23.1 Water

We live on a watery planet. All life on Earth depends on this combination of hydrogen and oxygen atoms. Fortunately, we have a lot of water on Earth. For example, if you could form the water in the oceans into a giant ball, you would have a sphere that is about half the size of the moon.

While water is one of our most common substances, its combination of unique properties makes it essential to life. We cannot live without water. In fact, our bodies are made up of about 60 percent water. What are the properties of water that make it so unique?

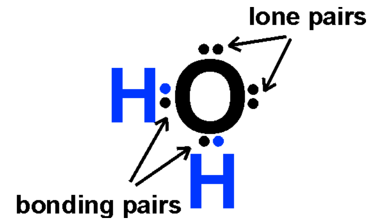
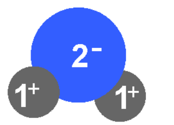


Figure 23.1: *The Lewis dot structure for water. The electron pairs involved in forming the bonds are called bonding pairs. The pairs that are not involved are called lone pairs.*

The shape of a water molecule

How a water molecule is formed



neutral molecule

$(2^-) + (1^+) + (1^+) = 0$

A water molecule is made of one oxygen atom that forms a chemical bond with two hydrogen atoms. Recall that oxygen has an oxidation number of 2- and has six valence electrons. Hydrogen, with an oxidation number of 1^+ has only one valence electron. When two hydrogens share their electrons with one oxygen atom, a neutral molecule is formed (shown at left). Note that the oxygen atom in the molecule now has eight valence electrons, the same number as a noble gas (as shown in Figure 23.1). Each hydrogen atom now has two valence electrons giving them the same number of valence electrons as a helium atom.

The shape of a water molecule

A water molecule forms the shape of a "V." An oxygen atom forms the point of the "V," and the bonds with the two hydrogen atoms are the two legs. Why does a water molecule form this shape? Look at the Lewis dot structure for water (Figure 23.1). Note that there are four pairs of electrons around the oxygen atom. Only two of these pairs are involved in forming the chemical bonds. These two pairs are called *bonding pairs*. The other two pairs of electrons are not involved in forming chemical bonds and are known as *lone pairs*.

Electron pairs repel each other

Because negative charges repel, the four electrons pairs around the oxygen atom are located where they can be the farthest apart from each other. The geometric shape that allows them to be the farthest apart is called a *tetrahedron*. Since only two of the electron pairs are bonded with hydrogen atoms, the actual shape of the water molecule is a "V" (Figure 23.2).

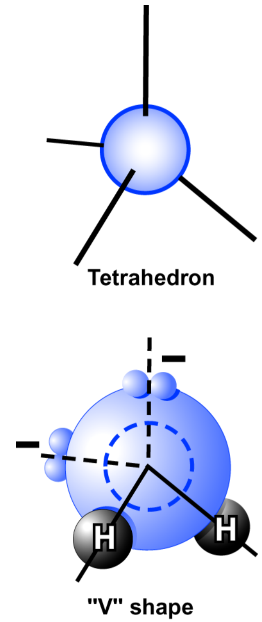


Figure 23.2: *The geometric shape that allows the electron pairs to be farthest apart is called a tetrahedron. Because only two of the pairs are involved in bonds with hydrogen, the shape of the molecule is a "V".*

Water is a polar molecule

What is a polar molecule?

Water is a polar molecule that is, it has a *negative* end (pole) and a *positive* end (pole). In a molecule of water, the electrons are shared *unequally* between oxygen and hydrogen. This is because oxygen atoms attract electrons. Because of this, the electrons are pulled toward the oxygen atom and away from the two hydrogen atoms. The oxygen side of the molecule (the side with the lone pairs of electrons) therefore has a partially negative charge and the hydrogen side of the molecule has a partially positive charge (Figure 23.3).

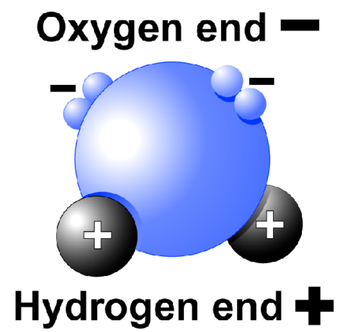


Figure 23.3: *Water is a polar molecule because it has a negative pole and a positive pole.*

Ammonia is another polar molecule

Ammonia, NH_3, is another example of a polar molecule. This molecule has one lone pair of electrons and three bonding pairs of electrons. This gives the ammonia molecule a pyramid shape. Figure 23.4 shows the shape of the molecule with the three hydrogens forming the base of the pyramid (the positive pole). The top of the pyramid is the negative pole.

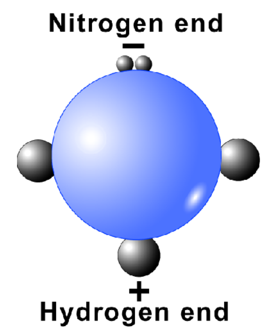


Figure 23.4: *Like water, a molecule of ammonia has a negative pole and a positive pole.*

Nonpolar molecules

Methane, CH_4, is an example of a nonpolar molecule. Nonpolar molecules do not have distinct positive and negative poles. Figure 23.5 shows a methane molecule. This molecule does not contain any lone pairs of electrons. Since there are no lone pairs of electrons, the electrons are shared equally between the carbon atom and the four surrounding hydrogen atoms.

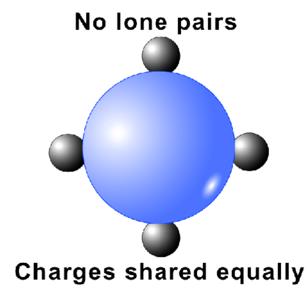


Figure 23.5: *Methane is an example of a nonpolar molecule.*

Comparing the physical properties of polar and nonpolar molecules

It takes energy to melt and boil compounds. The fact that the melting and boiling points of a polar molecule (water) are much higher than those of a nonpolar molecule (methane) provides evidence that there are attractions *between* polar molecules. This is because it takes more energy to pull apart molecules that are attracted to each other than those that have no attraction. Table 23.1 compares the melting and boiling points of water and methane. Notice that the melting and boiling points of water are much higher than those of methane.

Table 23.1: ***Comparing water, ammonia, and methane***

Compound	Melting point	Boiling point
Water	0°C	100°C
Methane	-182°C	-164°C

Attractions between water molecules

Water molecules behave like a group of magnets

If you place a group of magnets together, what happens? Recall that magnets have a positive side and a negative side. If you place a group of them together, you will find that they arrange themselves so that they alternate from positive to negative. The same is true if you put a group of water molecules together. The positive end of one water molecule will align with the negative end of another. When a group of water molecules is placed together, the positive and negative ends align among the molecules in the group. These *polar* attractions create organization among water molecules.

Hydrogen bonds

Figure 23.6 shows that the polar attractions in a group of water molecules are between one of the hydrogen atoms on one water molecule to the oxygen atom on another water molecule. This creates a type of chemical bond that is not as strong as the covalent bonds that hold the oxygen and hydrogen atoms in a water molecule together. The formation of a bond between the hydrogen on one molecule to another atom on another molecule is called a **hydrogen bond**. Hydrogen bonds are relatively weak. They are broken and constantly re-form as water molecules collide.

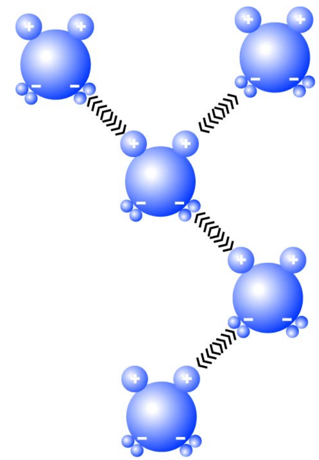


Figure 23.6: *Hydrogen bonds between water molecules.*

Water is a network of hydrogen-bonded molecules

In Figure 23.6, you can see that the oxygen atom in a water molecule has two lone pairs of electrons. Each pair of electrons is available to form a hydrogen bond with the partially positive hydrogen atom of a neighboring water molecule. Many neighboring water molecules connected by hydrogen bonds form a network of water molecules. As temperature increases, the organized structure of the hydrogen bonds among water molecules decreases. As temperature decreases, the organized structure becomes greater.

Frozen water has a honeycomb structure

Frozen water, also known as ice, has a very organized structure that resembles a honeycomb because each water molecule forms hydrogen bonds with four other water molecules (Figure 23.7). This creates a six-sided arrangement of molecules that is evident if you examine snowflakes under a microscope. As water freezes, molecules of water separate slightly from each other as a result of hydrogen bonding. This causes the volume to increase slightly and the density to decrease. This explains why water expands when it is frozen and floats. The density of ice is about 0.9 g/cm^3 whereas the density of water is about 1 g/cm^3.

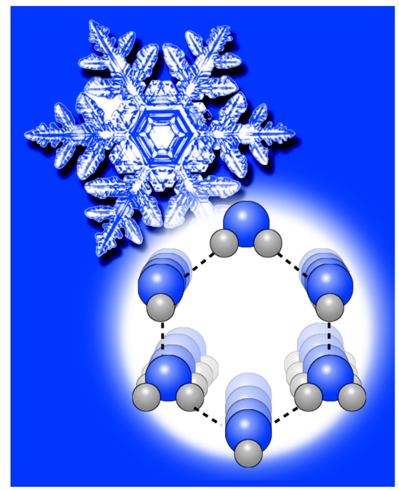


Figure 23.7: *The honeycomb structure of solid water—ice. Can you identify how each molecule forms four hydrogen bonds with other molecules?*

Hydrogen bonding and properties of water

The temperature of water changes slowly

Have you ever jumped into a lake, pond or pool at night after a hot day? If so, you may have wondered why the water temperature felt warmer than the air. This is because once water heats, it cools down slowly. In fact, water cools much slower than most other substances. You may notice that water heats much slower than most other substances. This is evident if you heat a kettle of water for tea. The kettle gets hot very fast, but the water takes a long time to boil.

Hydrogen bonds cause water to resist temperature change

Because hydrogen bonds create attractions between water molecules, it takes more heat to make molecules of water move faster. Once the molecules of water begin to move faster, the temperature rises. As molecules move faster, the temperature rises more. To cool the water, the same amount of energy that was put in must be taken out again. This explains why water cools more slowly. If a large amount of energy is needed to heat water to a certain temperature, the same amount will be have to be taken away to cool it back to the starting temperature. You will learn more about this property of water, called *specific heat*, in the next unit.

Hydrogen bonding and the gaseous state

Most of the water on Earth exists in the liquid and solid states, rather than as a gas. This is because the hydrogen bonds hold the water molecules together strongly enough so that individual molecules cannot escape as a gas at ordinary temperatures. The hydrogen bonds in water explain why water has such a high boiling point (100 °C). In order for water to boil and turn into a gas (water vapor), enough energy must be added to separate the hydrogen bonds that hold the molecules of water together. Once these molecules are separated, they are able to enter the gaseous state (Figure 23.8).

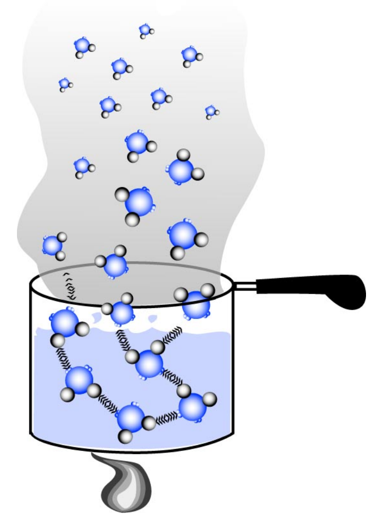


Figure 23.8: *In order for water to boil, enough energy must be added to separate the hydrogen bonds that hold the water molecules together.*

Hydrogen bonding and plants

Hydrogen bonding between water molecules is important to the function of plants. Plants obtain water from their roots. How then does a plant get water to its leaves? Plants have cells in their stems that are like soda straws. These sets of cells are microscopically thin. If a plant stem was transparent, you would see streams of water going from the roots to the leaves. As water molecules evaporate from the leaves, more water molecules are pulled into place. It is as if water molecules hold hands. If one molecule moves, the ones behind follow because they are connected by hydrogen bonds!

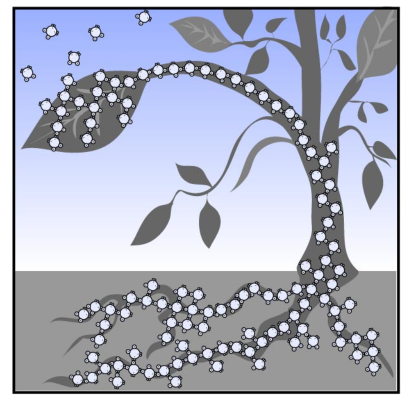


Figure 23.9: *Hydrogen bonds help water travel from root to stem to leaves.*