LESSON 1

# Unique Properties of Water

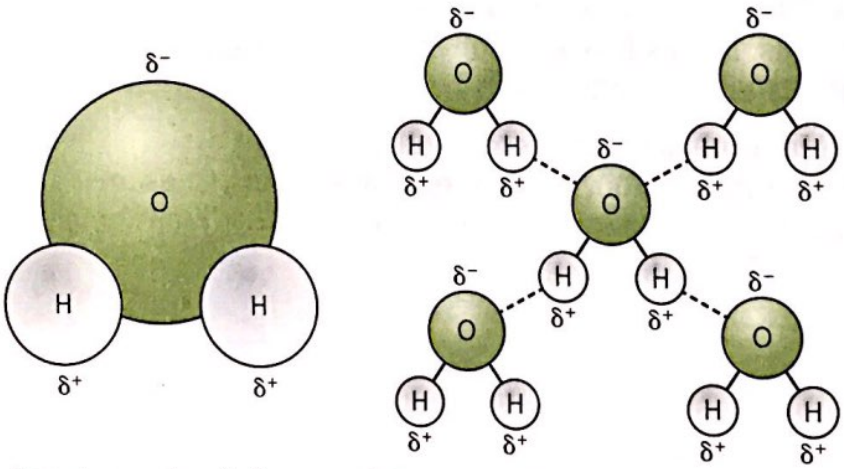
BIO.A.2.1.1

Life on Earth, as we know it, could not exist without water. Water is one of the most important, stable, and abundant molecules found in living things. The many millions of reactions that take place in the cell involve substances dissolved in water.

## The Molecular Structure of Water

Many of water's properties are a result of its molecular structure. A water molecule consists of two hydrogen atoms and one oxygen atom, held together by *covalent bonds*. This type of bond forms between atoms that share electrons. However, the atoms in a covalent bond do not always share electrons equally. In water, the oxygen atom pulls on the electrons more strongly than the hydrogen atoms do. This unequal sharing describes a polar covalent bond.

Because electrons spend more time near the oxygen atom, they give this part of the water molecule a partial negative charge. The hydrogen atoms, in contrast, gain partial positive charges. Although the entire molecule is neutral, different parts of it carry different charges. For this reason, water is described as a *polar* molecule.

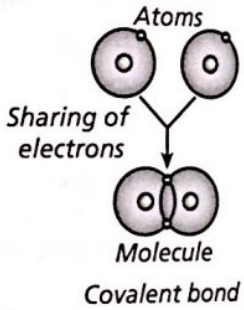



**A water molecule has partially charged regions, which form hydrogen bond interactions between molecules.**

Because they are polar, water molecules form *hydrogen bond interactions* with each other. In a volume of water, the positive regions of one water molecule attract the negative region of a neighboring water molecule. Hydrogen bond interactions are responsible for many of the unique and important properties of water.

Most of an organism's cells are made up of water. The average human body is up to 65% water.

*Covalent bonding* occurs when atoms share electrons.



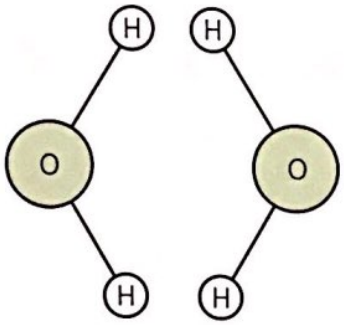

Remember that electrons are negatively charged.

A *polar* molecule has regions of opposite partial charge. It is called *partial* because it is not the full charge that results when an electron is completely gained or lost.

Opposite charges attract. Like charges repel.

A *hydrogen bond* is not a true bond, like the covalent bonds between atoms. For this reason, it is called a *bond interaction.*

Explain why two water molecules probably will **not** occur as shown in the diagram below.




The partial positive charges of the hydrogen atoms repel each other, making it unlikely that water molecules will be arranged in this way. The opposite partial charges of the hydrogen and oxygen atoms attract each other, and so these regions will likely be found together between water molecules.

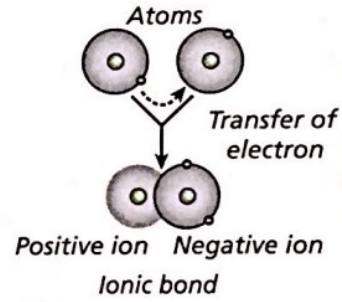
## Water, the (Nearly) Universal Solvent

Table salt is an *ionic* compound, meaning that it is composed of two ions with opposite charges ($Na^+$, $Cl^-$). When mixed with water, a salt crystal dissolves into charged ions as water molecules surround them. The ability of water to dissolve ionic compounds is essential to life. The proper concentrations of ions such as calcium, potassium, sodium, and chloride are essential to the functioning of cells.

Because water is a polar molecule, it also dissolves other polar molecules. Many important molecules in the cell are polar. Because water can dissolve many different polar and ionic substances, it is known as the *universal solvent.* The rule of solubility is that "like dissolves like." Table sugar is a common example of a polar molecule, which dissolves easily in water.

However, some substances do not dissolve easily in water. **Lipids** are composed of nonpolar molecules and are therefore insoluble in water. Lipids make up the plasma membrane of the cell, creating an effective barrier to the surrounding watery environment.

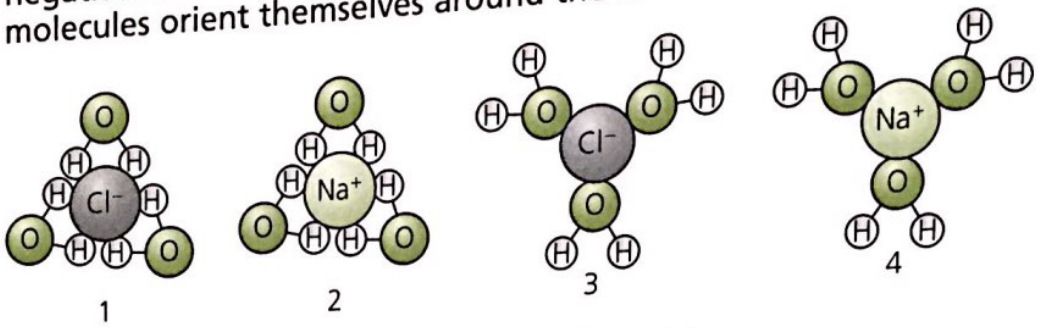
An *ion* is an atom with a positive or negative charge.




*Solubility* is the ability of one substance, the *solute,* to dissolve in another substance, the *solvent.*

**Lipids** include fats and oils and are nonpolar. Nonpolar molecules may be described as *hydrophobic,* or "water-fearing."

Salt is dissolved by water, resulting in positive sodium ions and negative chlorine ions. Which diagrams shows how water molecules orient themselves around the ions?




1 2 3 4

**A** 1 and 2

**B** 1 and 4

**C** 2 and 3

**D** 3 and 4

**The partial positive region of the water molecule will be attracted to the negative chlorine ion ($Cl^-$). The hydrogen atoms have a partial positive charge. The partial negative region of the water molecule will be attracted to the positive sodium ion ($Na^+$). The oxygen atom has a partial negative charge. Choice B, diagrams 1 and 4, is correct.**

## Adhesion and Cohesion

Hydrogen bonding interactions between water molecules give water the property of **cohesion.** That is, water sticks to itself. Cohesion causes high *surface tension,* meaning that more force is required to break the surface of a liquid. You have probably seen droplets or beads of water form from moisture in the air. Water forms beads because surface tension resists other forces, such as gravity, that work to break the surface.

In contrast, **adhesion** is the tendency of water to stick to substances other than itself. Adhesion is due to hydrogen bonding interactions between water molecules and non-water molecules. For example, water will adhere to the sides of a glass tube, forming a *meniscus.*

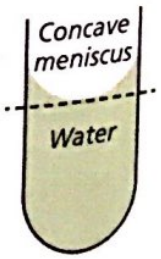
Thanks to cohesion and adhesion, tall plants are able to move water from their roots to the tops of their shoots, defying gravity. Plants conduct water through interconnected, tube-like cells. When water on an upper leaf evaporates, the water just below it is pulled up to take its place. All the water molecules, down to the roots, are pulled along, too. This movement of water is caused by cohesion between water molecules and the adhesion of water to the cell walls. The ability of a liquid to flow against gravity in a narrow space, such as a thin tube, is called *capillary action,* or *capillarity.*

**Cohesion** is the tendency of water molecules to attract each other and stick together.

*Surface tension* helps keep the surface of water intact.

**Adhesion** is the tendency of water molecules to stick to other surfaces.

A *meniscus* is a curve of water near the surface due to the adhesive force between the water molecules and the container.



The ability of the water strider insects shown here helps them to escape predators. Using the properties of water, explain how this is possible.

Water has high cohesion due to hydrogen bonding interactions. This results in a high surface tension. The weight of the water strider is not great enough to overcome the surface tension of the water. However, the weight of a larger predator would be great enough to overcome this force, causing the predator to sink into the water.

## Water and Heat Energy

If you have visited the beach on a summer day, the water may have felt cooler or hotter than the air. Water has a high capacity to absorb and retain heat, known as **specific heat.** Compared to other substances, water requires more heat energy for its temperature to change. Early in the summer, ocean water has not absorbed enough heat for its temperature to rise very much. Water also releases heat energy slowly. Late in the summer, ocean water will be warm because it has not cooled as quickly as the rest of the environment.

Bodies of water absorb and release heat slowly, creating a more moderate environment for organisms. This same property of water makes it easier for an organism to control its body temperature. A large amount of heat can be gained or lost before body temperature changes. Cold-blooded animals can absorb enough heat during the day to last them through the night. Warm-blooded animals can more easily maintain a constant internal temperature.

When a liquid absorbs enough heat, it begins to evaporate, changing to a gas. The amount of heat needed for water to evaporate, its *heat of vaporization,* is high. When people perspire, water on the skin absorbs heat as it evaporates. This is why sweating is such an effective way of cooling down.

Similarly, water must lose a large amount of heat before it freezes. This is water's *heat of fusion.* This means that, even if the temperature of the air changes drastically, water will resist the change and provide a more stable environment for aquatic organisms. Organisms can lose large amounts of heat before they freeze.

**Specific heat** is the amount of heat energy needed to increase the temperature of one unit of a substance.

Note that temperature is not the same thing as heat. Adding equal amounts of heat to different substances can have different effects on their temperatures.

Water has one of the highest specific heat capacities of any substance. For example, it takes five times as much heat to raise the temperature of a gram of water by 1°C as it does for a gram of sand.

Remember that animal cells are about 65% water.

*Heat of vaporization* is the heat absorbed when water changes from liquid to vapor.

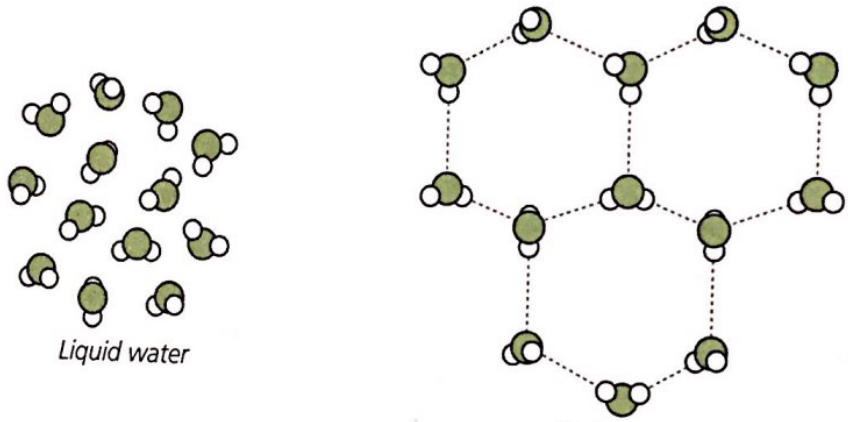
*Heat of fusion* is the heat released when liquid water freezes to ice.

Scientists debate whether dinosaurs were warm-blooded or cold-blooded. One position is that some dinosaurs were "accidentally" warm-blooded due their large size. Explain how this could be possible.

Animal bodies are 65% water. Because water can retain heat well, a large animal would have a large reserve of heat in its body. Once warm, the dinosaur body would remain warm for a long period.

## Water and Density

Water has one more unusual property: it has a greater *density* as a liquid than as a solid. When liquid water reaches its **freezing point,** the water molecules arrange themselves into an orderly structure, leaving more space between them. The same amount of matter takes up more volume (space), making it less dense.




**Molecules of liquid water and of ice (solid water) differ in the amount of space between them.**

Because ice is less dense than liquid water, it floats on the surface of ponds and other bodies of water. As temperatures drop in winter, streams and lakes freeze from the top, down. The less-dense ice remains above the denser liquid water. It also acts as an insulating barrier for the water below it. It is therefore possible for smaller bodies of water not to freeze completely and for aquatic organisms to survive cold winters.

When leafy, green vegetables are frozen and then thawed, their texture changes. Explain why freezing causes this change.

Plant cells contain a high percentage of water, particularly in the central vacuole. When frozen, the density of the water decreases and the ice takes up a larger volume inside the cell. This causes the cell wall to burst and results in leafy vegetables losing their "crunch."

*Density* is the mass of a substance divided by its volume:

$$\text{Density} = \frac{\text{mass}}{\text{Volume}}$$

For equal masses, a less-dense substance takes up a larger volume.

Most substances are less dense as liquids than solids. Water is an exception.

Think of a bottle of oil-and-vinegar salad dressing. The less-dense oil floats above the denser vinegar.

**Freezing point** is the temperature at which a liquid becomes a solid. The freezing point of water is 0°C, or 32°F. This is also called its *melting point.*

**Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.**

1 Which property of water molecules explains the other properties listed below?

**A** adhesion

**B** cohesion

**C** hydrogen bond

**D** polar covalent bond

2 One property of water that makes it unique is its density. Which example describes a result of this property?

**A** Polar bears float on ice floes to hunt for food.

**B** Trees transport water from their roots to their leaves.

**C** Water strider insects walk on the surface of pond water.

**D** Plants receive enough light to grow under the surface of a lake.

***Use the picture below to answer question 3.***

3 The picture shows water droplets hanging on the tips of pine needles. How do the physical properties of water result in the image shown?

**A** Cohesion allows droplets to form, and adhesion keeps the droplets on the needles.

**B** Adhesion allows droplets to form, and cohesion keeps the droplets on the needles.

**C** Cohesion allows droplets to form, and capillarity keeps the droplets on the needles.

**D** Adhesion allows droplets to form, and capillarity keeps the droplets on the needles.

4 Which statement correctly describes one way that the properties of water affect heat and temperature?

A Water retains more heat than other materials, making coastal ecosystems warmer year-round.

B Water absorbs heat when it freezes, helping to insulate lakes and ponds from cold temperatures.

C Water absorbs heat when it changes to vapor, helping to keep animals cool through perspiration.

D Water retains less heat than other materials, keeping aquatic ecosystems cooler than those on land.

5 A tree absorbs water from its roots and loses water that evaporates from leaves. Inside the tree, capillary action allows water to flow upwards through tissue called *xylem*, which is composed of tubes made from cell walls.

A Identify and explain how two (2) properties of water contribute to capillary action within the xylem.

B A tree can experience *cavitation*, which occurs when a bubble of air forms inside a xylem tube. Explain how cavitation affects a tree's ability to conduct water.