1.3 Atomic Theory

Atoms are composed of particles including protons, neutrons, and electrons. Atoms have a tiny, positively charged, dense nucleus made up of protons and neutrons. Surrounding the nucleus are one or more electrons. A neutral atom has the same number of electrons as protons. Electrons occupy specific energy levels in the space around the nucleus. The number of protons in an atom is called the atomic number.

Words to Know

atom
electron
neutron
nucleus
proton
subatomic particle

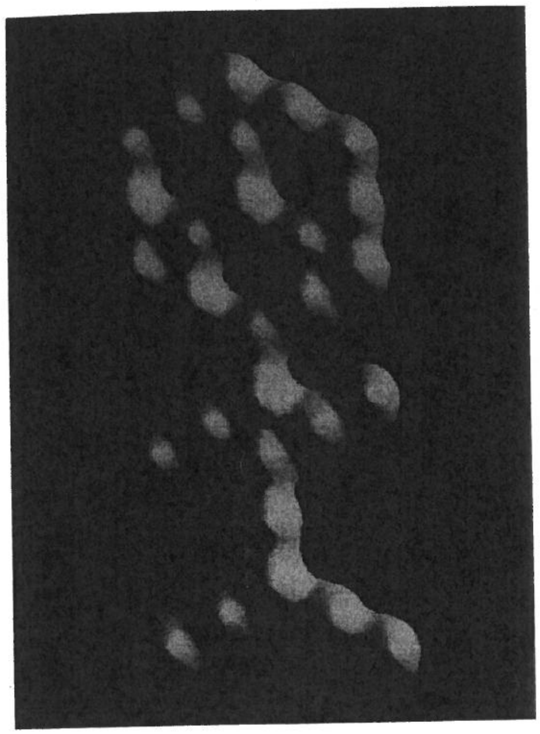

Figure 1.12 An image of "carbon monoxide person" showing individual atoms of carbon and oxygen.

Today, we know that everything—a breath of air, a pod of killer whales, a video game, and you—is made of huge numbers of tiny particles like those shown in Figure 1.12. But for thousands of years, people described the composition of matter in very different ways.

Greek philosophers debated 2500 years ago whether matter could be divided endlessly into smaller and smaller pieces, or whether there was a smallest piece. They called this smallest piece *atomos*, from which we get the word atom. However, Aristotle, the most respected philosopher of the day, argued against the idea that all matter is made of tiny particles called atoms. He described matter instead as being made up of different combinations of earth, air, fire, and water. Aristotle's view was highly influential. No one seriously challenged it for the next 2000 years.

Did You Know?

The ancient Chinese believed the world was based on five elements: earth, water, fire, metal, and wood. These elements promoted but also restrained each other. For example, water restrained fire but promoted wood. Fire promoted earth but restrained metal. In this way, the universe remained in balance.

Teacher Demonstration

In this demonstration, your teacher will put a small amount of water into an empty soft drink can and bring the water to a boil. The can will then be turned upside down in a tray of cold water.

What to Do

1. While the water is heating in the soft drink can, try to imagine what is happening inside the can. What would you see if the can were transparent? What is happening to individual particles of water during this process?
2. Watch as the can is inverted in the cold water. Try to think of an explanation for what is going on and discuss it with your neighbour.

What Did You Find Out?

1. Suggest a reason for what happened to the can. Use the particle model in your explanation.
2. Predict what would happen if the experiment were repeated using an identical can but without any water in it.

Early Ideas about Matter

Alchemists were researchers who worked in Europe and the Middle East during the Middle Ages (Figure 1.13). They did experiment with matter, but their main purpose was more technological than scientific. They wanted to turn common metals such as lead and mercury into gold. In pursuing that goal, they combined their investigations with mystical thinking and often worked in secret. Although they tried for more than a thousand years, they did not turn anything into gold.

By the 19th century, many people were doing experiments that led them to question the earth-air-fire-water view of matter. This was the beginning of a revolution in our understanding of matter.

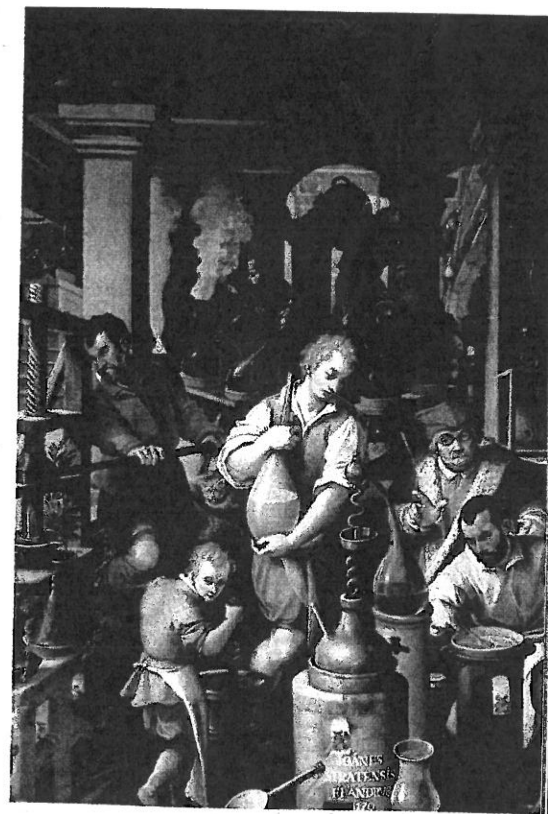

Figure 1.13 The alchemists tried to turn base metals into gold.

Development of the Atomic Theory

Many men and women in different countries of the world have contributed to our understanding of atoms. The following describes several highlights of their research.

John Dalton

John Dalton (1766–1844) is credited with developing a theory that was a new way of describing matter. He was a British schoolteacher and a scholar. His interest in the gases that make up Earth's atmosphere led him to investigate the composition of a number of substances, such as carbon dioxide, water, and nitrogen oxide. In explaining some of his experimental results, he suggested that the particles that make up matter are like small, hard spheres that are different for different elements. He defined an atom as the smallest particle of an element (Figure 1.14 on the next page). This is the basis for what is now known as Dalton's atomic theory. His theory is summarized on the next page.

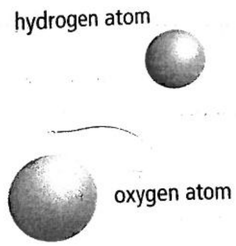

Figure 1.14 Dalton's model: Different elements consist of different atoms.

Dalton's Atomic Theory

- All matter is made 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, but they 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.

According to Dalton's theory, the atoms that make up gold are different from the atoms that make up lead, and atoms cannot be created or destroyed. You can use these points to explain why the alchemists were unable to change lead into gold (Figure 1.15).

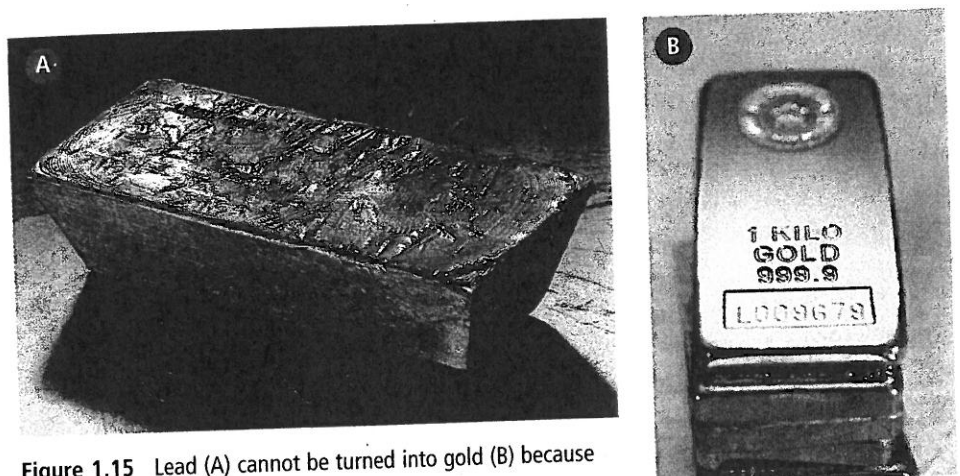

Figure 1.15 Lead (A) cannot be turned into gold (B) because lead atoms cannot change into gold atoms.

J. J. Thomson

Joseph John Thomson (1856–1940) was a British physicist who studied electric currents in gas discharge tubes, which are related to today's fluorescent lights. He determined in 1897 that the currents were streams of negatively charged particles, later called **electrons**. He found that all substances used in his discharge tubes produced these particles. From the results of his experiments, he reasoned that all atoms must therefore contain such particles. In other words, he was hypothesizing that atoms are made up of much smaller particles. This was a startling proposal, since most scientists at the time thought that atoms were indivisible.

Thomson proposed a "raisin bun" model of the atom. His model pictured a positively charged ball like a bun with negatively charged particles embedded in it like raisins (Figure 1.16). His model was short-lived, however. Experiments by his student Ernest Rutherford soon pointed to a more accurate picture of the particles of an atom.

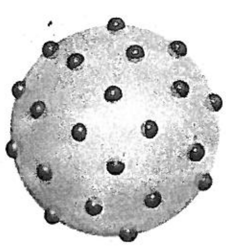

Figure 1.16 Thomson's model: Atoms have smaller particles called electrons.

Ernest Rutherford

Ernest Rutherford (1871–1937) was a scientist from New Zealand who worked for a while at McGill University in Montreal. In 1909 he designed an experiment to probe inside atoms. He exposed a very thin sheet of gold to a stream of high speed, heavy particles that had a positive charge, called alpha particles. The alpha particles were like tiny bullets. Rutherford wanted to see what would happen to alpha particles when they made contact with the gold atoms. He put a detector screen around the gold foil; an alpha particle became visible whenever it struck the screen. Figure 1.17 shows the set-up for this experiment.

Word Connect

"Alpha" is the first letter of the Greek alphabet. Rutherford chose the name alpha particle because he was naming the first radioactive rays he discovered in uranium radiation.

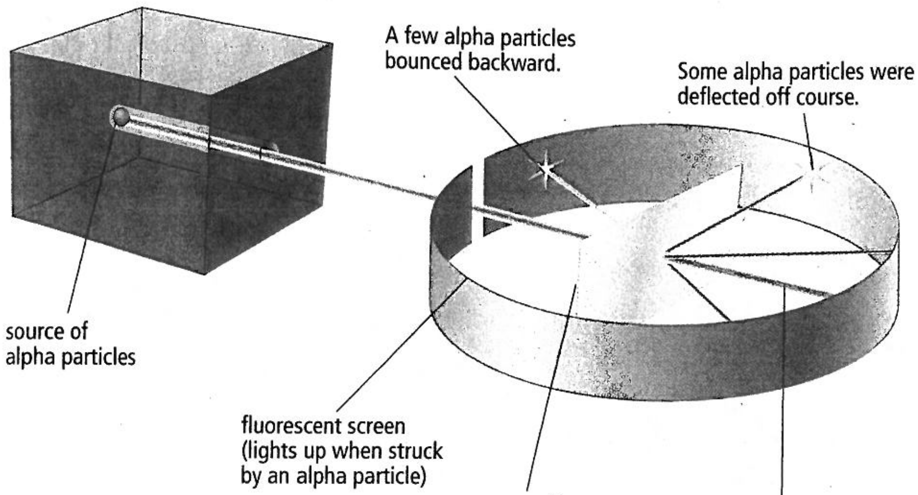

Figure 1.17 Ernest Rutherford discovered the nucleus of the atom with his famous gold foil experiment.

Rutherford's results indicated that most of the alpha particles went right through the gold atoms without being affected. He had expected this, because he knew there must be relatively large space within atoms. However, he was astonished to see that a few alpha particles rebounded from the foil much as a ball rebounds from a solid wall. Rutherford had discovered the **nucleus**—the tiny, dense, positively charged centre of the atom. This was a tremendously important discovery. Rutherford had allowed us to peer inside the nucleus for the first time. A decade later, he also established that there must be at least two kinds of particles inside the nucleus of an atom. One particle, later called a **proton**, had a positive electric charge, and the other particle, called a **neutron,** had no electric charge (Figure 1.18).

Planetary Model

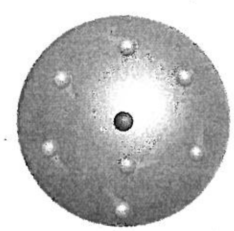

Figure 1.18 Rutherford's model: Electrons move about a nucleus.

Niels Bohr

Niels Bohr (1885–1962), a Danish physicist working under Rutherford, studied the regions surrounding the nucleus, which were now known to contain negatively charged electrons. Bohr studied the results of experiments on the light released by gaseous samples of atoms, such as those of hydrogen. In the experiments, the gases had been made to glow by passing an electric current through them. He proposed that electrons surround the nucleus in specific energy "levels" or "shells." This meant that each electron has a particular amount of energy.

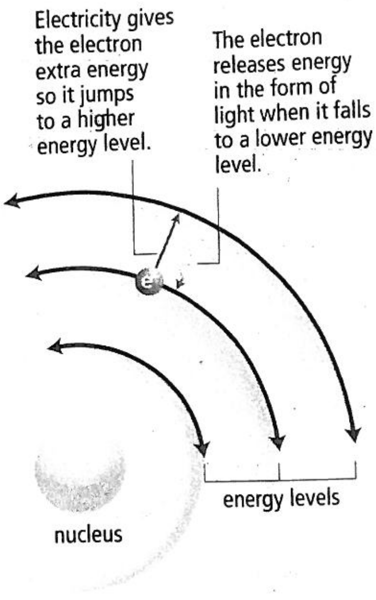

Figure 1.19 Bohr's model: Electrons have different amounts of energy.

If you have ever seen a neon light, you have seen the effect of electrons jumping from one energy level to another (Figure 1.19). When electricity is added to the neon gas, the electrons in the neon atoms gain extra energy. They jump from low to high energy levels. When the electrons drop to lower energy levels, they release energy in the form of visible light. This light is evidence that the electrons exist in specific energy levels and can jump back and forth between them.

Inside the Atom

An **atom** is the smallest particle of an element that retains the properties of the element. We now know that atoms are not the smallest, or most basic, particles. All atoms are made up of three kinds of smaller particles called **subatomic particles** ("sub-" means below). They are called protons, neutrons, and electrons. Each has its own set of properties. All three particles have mass, but only protons and electrons have an electric charge. Neutrons have no electric charge at all.

Mass

Protons and neutrons have much more mass than electrons. This means that when you lift up a large rock, it is the protons and neutrons in the rock that weigh it down. While protons and neutrons have about the same mass as each other, they have about 1800 times more mass than an electron.

Electric charge

Electric charge comes in two types: positive and negative. Protons have a positive charge, and electrons have a negative charge. Because negative and positive charges attract each other, protons (positive) and electrons (negative) are attracted together. Each proton counts as +1, and each electron counts as −1. All atoms have an equal number of protons and electrons. This means that the charges add up to zero, making the atom uncharged or neutral.

Figure 1.20 shows the structure of one type of atom. Table 1.2 lists the three subatomic particles and some of their properties.

Figure 1.20 Structure of a carbon-13 atom

Connection

Section 7.1 has more information about electric charge in atoms.

Table 1.2 Subatomic Particles

Name	Symbol	Relative Mass	Electric Charge	Location in the Atom
Proton	p	1836	+	Nucleus
Neutron	n	1837	0	Nucleus
Electron	e	1	−	Surrounding the nucleus

The nucleus

The nucleus is a tiny region at the centre of the atom.

- It would take 10 000 nuclei lined up side by side to stretch across the diameter of a typical atom.
- The nucleus always has a positive charge because of its protons. For any atom more complicated than hydrogen, the nucleus must also contain neutrons. Hydrogen is the only element that has a single proton as its nucleus and a nuclear charge of +1 (Figure 1.21). Neutrons have no charge, so the nucleus of a nitrogen atom, with seven protons, has a charge of +7. A nucleus with 92 protons (as in uranium) has a charge of +92.
- Protons and neutrons are held in the nucleus and cannot normally enter or leave it.

Electrons

Electrons occupy special regions called energy levels, or shells, which surround the nucleus.

- The region that electrons occupy accounts for well over 99.99 percent of the volume of an atom. If a nucleus were the size of a hockey puck sitting at centre ice, the whole atom would include the entire ice sheet, the spectator seats, the building, and the parking lot surrounding it.
- Each electron occupies one whole energy level at a time. An electron is not like a fast-moving particle racing around the nucleus. It is more like a spread-out negative charge that exists in the whole region all at once.

Suggested Activity

Conduct an Investigation 1-3C on page 35

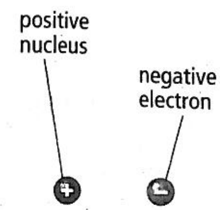

Figure 1.21 Structure of a hydrogen atom

Reading Check

1. What was the main goal of the alchemists?
2. What was the difference between Dalton's model of the atom and Thomson's model?
3. What did Rutherford discover in his gold foil experiment?
4. What was the difference between Thomson's model of the atom and Rutherford's model?
5. What did Bohr discover about how electrons are arranged in atoms?
6. What type of charge does the nucleus have?
7. What type of charge do electrons have?

Explore More

Ernest Rutherford was a student of J. J. Thomson. Niels Bohr was a student of Ernest Rutherford. Each man replaced his teacher's model of the atom with a more refined model. All three received Nobel Prizes for their contributions to science. Find out more about these and other researchers at **www.bcscience9.ca.**