WATER

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A1.1.4	Adhesion of water to materials that are polar or charged and impacts for organisms
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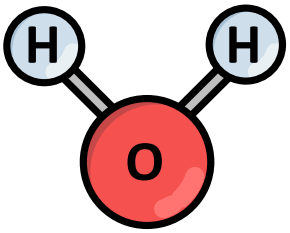
WATER

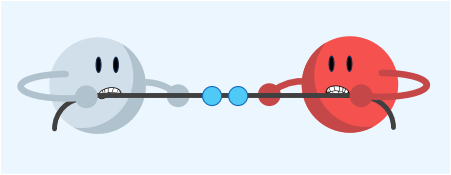
Water is made up of two hydrogen atoms covalently bonded to an oxygen atom (molecular formula = H_2O). Liquid water is essential for life to exist. The cytosol of a cell is predominantly composed of water (>70%), which allows for solutes to be dissolved and able to interact. Water is also an important metabolite within cells and is involved as either a substrate or a product in essential processes such as hydrolysis reactions, photosynthesis and cell respiration. Water also functions as a temperature buffer, maintaining a homeostatic temperature range in cells.



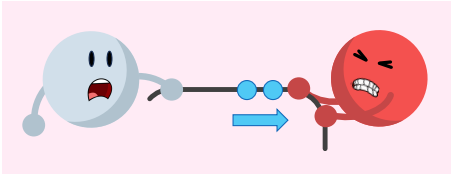
Water (H_2O)

POLARITY

While covalent bonding involves the sharing of electrons, they are not shared equally between the atoms in water, resulting in a slight difference in charge between the poles of the water molecule (creating **polarity**). Oxygen has a comparatively high electronegativity (greater affinity for electrons) and attracts the electrons more strongly than hydrogen, so oxygen becomes slightly negative (δ^-) and hydrogen slightly positive (δ^+).



COVALENT – NO CHARGE
(electrons shared equally)

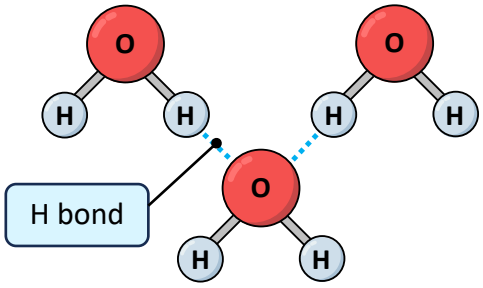


POLARITY – SLIGHT CHARGE
(*unequal* electron sharing)

IONIC – FULLY CHARGED
(gain or loss of electrons)

HYDROGEN BONDING

Hydrogen bonds are relatively strong polar associations that form between a δ^+ hydrogen atom and a δ^- fluorine, oxygen or nitrogen atom on. In water, hydrogen bonding will occur between the oxygen and hydrogen dipoles of different water molecules. Hydrogen bonds are constantly forming, breaking and reforming based on the motion of the water molecules.



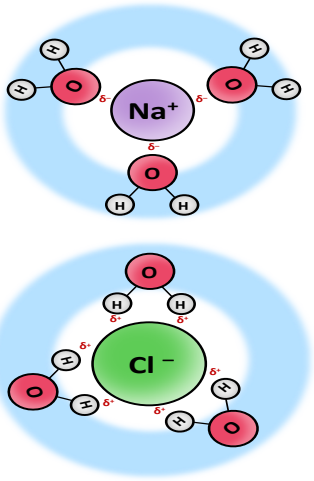
PROPERTIES OF WATER

Water has several unique properties which contribute to its biologically significant role as the medium for life. These properties arise primarily due to the polarity of water and its capacity to form hydrogen bonds.

- Water has solvent properties (it is the universal solvent and can dissolve charged and polar substances)
- Water has cohesive and adhesive properties (water can form associations with other water molecules)
- Water has several unique thermal properties (water has the highest specific heat capacity of any liquid)
- Water has certain physical properties (its overall density contributes towards its buoyancy and viscosity)

1. SOLVENT PROPERTIES

A solvent is a substance that dissolves another substance (the solute) to form a solution. Water is commonly referred to as the **universal solvent** due to its capacity to dissolve a large number of substances. Due to its polarity, water can associate with any substance that is charged (ions) or has electronegative atoms (polar). The polar regions of a water molecule associate with molecular surfaces that have an opposing charge, forming dispersive **hydration shells**. Even though polar associations are significantly weaker than ionic bonds, sufficient quantities of water molecules can dissociate ionic compounds. A substance that is soluble in water is described as **hydrophilic** ('water-loving'), while substances that do not dissolve in water (non-polar substances – such as lipids) are consequently described as being **hydrophobic** ('water-hating').



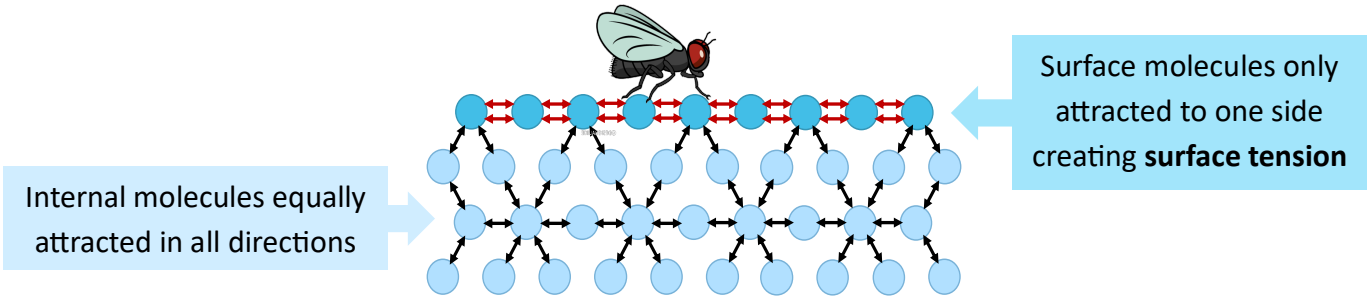
Hydration Shells

The capacity of water to dissolve a large variety of substances makes it an important **medium for metabolic reactions**. Solutes that are dissolved to form aqueous solutions are more likely to collide with enzymes and undergo necessary chemical reactions. Water is also a reagent and a product for many metabolic processes that occur within a cell (condensation reactions produce water, while hydrolysis reactions consume water).

The solvent properties of water make it an important **transport medium** within multicellular organisms. In animals, the *blood plasma* transports dissolved solutes. In vascular plants, mineral ions are transported via *xylem vessels* while dissolved nutrients are transported via the *phloem*. Substances that are insoluble in water cannot be transported freely and are typically complexed to soluble components (in animals, lipids are packaged with proteins to form water-soluble lipoproteins that can then be transported via the blood).

2. COHESIVE PROPERTIES

Water is cohesive as water molecules can stick together by forming intermolecular hydrogen bonds. These cohesive properties are biologically significance as they contribute towards water having one of the highest **surface tensions** of all liquids. At the fluid surface, water molecules can only form hydrogen bonds with the internal molecules. This creates an inward force that gives the fluid surface an elastic tendency and causes the surface molecules to cohere more strongly, allowing small insects to glide along the surface of water.



3. ADHESIVE PROPERTIES

Water is adhesive as water molecules can stick to other molecules with similar properties (ionic or polar). The adhesive properties of water are what causes it to form a meniscus when placed in a glass measuring cylinder. The water adheres to the sides of the cylinder, creating a central depression. This does not occur in plastic measuring cylinders as the plastic is non-polar (hydrophobic) – the water will form a flat surface.

Water forms a *spherical* shape on a **hydrophobic** surface (reduce contact)

Water forms a *flatter* shape on **hydrophilic** surfaces (↑ adhesion)

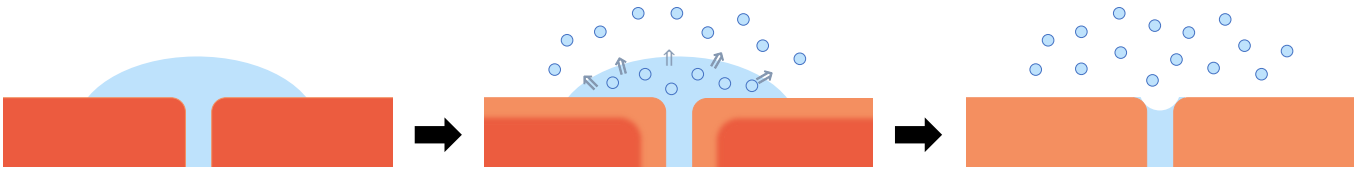
The attraction of water to charged or polar surfaces allows it to flow in opposition to gravitational forces when under tension. This is known as **capillary action**. The strength of the capillary action is dependent on the diameter of the pore the water is moving through (smaller diameter = more capillary action). Capillary action allows water to be transported up the stems of plants via xylem vessels. The evaporation of water from the leaves creates a negative pressure gradient that pulls water molecules towards the leaf due to the cohesive properties of water molecules. The water molecules are able to adhere to the walls of the xylem because the cell walls of the xylem vessels are made of cellulose – which is a polysaccharide that is polar.

4. THERMAL PROPERTIES

Water has the capacity to absorb significant amounts of thermal energy (heat) before changing state. This is due to the extensive hydrogen bonding between water molecules – these bonds must be broken before water changes state and this requires heat absorption. Consequently, water has the following properties:

- Water has a relatively high *melting point* (0°C) and *boiling point* (100°C) compared to similar liquids
- Water has a very high *specific heat capacity* (the energy required to heat 1 gram of a substance by 1°C)
- Water has a high *heat of vaporisation* (the energy absorbed per gram to change from a liquid to a gas)
- Water has a high *heat of fusion* (amount of energy lost when 1g of liquid becomes 1g of solid at 0°C)

Consequently, water is an excellent medium for living organisms as it is **slow to change temperature** and thus supports the maintenance of constant conditions (both internal and external). One specific benefit of the thermal properties of water is that it makes an excellent coolant. Many animals employ sweating as a means of cooling down. The evaporation of sweat requires significant inputs of thermal energy (due to the high specific heat capacity). As body heat is used to convert sweat into vapour, the organism begins to cool.



Hot skin produces sweat → *Heat causes evaporation* → *Heat absorbed, skin cool*

Another property of water is that it has high **thermal conductivity**. Thermal conductivity is a measure of a medium's ability to move heat across a temperature gradient. Water will absorb and transfers heat more readily than air because the water particles are packed more tightly together (due to polarity and hydrogen bonding). The thermal conductivity of water allows a body to transfer heat effectively via the blood plasma, allowing for thermoregulation. However, aquatic organisms will lose heat more quickly in cold water as the water will rapidly transfer body heat into the surrounding water (this may potentially lead to hypothermia).

5. PHYSICAL PROPERTIES

The capacity for water to form polar associations results in both buoyancy and viscosity. **Buoyancy** is the upward force applied to an object in a medium and is determined by the density of the medium (higher density results in greater buoyancy). As water forms hydrogen bonds, it is denser than other substances (such as organic solvents and air). The buoyancy of water can be further increased by forming a solution (salt water is more buoyant than fresh water). The buoyancy of water allows certain organisms to float.

As hydrogen bonding makes water denser, it also makes it more viscous than other substances. **Viscosity** is a measure of a fluid's tendency to flow. Hydrogen bonding between water molecules will generate friction and reduce flow rates. The presence of cells and dissolved solutes within blood plasma increases viscosity.

WATER VERSUS AIR

The physical and thermal properties of water have significant consequences for how organisms survive in terrestrial or marine habitats. The different properties of water and air present distinct survival challenges.

	Thermal Conductivity	Specific Heat Capacity	Buoyancy	Viscosity
Air	Low (0.024WmK)	Low (1.005 J/g.ºC)	Low (less dense)	Low (less viscous)
Water	High (0.58WmK)	High (4.186 J/g.ºC)	High (1000× denser)	High (50× viscous)
Biological significance	Heat is lost more rapidly in water	Water temperature is harder to change	Objects more likely to float in water	Water is more resistant to flow

AQUATIC ADAPTATIONS

The black-throated loon *(Gavia arctica)* and the ringed seal *(Pusa hispida)* both live in the Arctic where they interact with both water and air. Both of these organisms have adapted to the physical properties of water.

Black-Throated Loon

While most birds have hollow bones (for flight), the loon has solid bones that are less dense than the bones found in most other terrestrial organisms. This allows the loon to dive under water in search of prey, while still retaining the capacity to float (buoyancy). The loon's legs are located at its rear, making it hard to walk on land but very effective at propulsion in water (more viscous). The loon's feathers form an interlocking structure that functions as a barrier to water, so as to prevent heat loss (water has a high thermal conductivity).

Ringed Seal

The ringed seal has denser bones than the loon, allowing it to stay submerged for longer periods of time (less buoyancy). The seals have a streamlined body shape to move efficiently through water (higher viscosity than air). The ringed seal has an outer coat of fur that traps air for waterproofing and also has a thick layer of blubber to prevent heat loss while in water. They do not possess many effective physiological cooling mechanisms as water temperatures are generally stable (water has the highest specific heat capacity of any liquid). This makes ringed seals particular vulnerable to the effects of climate change.