Water and living organisms

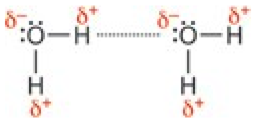
Water has a number of roles in living organisms:

- solvent
- temperature buffer
- metabolite
- living environment

These roles can be explained once we have understood the structure and bonding in a water molecule, and between water molecules.

A molecular compound

Water is a molecular compound, with molecular formula H_2O. The atoms in a water molecule are held together by strong covalent bonds. These are very difficult to break.



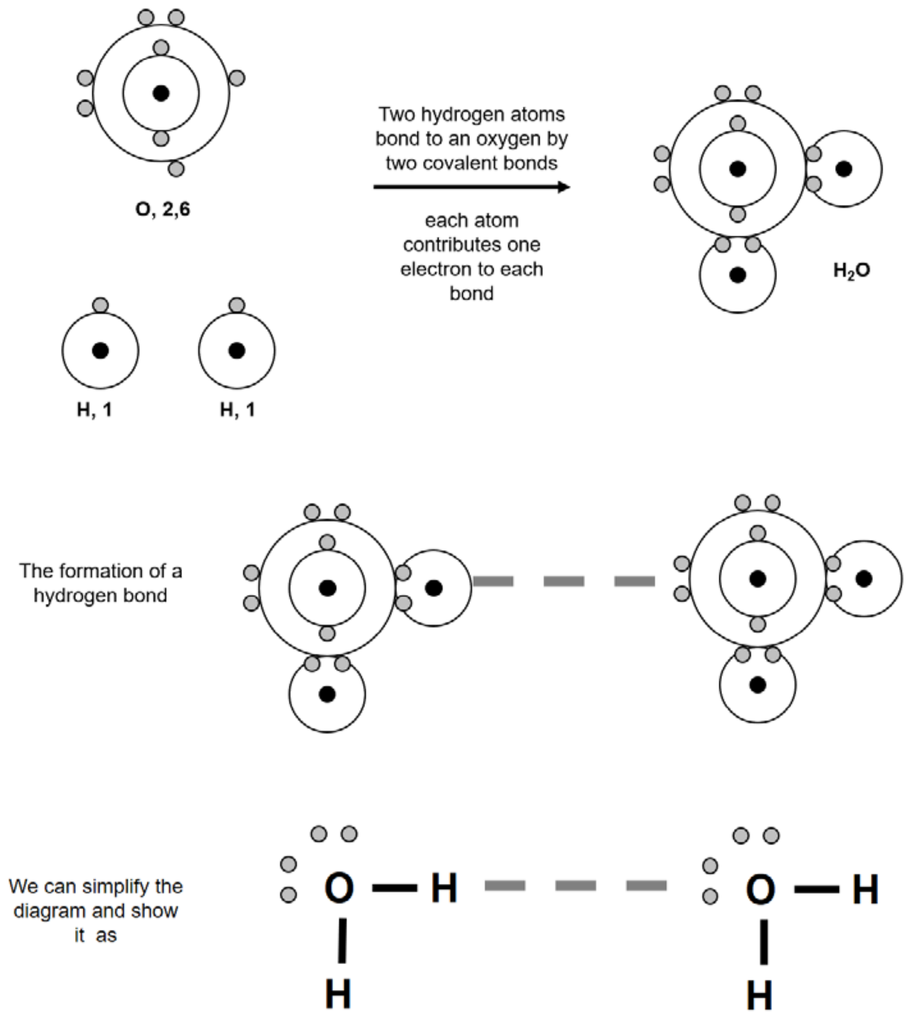
Water

The dot-and-cross diagram for a water molecule shows there are two **bonding pairs of electrons**and two **non-bonding pairs of electrons**. The four pairs repel one another, forming a tetrahedral pattern. In this way they are as far from one another as possible. The molecule itself (the spatial distribution of atoms) is described as 'bent', 'angular' or 'non-linear'.

The two electrons in each oxygen-hydrogen bond are not shared equally. They are more strongly attracted to the oxygen atom. The bond is **polar**, it has a 'negative end' (the oxygen atom) and a 'positive end' (the hydrogen atom).

A **hydrogen bond** forms between a non-bonding pair of electrons on the oxygen atom of one water molecule and the hydrogen atom ('positive end') of another water molecule. The hydrogen bond is about ten times weaker than a single covalent bond.

Formation of a water molecule



With this understanding we can begin to understand how water fulfils its various roles in biological systems.

Solvent

Most compounds with **ionic bonding**, e.g. metal salts, dissolve in water. The oxygen atoms of water molecules are attracted to cations (ions with a positive charge) and water molecules surround it. These water molecules attract more water molecules and hydrogen-bonds form between them. The result is a cluster of water molecules around the ion. We say the ion is hydrated.

Similarly anions (ions with a negative charge) become surrounded by clusters of water molecules. This time it is the positive ends of the water molecule, the hydrogen atoms, that are attracted to the anion.

A wide range of molecular compounds also dissolve in water, including sugars, amino acids, small nucleic acids and proteins. All these molecules are **polar**. This means they have a positive end and a negative end as the result of polar covalent bonds within them. Of the important biological molecules only the non-polar lipids (fats and oils) and large polymers (e.g. polysaccharides, large proteins and DNA) do not dissolve.

The water acts as a solvent for chemical reactions and also helps transport dissolved compounds into and out of cells.

Another important property is that many compounds dissolve and transfer a proton (a hydrogen nucleus) to a water molecule. The result is an acidic solution with pH < 7. Compounds that release a proton in this way are called **acids**. For example,

CH_3COOH (aq) + H_2O (aq) $\rightleftharpoons$ CH_3COO^- (aq) + H_3O^+ (aq)

H_3O^+(aq) is called a **hydroxonium ion** and is responsible for the acidic properties of the solution.

$pH = -\log_{10}[H_3O^+]$

Some molecules receive a proton from a water molecule. The result is an alkaline solution with pH > 7. Compounds that accept a proton in this way are called **bases**. For example, OH^-(aq) is called a **hydroxide ion** and is responsible for the alkaline properties of the solution.

Proton transfer reactions

Acid-base reactions involve the transfer of a hydrogen ion, H^+, (which is simply a proton) to a base

A base is a compound with a lone pair of electrons that can form a covalent bond to the hydrogen ion

The proton is transferred, leaving behind a pair of electrons

hydroxide ion, OH^-

Remember: a straight line in a formula represents two electrons; the coloured circles help you follow where the electrons end up

Temperature buffer

Cells host a huge range of chemical reactions. Many of these are catalysed by Enzymes. Enzyme activity is sensitive to temperature and reactions only occur in a narrow range of temperatures. Water helps to buffer temperature changes because of its relatively high **specific heat capacity** (the heat required to raise 1 kg of water by 1 ^{o}C). It also has relatively large **enthalpy of vaporisation** (heat energy required to convert a liquid to a gas) and **enthalpy of fusion** (heat energy required to convert a solid to a liquid). This is reflected in the unusually high boiling and melting points of water:

Liquid	Molecular formula	Bpt / ^{o}C	Mpt / ^{o}C	Specific heat capacity / kJ kg^{-1} ^{o}C $^{-1}$
Water	H_2O	100	0	4.18
Ethanol	C_2H_5OH	79	-117	2.46
Benzene	C_6H_6	80	6	1.05
Tetrachloromethane	CCl_4	77	-23	0.86

These properties are a consequence of hydrogen bonding.

Metabolite

Chemical reactions take place in cells. Collectively these reactions together are called **metabolism**, i.e. all the chemical and physical processes within a cell. The chemicals involved are called **metabolites**. Water is a metabolite in many reactions, either as a reactant or as a product of reaction. For example, it's involved in **photosynthesis**, **digestion** and **aerobic respiration**.

> See the topic about Photosynthesis

> See the topic about Respiration

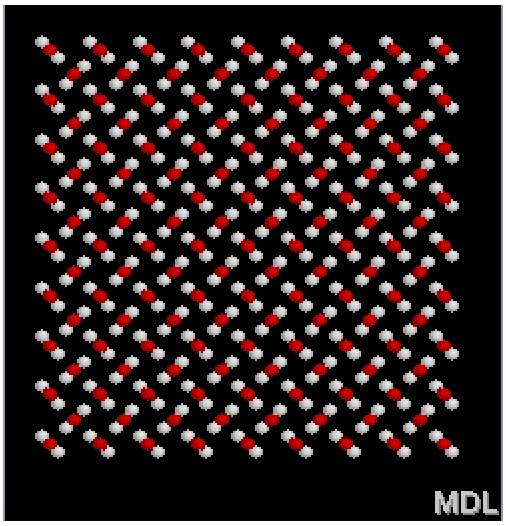
When water reacts with a chemical to break it into smaller molecules the reaction is described as **hydrolysis**.

When water is formed as one of the products when two molecules join together the reaction is described as **condensation**.

Living environment

Many organisms, such as fish, live in water and cannot survive out of it. They have adapted to living in it.

Ice floats on water. This is because ice is less dense than water. The reason is that ice has a giant structure with every oxygen atom at the centre of a tetrahedral arrangement of hydrogen atoms (two are covalently bonded and two are hydrogen-bonded).



Ice giant structure

In freezing weather, ice forms on the surface of ponds and lakes forming an insulating layer above the water below. This provides a living environment for some organisms until the ice melts. Organisms can also live under the ice.

The surfaces of ponds and lakes (and other forms of water) are covered in a 'skin' of water molecules. While most objects break through this skin, it is strong enough to support small insects such as pond skaters. The skin forms because of the increased attraction between water molecules (**cohesive forces**) at the surface.

Test your knowledge

Take quiz on Water and living organisms