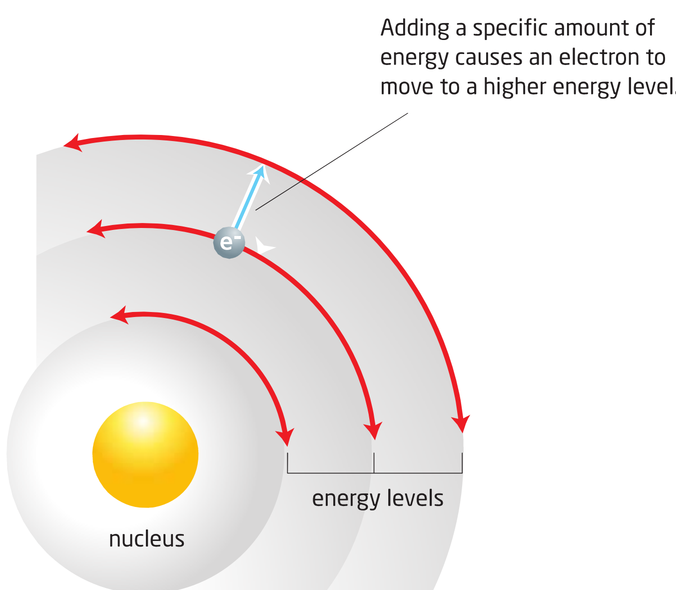
This model of the atom, with a central positive nucleus and electrons in energy levels around the nucleus, is often called the *Bohr-Rutherford model*. Although there have been additional changes and refinements to our understanding of the atom, this model is still very useful today. You will learn how to draw the Bohr-Rutherford model in the next section.

Study Toolkit

Asking Questions While reading this page, stop periodically to ask who, what, and why questions related to energy levels. As you read, record your answers in your notebook. If a question is not answered, check to make sure you understand the relevant material.

Figure 5.7 Bohr proposed that electrons could only occupy certain energy levels. This is similar to how a person on a ladder can only be at certain heights, according to the position of each rung.





Learning Check

5. What did Bohr discover about the movement of electrons?
6. Sketch the Bohr-Rutherford model of the atom.
7. How can an electron move from one energy level to a higher energy level?
8. Provide an everyday example that represents how electrons occupy specific energy levels.

The Nucleus

Since before Thomson proposed his model of the atom, scientists knew that atoms must have some type of positive charge. Rutherford's model of the atom showed that this positive charge had to be within the nucleus. Eventually, after many years of work by several scientists, the positive charge was identified and called the **proton**. Scientific evidence indicated, however, that there had to be more to the nucleus than just the protons. For example, Rutherford knew that the mass of a nucleus was more than the mass of the protons alone. From this, he inferred that the nucleus must be composed of two types of particles: the positively charged proton and a neutral particle. Although scientists knew that this neutral particle existed, it was not until 1932 that someone was able to demonstrate this. A British physicist named James Chadwick, who had once worked for Rutherford, was the first person to show experimentally that neutral particles, now called **neutrons**, help to make up the nuclei of most atoms. In 1935, Chadwick was awarded the Nobel Prize in physics for this discovery.

Sense of scale

Suppose that you represented the nucleus of an atom by a loonie placed at centre ice of a hockey rink. The atom itself would be larger than the hockey arena!

proton a positively charged particle that is part of every atomic nucleus

neutron an uncharged particle that is part of almost every atomic nucleus

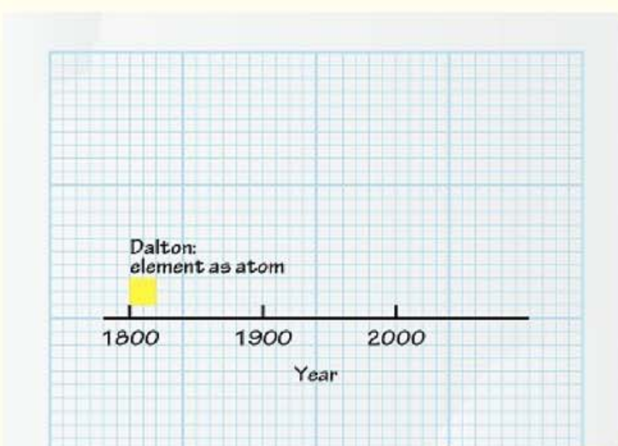
Activity 5-3

Atomic Model Time Line

The model of the atom, as we know it today, is the combined result of the work of many scientists. In this activity, you will draw a time line to summarize the essential discoveries that contributed to the evolution of the atomic model. Do you see any important connections between the scientists on your time line?

Materials

- graph paper
- coloured pencils



Procedure

1. Place a piece of graph paper in landscape orientation.
2. Draw a line along the bottom of the paper. For the scale on your time line, let each square represent 10 years. Begin the scale at the year 1800, and mark the years 1900 and 2000 along the bottom of the paper, below the line you drew.
3. Draw a coloured line on your grid to represent Dalton's work. The coloured lines that you draw need only represent an estimated time frame, based on the dates provided. Print Dalton's name and one or two of his accomplishments. Include a sketch of his proposed atomic model. Add the names and accomplishments of the other scientists you learned about in this section. If there is some type of relationship between the scientists (for example, if one was a student of another), include the relationship on your time line.

Questions

1. How does your time line show that the development of the model of the atom was dependent on scientists working together and communicating with each other?
2. How do you think improvements in technologies helped to improve the model of the atom?