STRUCTURE OF WATER AND HYDROGEN BONDING

COHESION AND ADHESION

Cohesion of water

Have you ever filled a glass of water to the very top and then slowly added a few more drops? Before it overflows, the water forms a dome-like shape above the rim of the glass. This dome-like shape forms due to the water molecules' cohesive properties, or their tendency to stick to one another. **Cohesion** refers to the attraction of molecules for other molecules of the same kind, and water molecules have strong cohesive forces thanks to their ability to form hydrogen bonds with one another.

Cohesive forces are responsible for **surface tension**, a phenomenon that results in the tendency of a liquid's surface to resist rupture when placed under tension or stress. Water molecules at the surface (at the water-air interface) will form hydrogen bonds with their neighbors, just like water molecules deeper within the liquid. However, because they are exposed to air on one side, they will have fewer neighboring water molecules to bond with, and will form stronger bonds with the neighbors they do have. Surface tension causes water to form spherical droplets and allows it to support small objects, like a scrap of paper or a needle, if they are placed carefully on its surface.

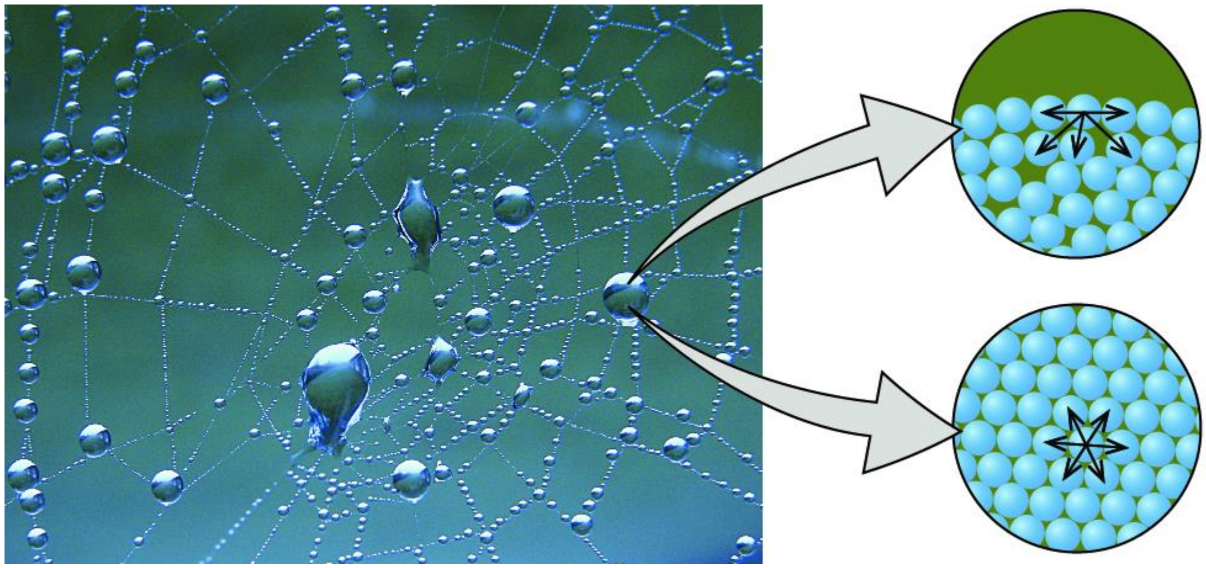


Illustration of surface tension in a water droplet suspended in a spider's web. Water molecules inside the center of the droplet have more neighboring water molecules to interact with than water molecules at the surface. Thus, the water molecules at the surface form stronger interactions with the neighbors they do have.

Adhesion of water

Water likes to stick to itself, but under certain circumstances, it actually prefers to stick to other types of molecules. **Adhesion** is the attraction of molecules of one kind for molecules of a different kind, and it can be quite strong for water, especially with other molecules bearing positive or negative charges.

For instance, adhesion enables water to “climb” upwards through thin glass tubes (called capillary tubes) placed in a beaker of water. This upward motion against gravity, known as **capillary action**, depends on the attraction between water molecules and the glass walls of the tube (adhesion), as well as on interactions between water molecules (cohesion).

The water molecules are more strongly attracted to the glass than they are to other water molecules (because glass molecules are even more polar than water molecules). You can see this by looking at the image below: the water extends highest where it contacts the edges of the tube, and dips lowest in the middle. The curved surface formed by a liquid in a cylinder or tube is called a **meniscus**.

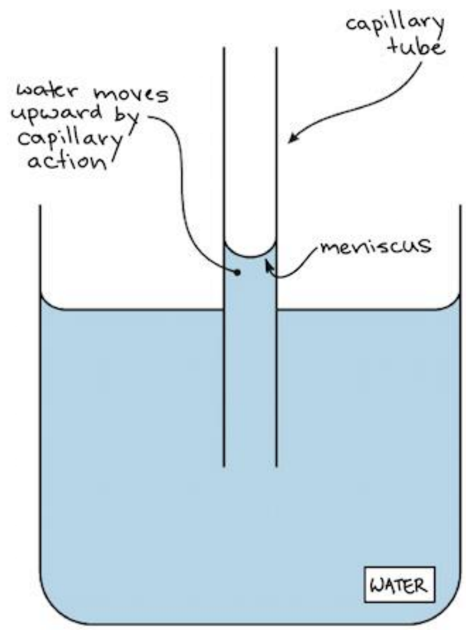


Illustration of water ascending a small tube via capillary action. The thin tube is inserted into a cup of water, and the water climbs up in the tube, reaching a higher level than it does in the cup. Also, the water extends the highest close to the sides of the tube, and dips down in the middle of the tube. This is because the water molecules are more strongly attracted to the sides of the tube than to each other. The curved surface of the water in the capillary tube is called the meniscus.

Why are cohesive and adhesive forces important for life? They play a role in many water-based processes in biology, including the movement of water to the tops of trees and the drainage of tears from tear ducts in the corners of your eyes^11start superscript, 1, end superscript. A simple example of cohesion in action comes from the water strider (below), an insect that relies on surface tension to stay afloat on the surface of water.

SPECIFIC HEAT, HEAT OF VAPORISATION, AND DENSITYOF WATER

Water: Solid, liquid, and gas

Water has unique chemical characteristics in all three states—solid, liquid, and gas—thanks to the ability of its molecules to hydrogen bond with one another. Since living things, from human beings to bacteria, have a high-water content, understanding the unique chemical features of water in its three states is key to biology.

In liquid water, hydrogen bonds are constantly being formed and broken as the water molecules slide past each other. The breaking of these bonds is caused by the energy of motion (kinetic energy) of the water molecules due to the heat contained in the system.

When the heat is raised (for instance, as water is boiled), the higher kinetic energy of the water molecules causes the hydrogen bonds to break completely and allows water molecules to escape into the air as gas. We observe this gas as water vapor or steam.

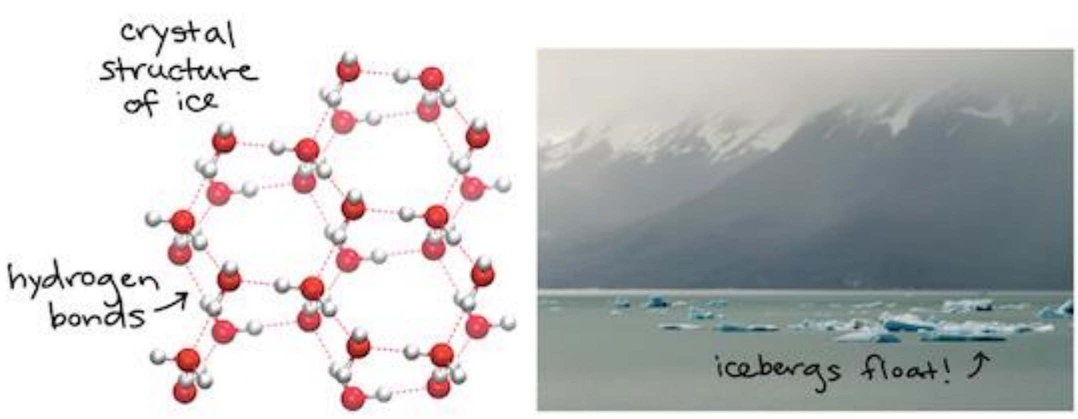
On the other hand, when the temperature drops and water freezes, water molecules form a crystal structure maintained by hydrogen bonding (as there is too little heat energy left to break the hydrogen bonds). This structure makes ice less dense than liquid water.

Density of ice and water

Water's lower density in its solid form is due to the way hydrogen bonds are oriented as it freezes. Specifically, in ice, the water molecules are pushed farther apart than they are in liquid water.

That means water expands when it freezes. You may have seen this for yourself if you've ever put a sealed glass container containing a mostly-watery food (soup, soda, etc.) into the freezer, only to have it crack or explode as the liquid water inside froze and expanded.

With most other liquids, solidification—which occurs when the temperature drops and kinetic (motion) energy of molecules is reduced—allows molecules to pack more tightly than in liquid form, giving the solid a greater density than the liquid. Water is an anomaly (that is, a weird standout) in its lower density as a solid.



(Left) Crystal structure of ice, with water molecules held in a regular 3D structure by hydrogen bonds. (Right) Image of icebergs floating on the surface of the ocean.

Because it is less dense, ice floats on the surface of liquid water, as we see for an iceberg or the ice cubes in a glass of iced tea. In lakes and ponds, a layer of ice forms on top of the liquid water, creating an insulating barrier that protects the animals and plant life in the pond below from freezing.

Why is it harmful for living things to freeze? We can understand this by thinking back to the case of a bottle of soda pop cracking in the freezer. When a cell freezes, its watery contents expand and its membrane (just like the soda bottle) is broken into pieces.

Heat capacity of water

It takes a lot of heat to increase the temperature of liquid water because some of the heat must be used to break hydrogen bonds between the molecules. In other words, water has a high **specific heat capacity**, which is defined as the amount of heat needed to raise the temperature of one gram of a substance by one degree Celsius. The amount of heat needed to raise the temperature of 1 g water by 1 °C is has its own name, the **calorie**.
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Because of its high heat capacity, water can minimize changes in temperature. For instance, the specific heat capacity of water is about five times greater than that of sand. The land cools faster than the sea once the sun goes down, and the slow-cooling water can release heat to nearby land during the night. Water is also used by warm-blooded animals to distribute heat through their bodies: it acts similarly to a car's cooling system, moving heat from warm places to cool places, helping the body keep an even temperature.

Heat of vaporization of water

Just as it takes a lot of heat to increase the temperature of liquid water, it also takes an unusual amount of heat to vaporize a given amount of water, because hydrogen bonds must be broken in order for the molecules to fly off as gas. That is, water has a high **heat of vaporization**, the amount of energy needed to change one gram of a liquid substance to a gas at constant temperature.

Water’s heat of vaporization is around 540 cal/g at 100 °C, water's boiling point. Note that *some* molecules of water – ones that happen to have high kinetic energy – will escape from the surface of the water even at lower temperatures.

As water molecules evaporate, the surface they evaporate from gets cooler, a process called **evaporative cooling**. This is because the molecules with the highest kinetic energy are lost to evaporation (see the video on evaporative cooling for more info). In humans and other organisms, the evaporation of sweat, which is about 99% water, cools the body to maintain a steady temperature.

Key terms

Term	Meaning
Polar molecule	A neutral, or uncharged molecule that has an asymmetric internal distribution of charge, leading to partially positive and partially negative regions

Term	Meaning
Cohesion	The attraction of molecules for other molecules of the same kind
Adhesion	The attraction of molecules for other molecules of a different kind
Density	The mass per unit volume of a substance
Specific heat capacity	The amount of heat needed to raise the temperature of one gram of a substance by one degree Celsius
Heat of vaporization	The amount of energy needed to change one gram of a liquid substance to a gas at constant temperature

Unique properties of water

1. **Water is polar.** Water molecules are polar, with partial positive charges on the hydrogens, a partial negative charge on the oxygen, and a bent overall structure. This is because oxygen is more *electronegative*, meaning that it is better than hydrogen at attracting electrons.
2. **Water is an excellent solvent.** Water has the unique ability to dissolve many polar and ionic substances. This is important to all living things because, as water travels through the water cycle, it takes many valuable nutrients along with it!

3. **Water has high heat capacity.** It takes a lot of energy to raise the temperature of a certain amount of water by a degree, so water helps with regulating temperature in the environment. For example, this property allows the temperature of water in a pond to stay relatively constant from day to night, regardless of the changing atmospheric temperature.
4. **Water has high heat of vaporization.** Humans (and other animals that sweat) use water's high heat of vaporization to cool off. Water is converted from its liquid form to steam when the heat of vaporization is reached. Since sweat is made mostly of water, the evaporating water absorbs excess body heat, which is released into the atmosphere. This is known as *evaporative cooling*.
5. **Water has cohesive and adhesive properties.** Water molecules have strong *cohesive* forces due to their ability to form hydrogen bonds with one another. Cohesive forces are responsible for *surface tension*, the tendency of a liquid's surface to resist rupture when placed under tension or stress. Water also has *adhesive* properties that allow it to stick to substances other than itself.
   These cohesive and adhesive properties are essential for fluid transport in many forms of life. For example, they allow nutrients to be transported to the top of a tree against the force of gravity.
6. **Water is less dense as a solid than as a liquid.** As water freezes, the molecules form a crystalline structure that spaces the molecules further apart than in liquid water. This means that ice is less dense than liquid water, which is why it floats.
   This property is important, as it keeps ponds, lakes, and oceans from freezing solid and allows life to continue to thrive under the icy surface.