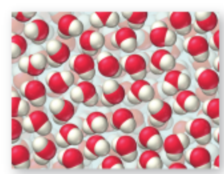
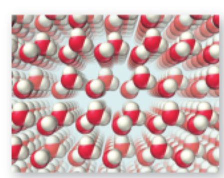
11.2: Solids, Liquids, and Gases: A Molecular Comparison

We are all familiar with solids, liquids, and gases. Water, gasoline, rubbing alcohol, and nail polish remover are common liquids. Ice, dry ice, and diamond are familiar solids. Oxygen, nitrogen, and helium are common gases. To begin to understand the differences between the three common states of matter, examine Table 11.1, which shows the density and molar volume of water in its three different states, along with molecular representations of each state. Notice that the densities of the solid and liquid states are much greater than the density of the gas state. Notice also that the solid and liquid states are more similar in density and molar volume to one another than they are to the gas state. The molecular representations show the reason for these differences. The molecules in liquid water and ice are in close contact with one another—essentially touching—while those in gaseous water are separated by large distances. The molecular representation of gaseous water in Table 11.1 is actually out of proportion—the water molecules in the figure should be much farther apart given their size. (Only a fraction of a molecule could be included in the table if it were drawn to scale.) From the molar volumes, we know that 18.0 mL of liquid water (slightly more than a tablespoon) occupies 30.5 L when converted to gas at 100 °C (at atmospheric pressure). The low density of gaseous water is a direct result of this large separation between molecules.

Table 11.1 The Three States of Water

Phase	Temperature (°C)	Density (g/cm^3, at 1 atm)	Molar Volume	Molecular View
Gas (steam)	100	5.90×10^{-4}	30.5 L	
Liquid (water)	20	0.998	18.0 mL	
Solid (ice)	0	0.917	19.6 mL	

Notice also that solid water is slightly less dense than liquid water. This is *atypical* behavior. Most solids are slightly more dense than their corresponding liquids because the molecules move closer together upon freezing. As we will discuss in Section 11.9, ice is less dense than liquid water because the unique crystal structure of ice results in water molecules moving slightly farther apart upon freezing.

Properties of the States of Matter

A major difference between liquids and solids is the freedom of movement of the constituent molecules or atoms. Even though the atoms or molecules in a liquid are in close contact, thermal energy partially overcomes the attractions between them, allowing them to move around one another. This is not the case in solids; the atoms or molecules in a solid are virtually locked in their positions, only vibrating back and forth about a fixed point. Table 11.2 summarizes the properties of liquids and solids, as well as the properties of gases for comparison.

Table 11.2 **Properties of the States of Matter**

State	Density	Shape	Volume
Gas	Low	Indefinite	Indefinite
Liquid	High	Indefinite	Definite
Solid	High	Definite	Definite

Liquids assume the shape of their containers because the atoms or molecules that compose liquids are free to flow (or move around one another). When we pour water into a beaker, the water flows and assumes the shape of the beaker (Figure 11.1). Liquids are not easily compressed because the molecules or atoms that compose them are already in close contact—they cannot be pushed much closer together. The molecules in a gas, by contrast, have a great deal of space between them and are easily forced into a smaller volume by an increase in external pressure (Figure 11.2).

Figure 11.1 **Liquids Assume the Shapes of Their Containers**

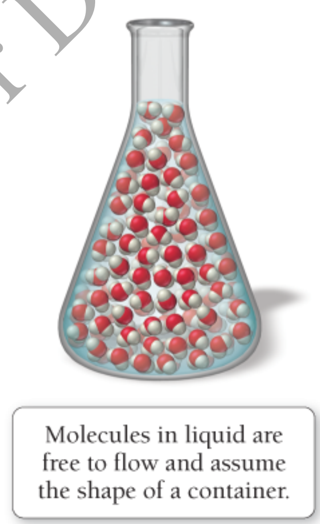
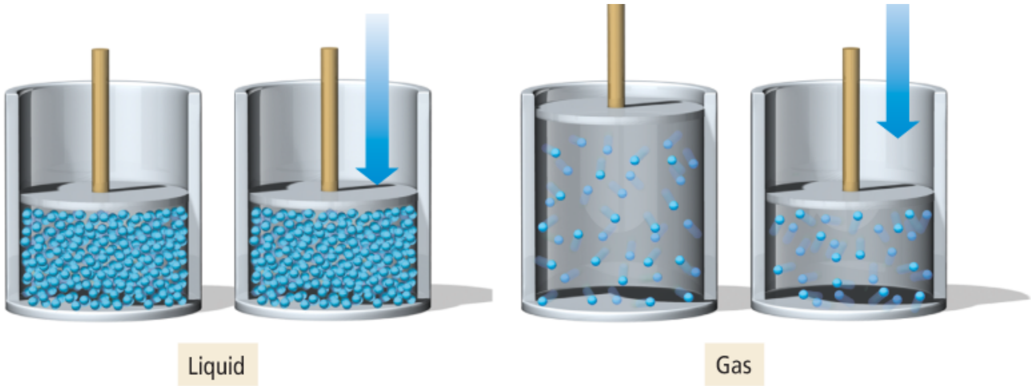
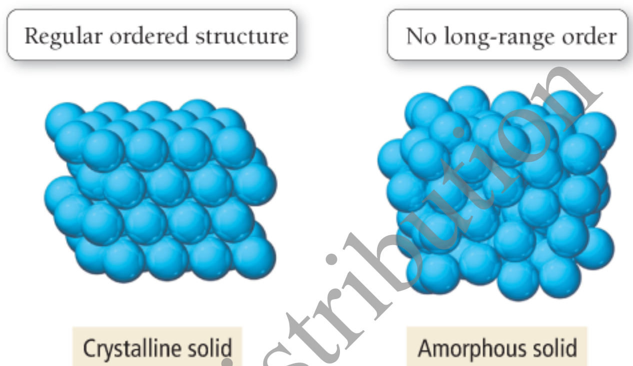


Figure 11.2 **Gases Are Compressible**



The definite shape of solids is due to the relative immobility of their atoms or molecules. Like liquids, solids have a definite volume and generally cannot be compressed because the molecules or atoms composing them are already in close contact. Solids may be **crystalline**, in which case the atoms or molecules that compose them are arranged in a well-ordered three-dimensional array, or they may be **amorphous**, in which case the atoms or molecules that compose them have no long-range order (Figure 11.3).

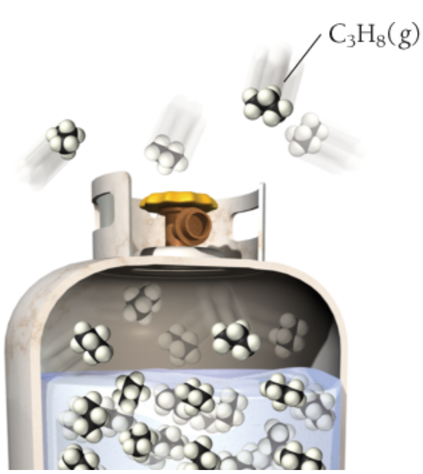
Figure 11.3 Crystalline and Amorphous Solids

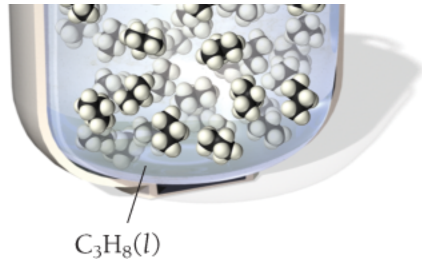


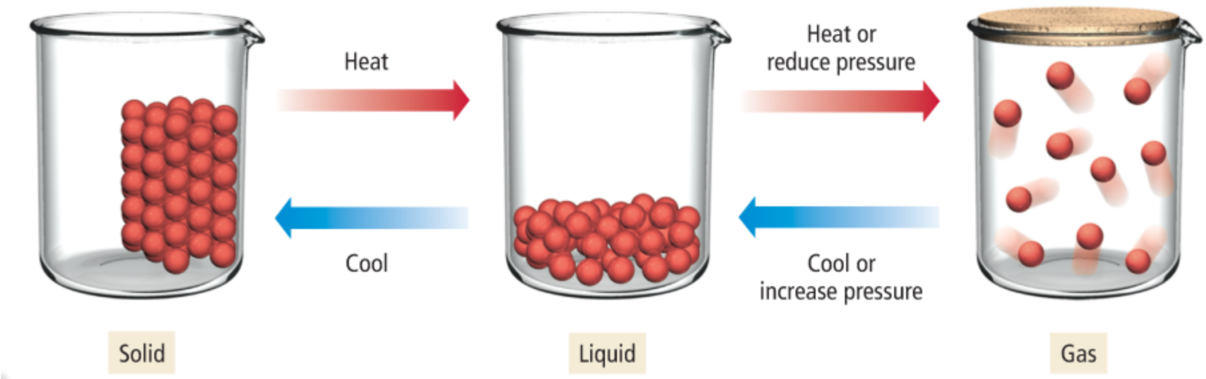
> According to some definitions, an amorphous solid is a unique state, different from the normal solid state because it lacks any long-range order.

Changes between States

We can transform one state of matter to another by changing the temperature, pressure, or both. For example, we convert solid ice to liquid water by heating, and liquid water to solid ice by cooling. The following diagram shows the three states of matter and the changes in conditions that commonly induce transitions between the states.







The propane in an LP gas tank is in the liquid state. When you open the tank, some propane vaporizes and escapes as a gas.

We can induce a transition between the liquid and gas state, not only by heating and cooling, but also by changing the pressure. In general, increases in pressure favor the denser state, so increasing the pressure of a gas sample results in a transition to the liquid state. A familiar example of this phenomenon occurs in the LP (liquefied petroleum) gas used as a fuel for outdoor grills and lanterns. LP gas is composed primarily of propane, a gas at room temperature and atmospheric pressure. However, it liquefies at pressures exceeding about 2.7 atm. The propane you buy in a tank is under pressure and therefore in the liquid form. When you open the tank, some of the propane escapes as a gas, lowering the pressure in the tank for a brief moment. Immediately, however, some of the liquid propane evaporates, replacing the gas that escaped. Storing gases like propane as liquids is efficient because, in their liquid form, they occupy much less space.

Conceptual Connection 11.1 State Changes

Interactive