7.1 Development of a Modern Atomic Theory

LEARNING TIP

Set a purpose for your reading. As you read Section 7.1, ask yourself, "How has the atomic theory changed with new discoveries?"

How can we see inside something that is not visible to us? The early Greek philosophers pondered this question, and it continues to challenge scientists 2000 years later. Today, scientists use conceptual and physical models to study phenomena that are not easily observed, and they test those models through experiments. Scientific models predict the behaviour of systems. Scientists evaluate the models they use by observing the behaviour of systems in controlled experiments.

TRY THIS: Seeing the Invisible

Skills Focus: observing, analyzing, inferring, interpreting data

Scientists have learned much about the invisible structure of matter by indirect observations, models, and inferences. In this activity, you will use indirect observations to make inferences about something that you can't see.

Materials: blindfold; a hard, flat object (a book); a hard, round object (a bucket); a soft object (a balled-up jacket or a backpack); 4–6 table-tennis balls

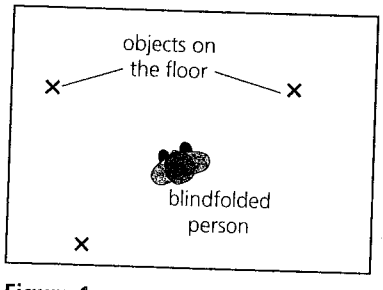


Figure 1

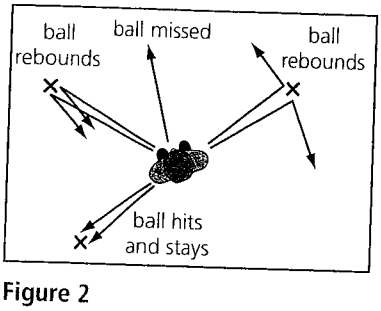


Figure 2

1. Work in groups. Have one group member sit blindfolded on the floor in a clear area, facing in one direction.
2. Place the three objects on the floor, out of reach of the blindfolded student.
3. Draw a diagram of the setup, showing only the location of the objects and the blindfolded student. With a pencil, draw a small X to show the centre of each object (Figure 1).
4. The blindfolded student will roll the table-tennis balls, one at a time, in a variety of directions to try and hit the objects. Draw the paths of the balls on your diagram, noting if they miss, hit and stay, or hit and rebound off the objects (Figure 2).
5. The blindfolded student will keep rolling the balls until each object has been hit several times. Then remove the objects from the floor and erase the X's from your diagram.
6. Exchange diagrams with another group.

A. Can your group identify the objects and determine their locations from the diagram? Indicate the objects on the diagram. Check with the other group to see if you were correct.

The First Scientific Atomic Theory

By the late 1700s, most scientists agreed that an element was a type of matter that could not be broken down into simpler substances. More than 30 elements had been identified by this time. Scientists knew that elements would combine to form compounds during chemical reactions, but they could not adequately explain how this happened. In 1808, the English chemist John Dalton proposed an atomic theory of matter that could explain the behaviour of chemical reactions (Figure 3). Dalton envisioned the **atom**, the smallest piece of any element, as a smooth solid sphere, without an electrical charge.

Dalton's Theory

- All matter is made of atoms, which are particles that are too small to see.
- Each element has its own kind of atom, with its own particular mass.
- All atoms of any one element are identical.
- Compounds are created when atoms of different elements combine in a specific ratio.
- Atoms cannot be created, destroyed, or subdivided during chemical changes.

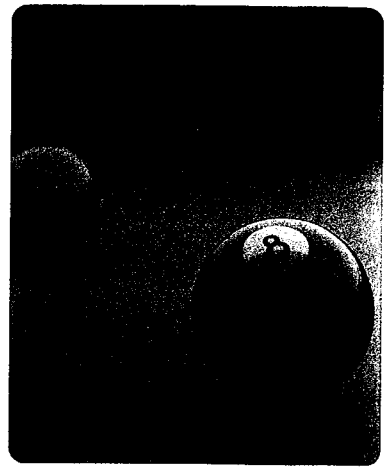
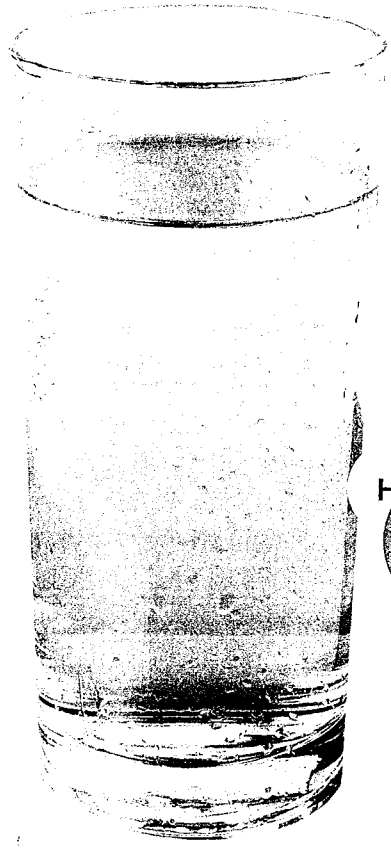


Figure 3 According to Dalton's theory, the atom was a solid sphere—much like this billiard ball.

Atoms and Molecules

The terms "atom" and "molecule" were used interchangeably until the early 19th century. Scientists now consider a molecule to be two or more non-metallic atoms combined—the smallest particle of most compounds (Figure 4.) Compounds that are formed from metals and non-metals technically do not have molecules. You will learn more about these compounds in this chapter and in Chapter 8.



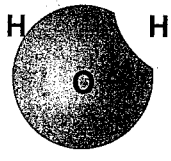


Figure 4 Water is a compound that is made up of molecules. Each water molecule is made up of two hydrogen atoms joined to one oxygen atom.

New Discoveries Revise the Atomic Theory

Have you ever walked across a carpet on a cold, dry day, and received a shock when you touched a doorknob? Dalton's theory explained chemical reactions reasonably well, but it could not account for the shock you received from the doorknob—the phenomenon of static electricity. More importantly, in the 1830s, Michael Faraday showed that atoms could gain electric charges. Dalton's theory did not include charged atoms (Figure 5), and so was modified to include the following ideas:

Revisions to Dalton's Theory

- Matter must contain positive and negative charges.
- Opposite charges attract, and like charges repel.
- Atoms combine to form the particles of a compound because of the electrical attraction between charged atoms.

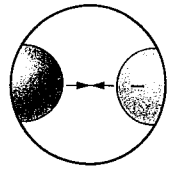


Figure 5 The atoms that form the particles of a compound are held together by the electrical attraction of positive and negative charges.

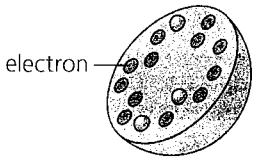


Figure 6 Thomson's "raisin-bun" model of an atom

The revised theory explained how atoms formed compounds, but scientists still did not know how the atoms became charged.

In the late 1800s, the discovery of a particle that is many times smaller than the smallest atom required another major change to the atomic theory. This particle, the negatively-charged **electron**, was discovered by J.J. Thomson in 1898. Thomson proposed that the atom is mostly made up of positively-charged matter, with small negatively charged electrons scattered randomly throughout. By 1904 Thomson's "raisin-bun" model became accepted by most scientists (Figure 6). The atomic theory was once again revised, to include these ideas:

LEARNING TIP

Explain to a partner (using the key terms from page 204 to 207—atom, electron, nucleus, protons, and neutrons) how the atomic theory has changed with new discoveries.

Thomson's Revision to the Atomic Theory: Electrons

- Atoms contain electrons.
- The electrons have a negative charge and a very small mass.
- The rest of the atom has a positive charge.
- The electrons are embedded randomly in the positive part of the atom.
- Electrons can be removed from, or added to, atoms to create charged atoms.

Did You KNOW

Cathode Ray Tube

Thomson used a device called a cathode ray tube (CRT) to measure the properties of electrons. The CRT is the basis for older televisions and computer monitors.

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The Theory Is Changed to Explain the Nucleus

In the Try This activity at the beginning of this section, you used small, light table-tennis balls to probe the structure and organization of the space around you. A similar technique was used by Ernest Rutherford to probe the structure of an atom. Working first at McGill University in Montreal, then at Cambridge University in England, Rutherford bombarded a very thin piece of gold foil (only a few atoms thick) with small, positively charged particles. Expecting most of the particles to be deflected slightly by the gold atoms (as predicted by Thomson's revision to the atomic theory), he was shocked to discover that most of the particles passed straight through as if passing through empty space. Moreover, a few particles bounced straight back. Based on this evidence, Rutherford concluded that almost all the matter in an atom is concentrated in a very small space (Figure 7).

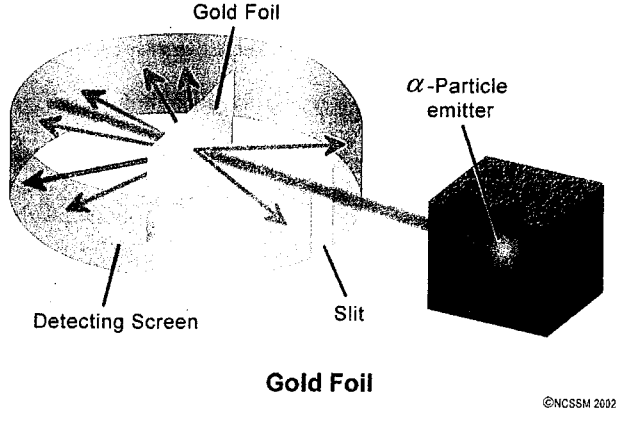

Figure 7 Rutherford's experiment showed that most of the particles fired at the gold atoms passed straight through. Some particles bounced back as if they had struck something of great mass, but very small, with a large positive charge. Rutherford had discovered the nucleus.

This dramatic and unexpected result required a significant change in how scientists viewed the atom. Rutherford reasoned that most of the mass of an atom, and all the positive charge, is concentrated in the centre. This location is called the **nucleus**, and it contains two types of particles: positively charged **protons** and uncharged **neutrons**. The remaining mass, and all the negative charge, is made up of electrons orbiting the nucleus. The electrons are held in orbit by the attraction between charged objects. Thus, there are three **subatomic particles**: electrons, protons, and neutrons. In 1911, Rutherford proposed his nuclear model of the atom (Figure 8).

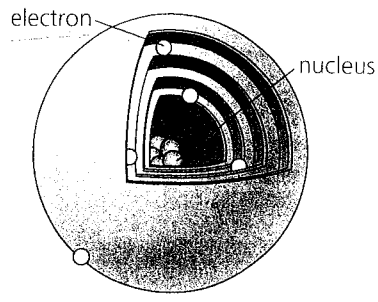

Figure 8 Rutherford's "nuclear" model of the atom

Rutherford's Revisions to the Atomic Theory: The Nucleus

- The nucleus contains all of the positive charge and most of the mass of the atom.
- The nucleus contains positively charged protons and uncharged neutrons.
- Neutrons have the same mass as protons.
- The nucleus is very small, compared with the size of the atom.
- The electrons orbit the nucleus, like satellites around a planet.
- The mass of an electron is $\frac{1}{1800}$ the mass of a proton.
- The size of the atom is determined by the size of the orbit of the electrons.
- There is only empty space between the electrons and the nucleus.

When Rutherford published his theory, he already knew it was not completely correct. A well-established theory of electromagnetic waves predicted that Rutherford's orbiting electrons should continuously emit energy, which they do not. Atomic theory required a further modification.

If you would like to learn more about the science and history behind the discoveries that changed the atomic theory, go to **www.science.nelson.com**

Did You KNOW

Visualizing the Atom

The size of an atom is hard for us to understand, because we don't have the ability to observe it directly. We can, however, imagine the scale of an atom by comparing an atom with something we can see.

- If a hydrogen atom was the size of an apple, then a real apple would be as large as Earth.
- If the nucleus in an atom was the size of a golf ball, the electrons of the atom would be more than one kilometre away and the size of a grain of sand.

TRY THIS: Building an Atom

Skills Focus: creating models, communicating

You can demonstrate your understanding of the three atomic theories presented in this section using household materials.

Possible Materials: table-tennis balls, small styrofoam balls, foam packing peanuts, or candies (for an edible model!); hot glue, putty, or cake icing; string, wooden skewers, or toothpicks

Use extreme caution when working with hot glue. Hot glue can cause severe burns.

1. Using a variety of household objects and your creativity, build three models of an atom, based on the theories of Dalton, Thomson, and Rutherford.

A. Write a paragraph that describes the main differences between your three models.

7.1 CHECK YOUR Understanding

1. Who was the first person to propose that matter is made of atoms?
2. Describe the physical appearance of an atom according to each of the following scientists.
   (a) Dalton
   (b) Thomson
   (c) Rutherford
3. (a) What are the main points of Dalton's theory?
   (b) Which of these main points were unchanged in the later theories?
4. (a) What did Michael Faraday discover that led to changes in Dalton's atomic theory?
   (b) What were these changes?
5. Who first proposed each of the following in the development of the atomic theory?
   (a) Atoms cannot be created, destroyed, or subdivided.
   (b) The atom has a nucleus that contains most of the mass and all of the positive charge.
   (c) Small negative particles are spread throughout a positive mass.
   (d) Atoms contain electrons and protons.
   (e) Atoms can become charged.
6. What did Thomson discover and use as the basis of his revision of the atomic theory?
7. Why is Thomson's model of the atom referred to as the "raisin-bun model?"
8. What unexpected result did Rutherford obtain in his gold-foil experiment?
9. Why did Rutherford know that his model would need to be modified right away?
10. What is found between the electrons and the nucleus in an atom (Figure 9)?

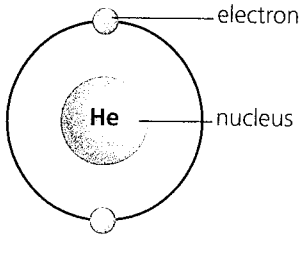

Figure 9

11. According to Rutherford's theory, how do we determine the size of an atom?
12. Neutrons have no charge. What do they contribute to the atom?
13. Look at the three objects below (Figure 10). Each object could be considered a model for one of the versions of the atomic theory.
   (a) Indicate which version of the atomic theory (Dalton, Thomson, Rutherford) matches each object.
   (b) Use one or two sentences to describe how the features of the object match the theory.

(a)

(b)

(c)

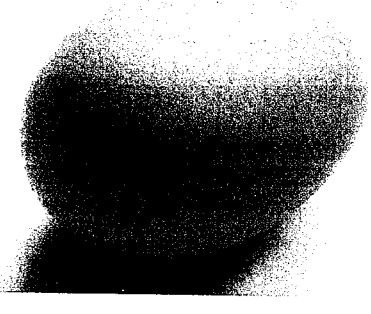

Figure 10 (a) chocolate chips (b) hamburger bun with seeds (c) an egg