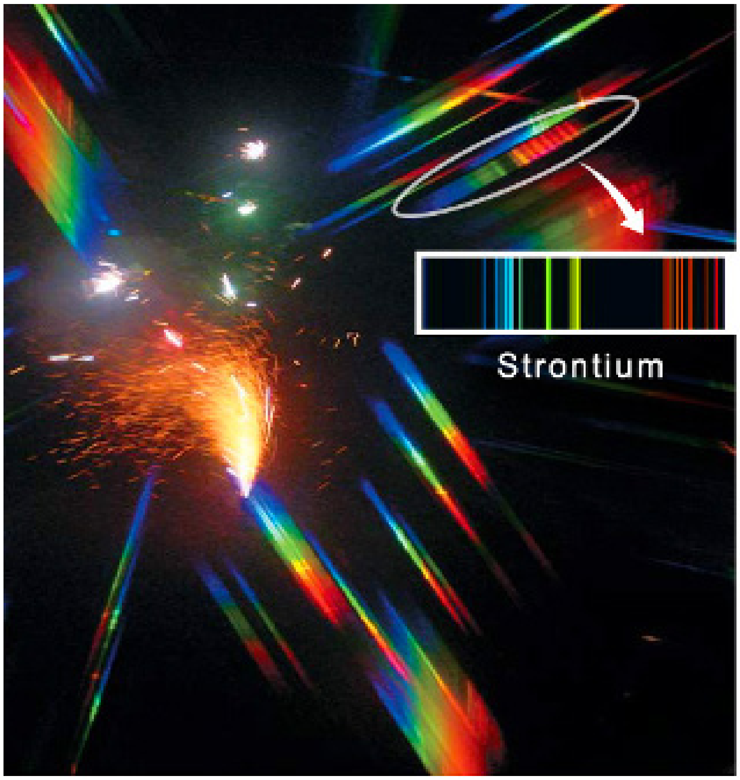


Chapter 4

Subatomic Particles

THE MAIN IDEA

Atoms are made of electrons, protons, and neutrons

4.1 Physical and Conceptual Models
4.2 The Electron
4.3 The Atomic Nucleus
4.4 Protons and Neutrons
4.5 Light Is a Form of Energy
4.6 Atomic Spectra and the Quantum
4.7 Electrons Exhibit Wave Properties
4.8 Orbitals and Energy-Level Diagrams
4.9 The Shell Model and Periodic Table

Λ Each element emits its own characteristic spectral pattern, which can be used to identify the element just as fingerprint can be used to identify a person. The inset image shows the spectral pattern from strontium, which is a common ingredient of fireworks.

You have already learned that matter is made of fundamental units we call atoms. In this chapter we'll be exploring how atoms themselves are made of even more fundamental units called subatomic particles, which include electrons, protons, and neutrons. We'll be looking at this from a historical perspective, beginning with the discovery of the electron in the early 20th century. You will learn that an atom is mostly empty space with nearly all of its mass concentrated in a tiny center called the atomic nucleus.

As electrons whiz around the atomic nucleus, they can absorb or emit energy in the form of light, which travels in distinct little packets called photons. Evidence of this is seen by looking at glowing elements through a glass prism, as shown in the opening photograph for this chapter. By studying this light, scientists have developed models of the atom. A few of these models are presented in this chapter. Through these models, which continue to be refined even today, we gain a powerful understanding of how atoms behave.

4.1 Physical and Conceptual Models

Atoms are so amazingly small that the number of them in a baseball is roughly equal to the number of Ping-Pong balls that could fit inside a hollow sphere as big as the Earth, as **Figure 4.1** illustrates.

Atoms are so small that we can never see them in the usual sense. This is because light travels in waves, and atoms are smaller than the wavelengths of visible light. As illustrated in **Figure 4.2**, a single object, at any magnification will remain invisible if it is smaller than the wavelength of light used to

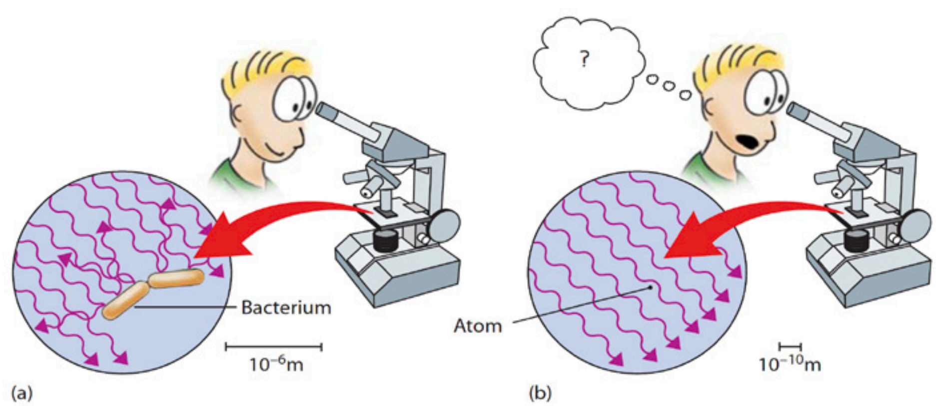
< Figure 4.1
If the Earth were filled with nothing but Ping-Pong balls, the number of balls would be huge and roughly equal to the number of atoms in a baseball. Said differently, if a baseball were the size of the Earth, one of its atoms would be the size of a Ping-Pong ball.

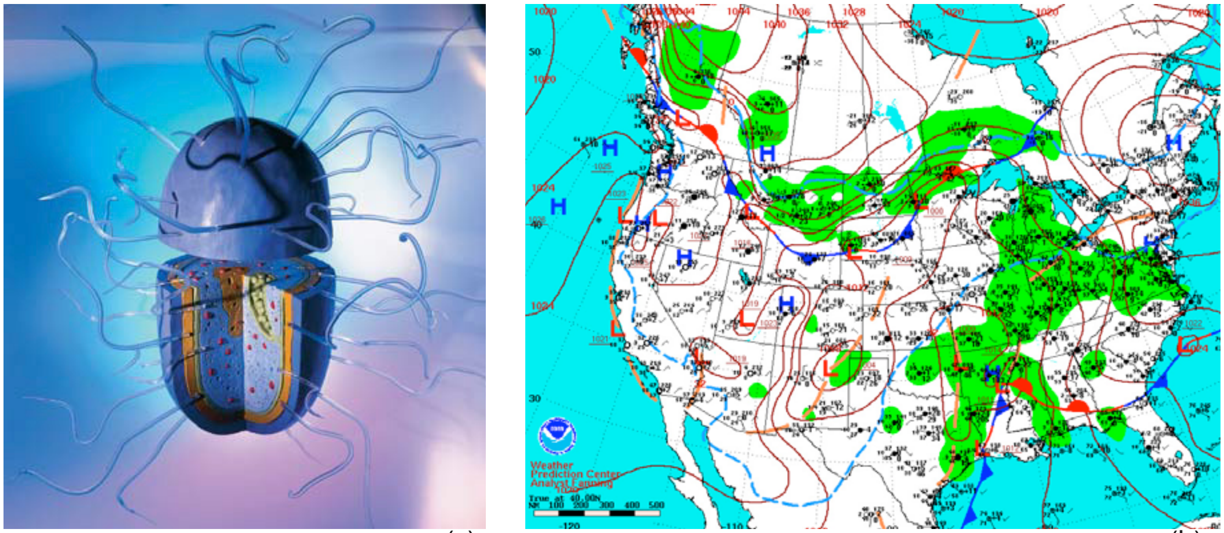
illuminate it. We could stack microscope on top of microscope and still not see an individual atom.

Although we cannot see atoms directly, we can generate images of them indirectly. As was discussed in Section 3.8, the scanning probe microscope does this by dragging an ultrathin needle back and forth over the surface of a sample. The result is a computer-generated image of the positions of the atoms on the surface. While such an image is both remarkable and useful, it is not a photograph showing the actual appearance of the atoms. Atoms do not have solid surfaces, as implied by these images. Rather, as we'll be discussing in this chapter, atoms are made of mostly empty space. Envision what empty space looks like. Then you will have a more accurate picture of what it's really like down there at the level of atoms and molecules.

A very small or very large visible object can be represented with a physical model, which is a model that replicates the object at a more convenient scale. **Figure 4.3a**, for instance, shows a large-scale physical model of a microorganism that a biology student might use to study the microorganism's structure. Because atoms are invisible, however, we cannot use a

Figure 4.2 >
(a) A bacterium is visible because it is much larger than the wavelengths of visible light. We can see the bacterium through the microscope because the bacterium reflects visible light back toward the eye. (b) An atom is invisible because it is smaller than the wavelengths of visible light, which pass by the atom with no reflection.





(a) (b)

Figure 4.3
(a) This large-scale model of a microorganism is a physical model. (b) Weather forecasters rely on conceptual models such as this map to predict the behavior of weather systems.

physical model to represent them. In other words, we cannot simply scale up the atom to a larger size, as we might with a microorganism. So, rather than describing the atom with a physical model, chemists use a conceptual model, which is a representation of a system that helps us predict how the system behaves. The more accurate a conceptual model, the more accurately it predicts the behavior of the system.

For example, the weather is best described using a conceptual model like the one shown in **Figure 4.3b**. Such a model shows how the various components of the system—humidity, atmospheric pressure, temperature, electric charge, the motion of large masses of air—interact with one another. Other systems that can be described by conceptual models are the economy, population growth, the spread of diseases, and team sports.

Like the weather, the atom is a complex system of interacting ultra-tiny components, notably electrons, protons, and neutrons. The atom, therefore, is best described with a conceptual model. Thus, you should be careful not to interpret any visual representation of an atomic conceptual model as a recreation of an actual atom. In Section 4.6, for example, you will be introduced to the planetary model of the atom, wherein electrons are shown orbiting a dense center of protons and neutrons (the atomic nucleus) much as planets orbit the Sun. This planetary model is limited, however, in that it fails to explain many properties of atoms. Therefore, newer and more accurate (and more complicated) conceptual models of the atom have since been introduced. In these models, electrons appear as a cloud, but even these models have their limitations.

READING CHECK
What is an accurate conceptual model able to predict?

FOR YOUR INFORMATION

Atoms are so small that there are more than the number of breaths in Earth's atmosphere. Within a few years, the atoms of your breath are uniformly mixed throughout the atmosphere. What this means is that anyone anywhere on the earth inhaling a breath of air takes in numerous atoms that were once part of you. And, of course, the reverse is true: you inhale atoms that were once part of everyone who has ever lived. We are literally breathing one another.

In this textbook, our focus is on conceptual atomic models that are easily represented by visual images, including the planetary model and a slightly more sophisticated model in which electrons are grouped in units called shells. Despite their limitations, such images are excellent guides to learning chemistry, especially for the beginning student. We will introduce these models as they were developed historically, beginning with the discovery of the subatomic particles.

CONCEPT **CHECK**

A basketball coach describes a playing strategy to her team by way of sketches on a game card. Do the illustrations represent a physical model or a conceptual model?

CHECK YOUR ANSWER The sketches are a conceptual model the coach uses to describe a system (the players on the court), with the hope of achieving an outcome (winning the game).