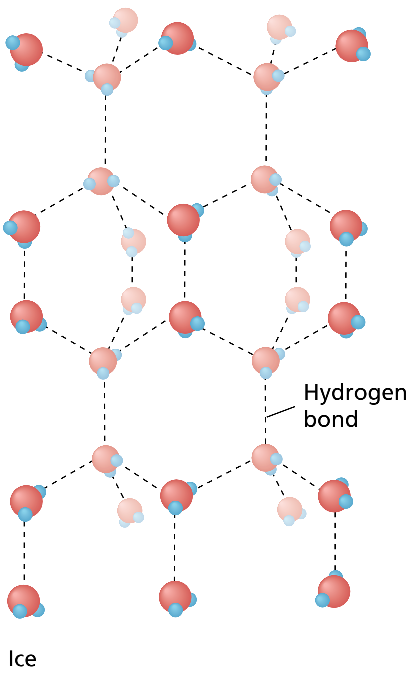

FIGURE 19 Ice contains the same types of bonding as liquid water. However, the structure of the hydrogen bonding is much more rigid and open than it is in liquid water.

molecules is so great that the rigid open structure of the ice crystals breaks down, and ice turns into liquid water.

Figures 18 and 19 also show that the hydrogen bonds between molecules of liquid water at 0.°C are fewer and more disordered than those between molecules of ice at the same temperature. Because the rigid open structure of ice has broken down, water molecules can crowd closer together. Thus, liquid water is denser than ice.

As the liquid water is warmed from 0.°C, the water molecules crowd still closer together. Water molecules are as tightly packed as possible at 3.98°C. At temperatures above 3.98°C, the increasing kinetic energy of the water molecules causes them to overcome molecular attractions. The molecules move farther apart as the temperature continues to rise. As the temperature approaches the boiling point, groups of liquid water molecules absorb enough energy to break up into separate molecules. Because of hydrogen bonding between water molecules, a high kinetic energy is needed, causing water's boiling point to be relatively high (100.°C) compared to other liquids that have similar molar masses.

Physical Properties of Water

At room temperature, pure liquid water is transparent, odorless, tasteless, and almost colorless. Any observable odor or taste is caused by impurities, such as dissolved minerals, liquids, or gases.

As shown by its phase diagram in **Figure 16,** water freezes and ice melts at 0.°C at a pressure of 1 atm (101.3 kPa). The molar enthalpy of fusion of ice is 6.009 kJ/mol. That value is relatively large compared with the molar enthalpy of fusion of other solids. As you have read, water has the unusual property of expanding in volume as it freezes, because its molecules form an open rigid structure. As a result, ice at 0.°C has a density of only about 0.917 g/cm^3, but liquid water at 0.°C has a density of 0.999 84 g/cm^3.

This lower density explains why ice floats in liquid water. The insulating effect of floating ice is particularly important in the case of large bodies of water. If ice were more dense than liquid water, it would sink to the bottom of lakes and ponds, where it would be less likely to melt completely. The water of such bodies of water in temperate climates would eventually freeze solid, killing nearly all the living things in it.

Under a pressure of 1 atm (101.3 kPa), water boils at 100.°C. At this temperature, water's molar enthalpy of vaporization is 40.79 kJ/mol. Both the boiling point and the molar enthalpy of vaporization of water are quite high compared with those of nonpolar substances of comparable molecular mass, such as methane. The values are high because of the strong hydrogen bonding that must be overcome for boiling to occur. The high molar enthalpy of vaporization makes water useful for household steam-heating systems. The steam (vaporized water) stores a great deal of energy as heat. When the steam condenses in radiators, great quantities of energy are released.