3.1 Solids, Liquids, and Gases

A chemist’s primary interest, as described in Chapter 1, is the behavior of matter, but to understand the behavior of matter, we must first understand its internal structure. What are the internal differences between the granite of Half Dome in Yosemite, the olive oil added to your pasta sauce, and the helium in a child’s balloon? A simple model of the structure of matter will help us begin to answer this question.

A model is a simplified approximation of reality. For example, architects often build a model of a construction project before actual construction begins. The architect’s model is not an exact description of the project, but it is still very useful as a representation of what the structure will be like. Scientific models are like the architects’ models; they are simplified but useful representations of something real. In science, however, the models are not always physical entities. Sometimes they are sets of ideas instead.

In the last hundred years, there has been a tremendous increase in our understanding of the physical world, but much of that understanding is based on extremely complicated ideas and mathematics. The application of the most sophisticated forms of these modern ideas is difficult, and not very useful to those of us who are not well trained in modern physics and high-level mathematics. Therefore, scientists have developed simplified models for visualizing, explaining, and predicting physical phenomena. For example, we are about to examine a model that will help you visualize the tiny particles of the solid metal in a car’s engine block, the liquid gasoline in the car’s tank, and the gaseous exhaust fumes that escape from its tail pipe. The model will help you understand why solids have constant shape and volume at a constant temperature, why liquids have a constant volume but can change their shape, and why gases can easily change both their shape and volume. Our model of the structure of solids, liquids, and gases says that

- All matter is composed of tiny particles. (We will start by picturing these as tiny spheres.)
- These particles are in constant motion.
- The amount of motion is related to temperature. Increased temperature reflects increased motion.
- Solids, gases, and liquids differ in the freedom of motion of their particles and in how strongly the particles attract each other.

**Solids**

Why does the metal in a car’s engine block retain its shape as you drive down the road while the fuel in the car’s gas tank conforms to the shape of the tank? What’s happening on the submicroscopic level when solid metal is melted to a liquid, and why can molten metal take the shape of a mold used to form an engine block? Our model will help us to answer these questions.

According to our model, the particles of a solid can be pictured as spheres held closely together by strong mutual attractions. (Figure 3.1). All the particles are in
motion, bumping and tugging one another. Because they’re so crowded and exert such strong mutual attractions, however, they only jostle in place. Picture yourself riding on particle 1 in Figure 3.1. An instant before the time captured in the figure, your particle was bumped by particle 3 and sent toward particle 5. (The curved lines in the figure represent the momentary direction of each particle’s motion and its relative velocity.) This motion continues until the combination of a bump from particle 5 and tugging from particles 2, 3, and 4 quickly bring you back toward your original position. Perhaps your particle will now head toward particle 2 at a greater velocity than it had before, but again, a combination of bumps and tugs will send you back into the small space between the same particles. A ride on any of the particles in a solid would be a wild one, with constant changes in direction and velocity, but each particle will occupy the same small space and have the same neighbors.

When a solid is heated, the average speed of the moving particles increases. Faster-moving particles collide more violently, causing each particle to push its neighbors farther away. Therefore, an increase in temperature usually causes a solid to expand somewhat (Figure 3.1).
**Liquids**

If any solid is heated enough, the movements of the particles become sufficiently powerful to push the other particles around them completely out of position. Look again at Figure 3.1. If your particle is moving fast enough, it can push adjacent particles out of the way entirely and move to a new position. For those adjacent particles to make way for yours, however, they must push the other particles around them aside. In other words, for one particle to move out of its place in a solid, all of the particles must be able to move. The organized structure collapses, and the solid becomes a liquid.

Particles in a liquid are still close together, but there is generally more empty space between them than in a solid. Thus, when a solid substance melts to form a liquid, it usually expands to fill a slightly larger volume. Even so, attractions between the particles keep them a certain average distance apart, so the volume of the liquid stays constant at a constant temperature. On the other hand, because the particles in a liquid are moving faster and there is more empty space between them, the attractions are easily broken and reformed, and the particles change location freely. Eventually, each particle gets a complete tour of the container. This freedom of movement allows liquids to flow, taking on the shape of their container. It is this freedom of movement that allows liquid metal to be poured into a mold where it takes the shape of an engine block (Figure 3.2).

**Figure 3.2**
Particles of a Liquid

- Particles move fast enough for attractions to be constantly broken and reformed.
- Particles are less organized, with slightly more space between them than in the solid.
- Particles move throughout the container.
Gases

If you’ve ever spilled gasoline while filling your car, you know how quickly the smell finds your nose. Our model can help you understand why.

Picture yourself riding on a particle in liquid gasoline. Because the particle is moving throughout the liquid, it will eventually come to the liquid’s surface. Its direction of movement may carry it beyond the surface into the space above the liquid, but the attraction of the particles behind it will most likely draw it back again. On the other hand, if your particle is moving fast enough, it can move far enough away from the other particles to break the attractions pulling it back. This is the process by which liquid is converted to gas. The conversion of liquid to gas is called vaporization or evaporation (Figure 3.3).

You might also have noticed, while pumping gasoline, that the fumes smell stronger on a hot day than on a cold day. When the gasoline’s temperature is higher, its particles are moving faster and are therefore more likely to escape from the liquid, so that more of them reach your nose.

The particles of a gas are much farther apart than in a solid or liquid. In the air around us, for example, the average distance between particles is about ten times the diameter of each particle. This leads to the gas particles themselves taking up only about 0.1% of the total volume. The other 99.9% of the total volume is empty space. In contrast, the particles of a liquid fill about 70% of the liquid’s total volume. According to the model, each particle in a gas moves freely in a straight-line path until it collides with another gas particle or with the particles of a liquid or solid. The particles are usually moving fast enough to break any attraction that might form between them, so after two particles collide, they bounce off each other and continue on their way alone.
Picture yourself riding on a gas particle at the instant captured in Figure 3.4. You are so far away from any other particles that you think you are alone in the container. An instant later, you collide with a particle that seems to have come out of nowhere. The collision changes your direction and velocity. In the next instant, you are again moving freely, as if your particle was the only one in the universe.

Unlike the liquid, which has a constant volume, the rapid, ever-changing, and unrestricted movement of the gas particles allows gases to expand to fill any shape or volume of container. This movement also allows our cars’ exhaust gases to move freely out of the cars and into the air we breathe.

You can review the information in this section and see particles of solids, liquids, and gases in motion at the textbook’s Web site.

3.2 The Chemical Elements

Chemists, like curious children, learn about the world around them by taking things apart. Instead of dissecting music boxes and battery-operated rabbits, however, they attempt to dismantle matter, because their goal is to understand the substances from which things are made. The model of the structure of matter presented in the last section describes the behavior of the particles in a solid, a liquid, or a gas. But what about the nature of the particles themselves? Are all the particles in a solid, liquid, or gas identical? And what are the particles made of? We begin our search for the answers to these questions by analyzing a simple glass of water with table salt dissolved in it.