



# SL IB Biology



## Water

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## Hydrogen Bonds



Your notes

## Medium for Life

### Water as the medium for life

- The first cells evolved in a watery environment
- This is believed to have been in the deep oceans, close to hydrothermal vents in the Earth's crust
- Some water and solutes got trapped within a membrane
- Chemical reactions began occurring within the membrane-bound structure
- This led to the **evolution of cells**
- Water in its liquid state allows **dissolved molecules to move around**, so they are easily able to collide and react with each other
- Most **life processes occur in water**
- The **link between water and life** is so strong that scientists looking for life on other planets and moons look for evidence of water to suggest that life could have occurred there



Your notes

## Hydrogen Bonds

- Hydrogen bonding plays an important role between many biological molecules
- Some key functions include:
  - Dissolving of solutes** in water
  - The cohesion and adhesion of water molecules
    - These properties allow water to move up the trunks of really tall trees
  - Base-pairing** between the two strands of DNA
  - Structure:
    - Hydrogen bonds help to form part of the **secondary** and **tertiary** levels of structure in proteins
    - The hydrogen bonds found between strands of **cellulose** and **collagen** give those molecules their **tensile strength**
  - Interactions between **mRNA** and **tRNA** during **protein synthesis**
  - Surface effects** on membranes between **polar phosphate groups** and **water**

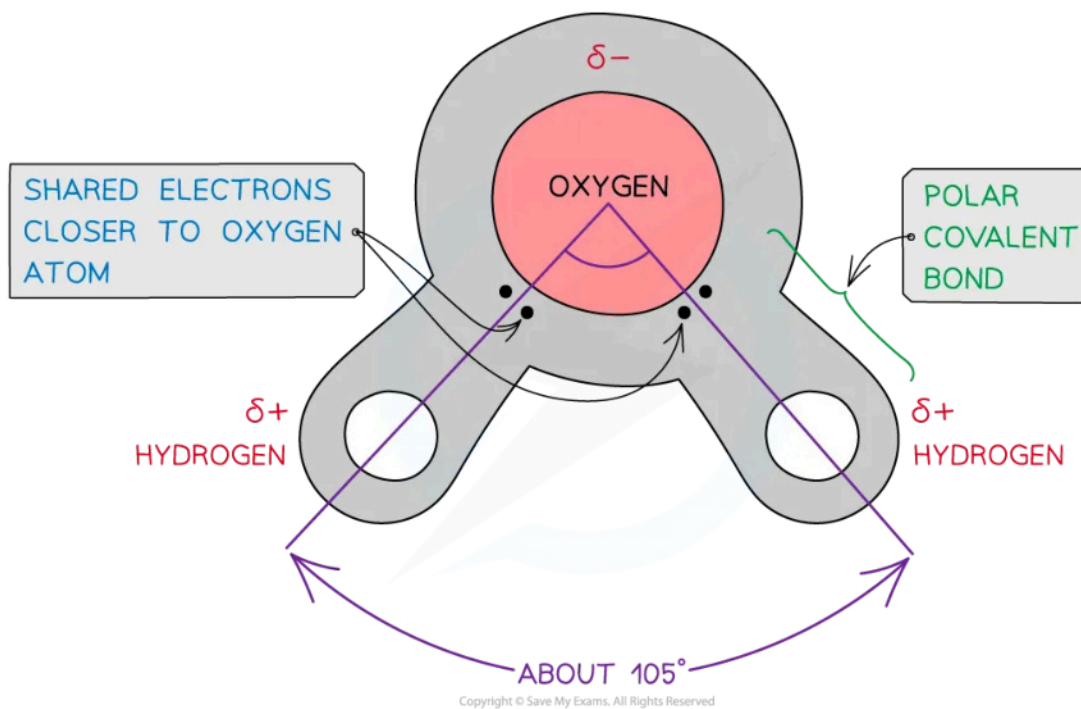
## Hydrogen bonding in water

- Hydrogen bonding is a fundamental property of **water**
- Water is of the **utmost biological importance**
  - It is the **medium** in which all **metabolic reactions** take place in cells
  - Between 70% to 95% of the mass of a cell is water
  - Water is **so fundamental to life** that astronomers look for **signs of water** on other planets and moons, as indicators of possible extra-terrestrial life
  - As 71% of the Earth's surface is covered in water it is a **major habitat** for organisms
- Water is composed of atoms of hydrogen and oxygen
  - One atom of oxygen combines with two atoms of hydrogen by sharing electrons (**covalent bonding**)
- Although water as a whole is electrically neutral, the **sharing** of the **electrons** is **uneven** between the oxygen and hydrogen atoms
  - The oxygen atom attracts the electrons more strongly than the hydrogen atoms, resulting in a **weak negatively charged region** on the oxygen atom ( $\delta^-$ ) and a **weak positively charged region** on the hydrogen atoms ( $\delta^+$ ), this also results in the molecule's asymmetrical shape
- This separation of charge due to the electrons in the covalent bonds being unevenly shared is called a **dipole**
- When a molecule has **one** end that is negatively charged and **one** end that is positively charged it is also a **polar molecule**
- Water is therefore a **polar molecule**

### Hydrogen bonds in a water molecule diagram



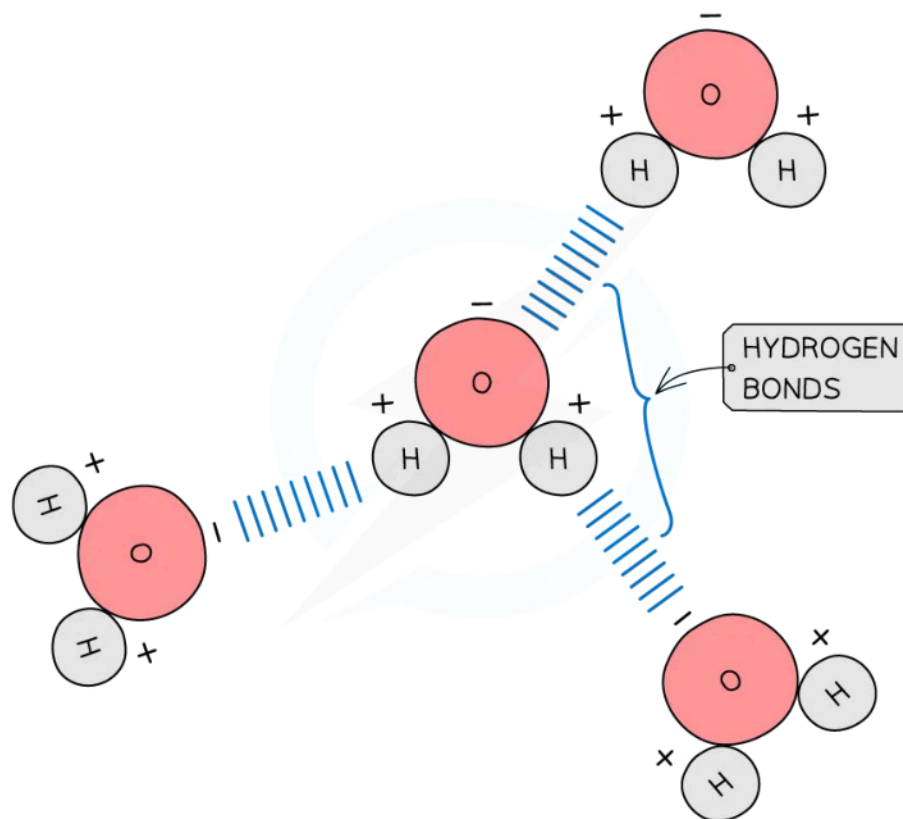
Your notes



**The covalent bonds of water make it a polar molecule**

- **Hydrogen bonds** form between water molecules
  - As a result of the polarity of water, **hydrogen bonds form** between the positive and negatively charged regions of adjacent water molecules
- Hydrogen bonds are weak, when there are few, so they are **constantly breaking and reforming**
- However, when there are large numbers present they form a strong structure
- Hydrogen bonds **cause many of the properties of water molecules** that make them so important to living organisms.

**Hydrogen bonds between water molecules diagram**



*The polarity of water molecules allows hydrogen bonds to form between adjacent water molecules*

### Examiner Tip

Familiarise yourself with the formation of hydrogen bonds between two or more water molecules. The delta symbol ( $\delta$ ) indicates that the charge is very small, so the slightly negative ( $\delta^-$ ) side of one water molecule will always be attracted to the slightly positive ( $\delta^+$ ) side of another water molecule.

## Physical & Chemical Properties of Water



Your notes

### Cohesion

- Hydrogen bonds within water molecules allows for strong **cohesion between water molecules**
  - Allowing **columns of water** to move under tension (called **mass transport**) through the xylem of plants
  - Enabling **surface tension** where a body of water meets the air, these hydrogen bonds occur between the top layer of water molecules to create a sort of film on the body of water
    - This layer is what allows insects such as **pond skaters** to move across the surface of water

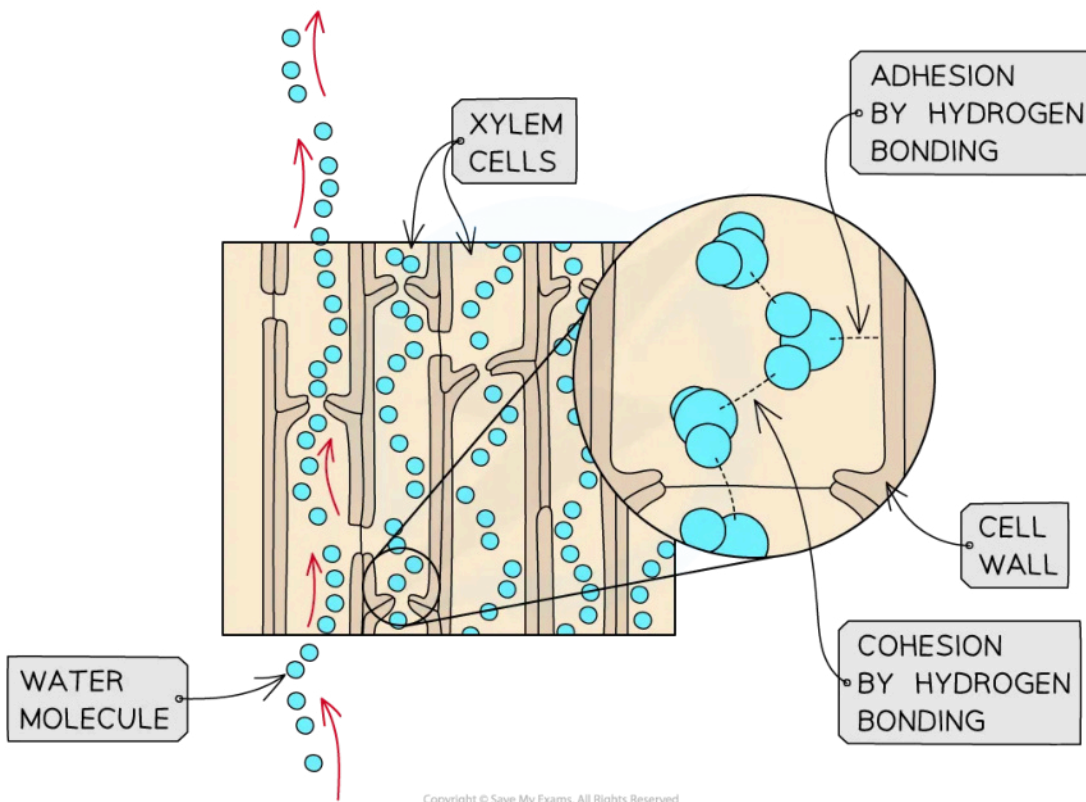


Your notes

## Adhesion

- Water is also able to bond via hydrogen atoms to **other molecules which are polar or charged**, such as cellulose, which is known as **adhesion**
  - This also enables water to move up the **xylem** during **transpiration**
  - Water is drawn up narrow channels in soil, called **capillary tubes**, by means of **capillary action**
  - Spaces between cellulose fibres in plant **cell walls** can also draw water from **xylem vessels** by capillary action and allow water to flow through plant tissue

### Cohesion and adhesion in xylem diagram



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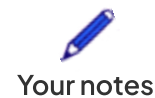
*Hydrogen bonding results in cohesion and adhesion forces in xylem which allows water molecules to flow through the plant in a continuous stream*

### Examiner Tip

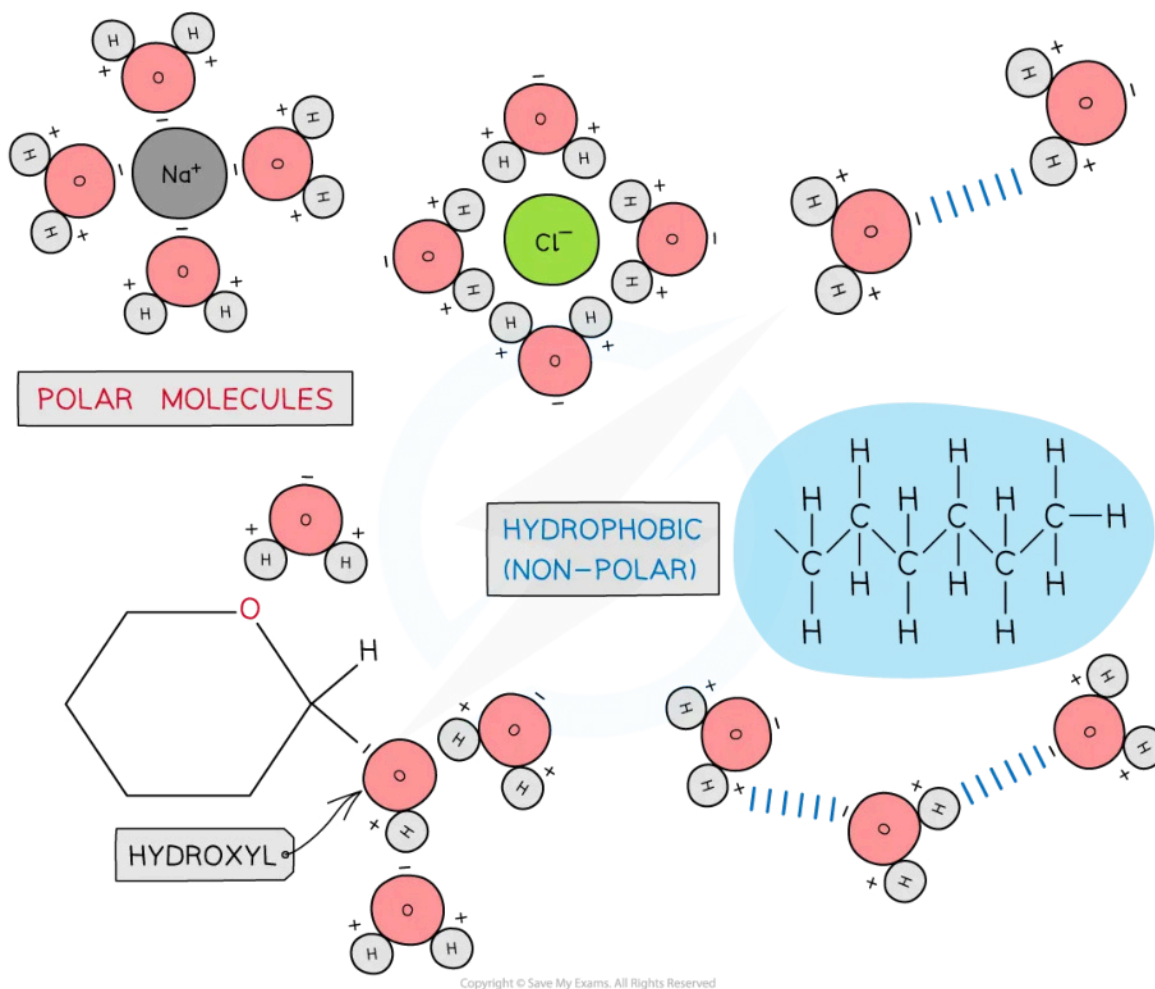
**CO**hesion = water particles sticking to **each other**. **AD**hesion = water particles sticking to **other materials**

## Water as a Solvent

- Biological molecules can be **hydrophilic** or **hydrophobic** (and sometimes both)
  - Hydrophilic = "water-loving"
  - Hydrophobic = "water-hating"
- Polar molecules** and molecules with **positive or negative charges** can form hydrogen bonds with water (and dissolve) so are generally **hydrophilic**
- Non-polar molecules** with no **positive or negative charge**, cannot form hydrogen bonds with water so are generally **hydrophobic**
  - These molecules tend to join together in groups due to **hydrophobic interactions** where hydrogen bonds form between water particles but not with the non-polar molecule
- Because most biological molecules are hydrophilic and can be dissolved, water is regarded as the **universal solvent**



### Water as a solvent diagram





*Due to its polarity water is considered a universal solvent*



Your notes

## Solvent properties of water

- Different solutes behave differently with water as a solvent
- Even though water is a universal solvent, different metabolites have **different solubilities in water**
- Different solutes have **different hydrophobic and hydrophilic properties** which affect their solubility in water

## Highly soluble molecules

- Some molecules are **highly soluble** (e.g. sodium chloride, urea) and some are **insoluble** (e.g. fats)
- Highly soluble molecules can be **easily transported** in solution within organisms
  - e.g. salts, glucose, amino acids
    - Even the amino acids with hydrophobic R groups are soluble enough to be freely transported in water
- Different transport mechanisms have evolved to assist in the transportation of the **less soluble molecules**

## Insoluble molecules

- **Non-polar, hydrophobic** molecules cannot dissolve in water
- The **function** of certain molecules in cells depend on them being **hydrophobic** and **insoluble**
  - e.g. phospholipids have **hydrophobic hydrocarbon tails** which forms the hydrophobic core of cell membranes

## Less soluble molecules

- A low solubility molecule such as **oxygen requires assistance** through **combining with haemoglobin**, to allow more oxygen to be carried than directly in blood plasma
  - Oxygen is less soluble at body temperature (37°C) than at 20°C
  - Oxygen is **sparingly soluble** but **soluble enough to allow it to dissolve** in oceans, rivers and lakes for aquatic animals to **breathe**
  - Haemoglobin can **bind oxygen** to allow sufficient oxygen to be transported to all body cells

## Enzyme action in water

- Most enzymes **require water** in order to hold its **shape** and improve its **stability**
- This enables them to **catalyse reactions** in aqueous solutions
- **Hydrogen bonds** will often facilitate the binding of the **enzyme active site** and its **substrate molecule**
  - This forms an **enzyme substrate complex**

## Physical Properties of Water

### Specific heat capacity

- Specific heat capacity is a measure of the **energy required to raise the temperature of 1 kg of a substance by 1°C**
- Water has a **higher** specific heat capacity (4200 J/kg/°C) compared to air (1000 J/kg/°C), meaning a relatively large amount of energy is required to raise its temperature
- The high specific heat capacity is due to the **many hydrogen bonds** present in water
  - It takes **a lot of thermal energy** to break these bonds and a lot of energy to build them, thus the temperature of water does not fluctuate greatly
- The advantage for living organisms is that it:
  - Provides suitable, **stable aquatic habitats** since water temperatures will change more slowly than air temperatures
  - Is able to maintain a **constant temperature** as water is able to absorb a lot of heat without wide temperature fluctuations
    - This is vital in maintaining temperatures that are optimal for **enzyme activity**
- Arctic and sub-arctic species, such as **the ringed seal** (*Pusa hispida*) are able to survive throughout the year due to **stable sea temperatures**
- The density of ice is **lower** than the density of liquid water, which means that **ice floats on water**
- This forms a **habitat for the seals** both on the floating ice sheets, as well as below the ice



Your notes



By NOAA Seal Survey, Public domain, [Wikimedia](#)



Your notes

## A ringed seal (*Pusa hispida*) in its native habitat

### Thermal conductivity

- Thermal conductivity refers to the **ability of a substance to conduct heat**
- The thermal conductivity of **water is almost 30 times higher** than that of air, which makes air a very good insulator for organisms living in colder climates
- The **black-throated loon** (*Gavia arctica*) is a species of diving bird which spends much time underwater catching its prey
- Their feathers trap an **insulating layer of air**, which assists them with regulating their body temperature



By Robert Bergman, Public domain, [Wikimedia](#)

### The black-throated loon (*Gavia arctica*)

- The seal on the other hand, relies on a layer of fat called **blubber** to insulate it from the outside air
- **Ice** in its environment will also form an **insulating layer above the water**, since the thermal conductivity of ice is much **lower** than liquid water
- This **increases the sea temperature** below the ice as thermal energy is trapped

### Buoyancy

- Buoyancy refers to the **ability of an object to float in water**
- To overcome the problem of buoyancy, the black-throated loon has **solid bones**, unlike the hollow bones that most bird species have to assist them with flight
- This **increases the weight** of the bird and **compresses air out of the lungs and feathers** during a dive
- For the ringed seal, the layer of **blubber** under its skin **will improve the buoyancy** of the animal, along with providing a **layer of insulation** against the cold temperatures of its habitat

## Viscosity

- Viscosity refers to the **resistance of a fluid to flow**
- The **viscosity of water is much higher than air**, which enables the black-throated loon to fly through the air without much friction
- The **body shapes** of both the loon and seal makes it easy for them to move through water
- Both organisms are adapted in their own way for movement through water:
  - The **seal has flippers** to propel itself
  - The **loon uses its webbed feet** to push against the water and the lateral location of its feet reduces drag as it moves through water

### Examiner Tip

You may use either the common name or scientific name for these organisms in an exam



Your notes