HL IB Biology

Your notes

Water

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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

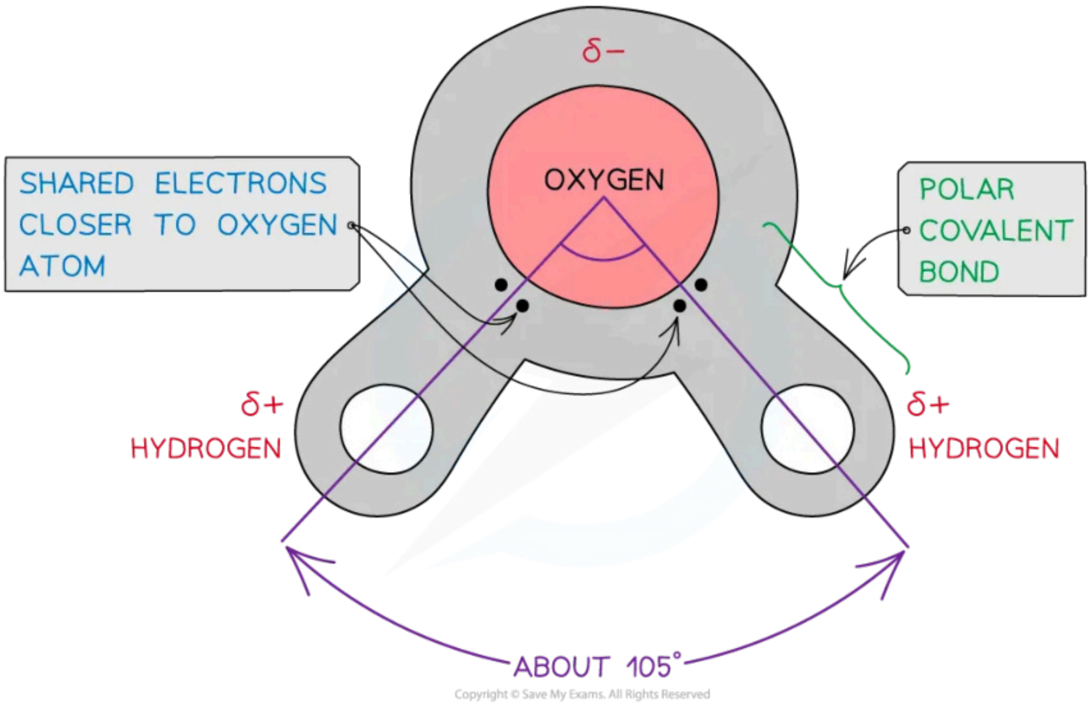
Hydrogen Bonds

- 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 (δ^-) and a **weak positively charged region** on the hydrogen atoms(δ^+), 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**

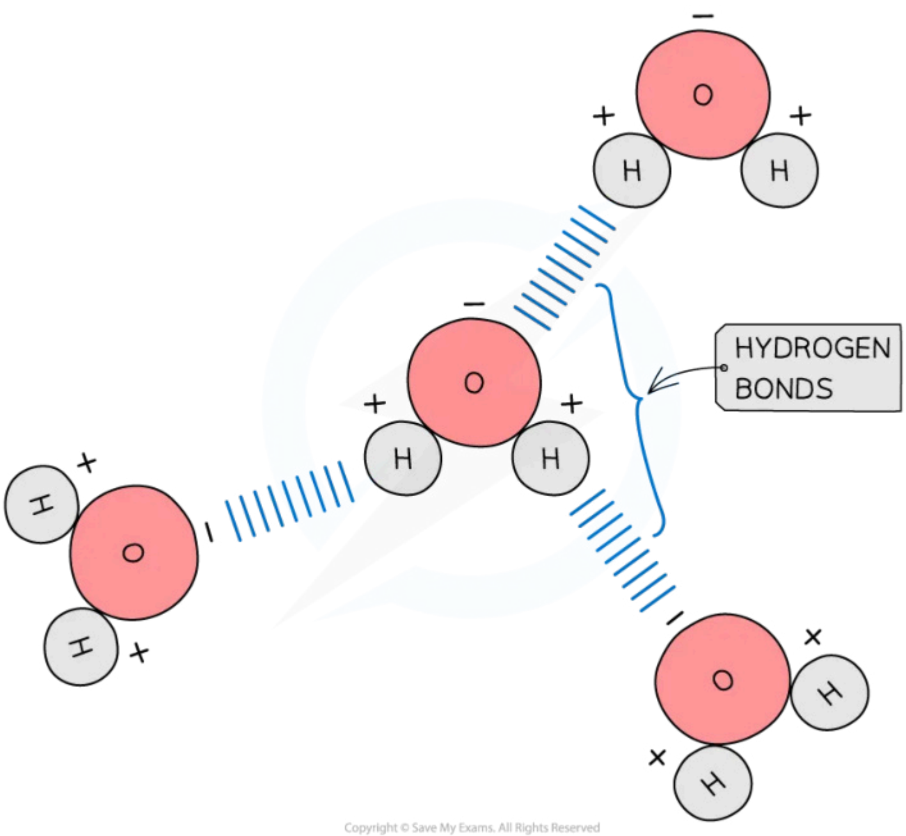
Hydrogen bonds in a water molecule diagram



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 (δ) indicates that the charge is very small, so the slightly negative (δ-) side of one water molecule will always be attracted to the slightly positive (δ+) side of another water molecule.

Physical & Chemical Properties of Water

Your notes

Cohesion

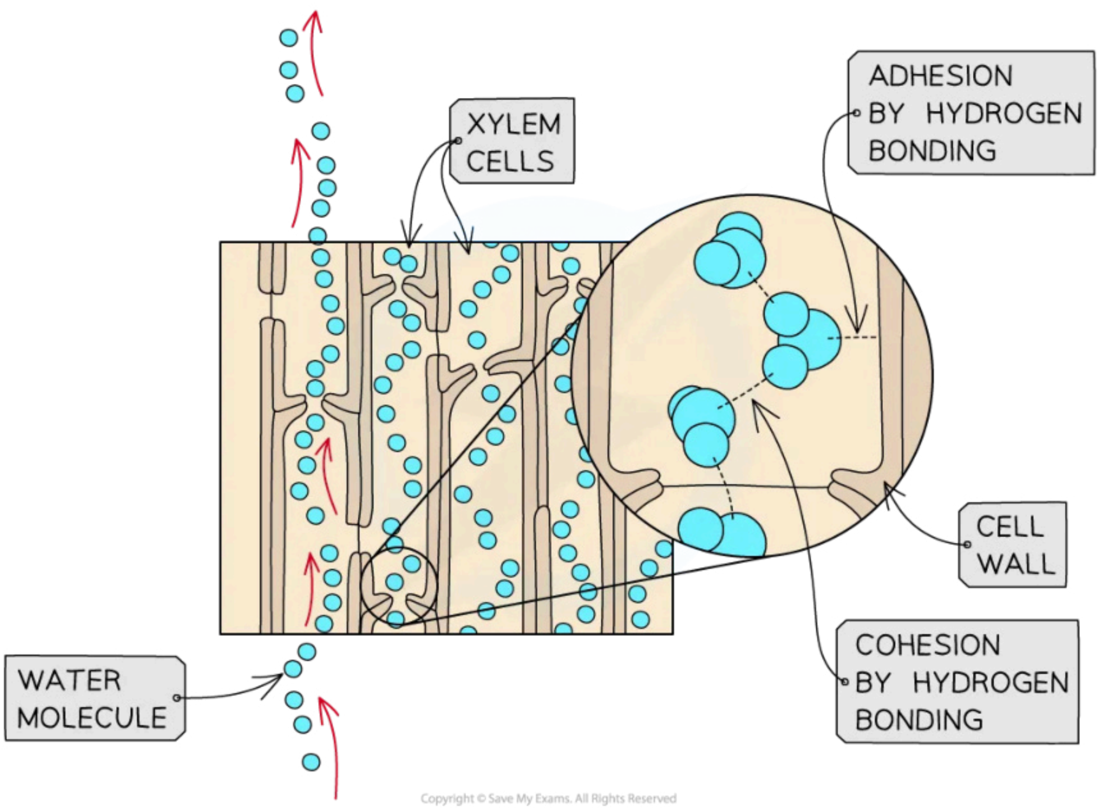
- Hydrogen bonds within water molecules allows for strong **cohesion between water molecules**
    - Allowing **columns of water** to move under tension (called **mass transport**) through the xylem of plants
    - Enabling **surface tension** where a body of water meets the air, these hydrogen bonds 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



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

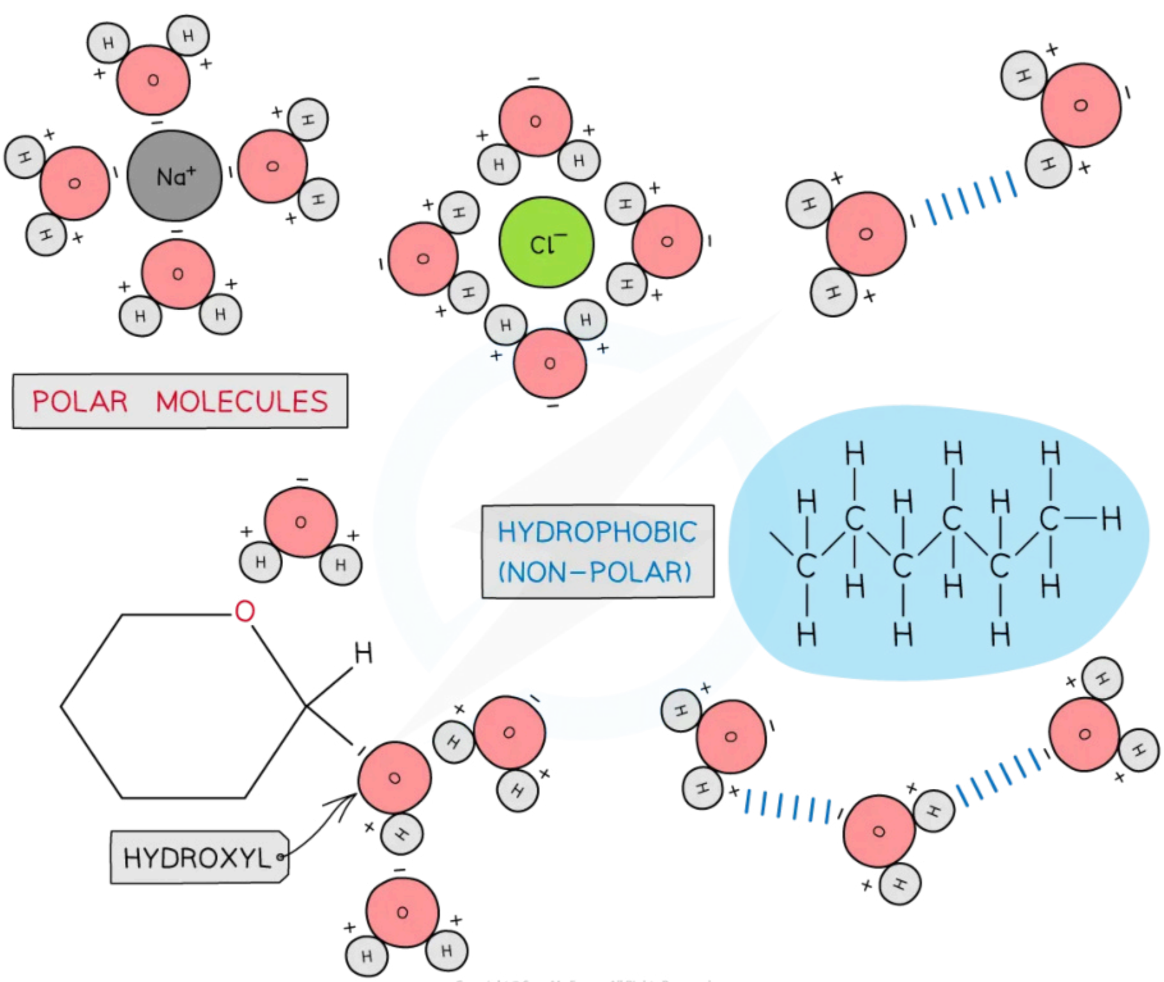
COhesion = water particles sticking to **each other. AD**hesion = water particles sticking to **other materials**

Your notes

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

Your notes

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**
- Artic and sub-artic 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

By NOAA Seal Survey, Public domain, Wikimedia

A ringed seal (Pusa hispida) in its native habitat

Your notes

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

Origin of Water on Earth (HL)

Your notes

Origin of Water on Earth

Extraplanetary origin of water

- Water is crucial for the existence of life but when Earth formed around 4.5 billion years ago, conditions were **too hot** for water vapour to **condense** into liquid water
- This has led scientists to believe that Earth's water must have originated from somewhere else
- One such hypothesis is that **asteroids**, and the **meteorites** that break off from them, may be the **origin of Earth's water**, since many of them **contain ice** and other **organic materials** that would have made it possible for life to evolve
- One of the oldest group of meteorites in the solar system are called **carbonaceous chondrites**
    - These meteorites contain **hydrogen** isotopes similar to those found in seawater
- Another group of ancient meteorites called **eucrite achondrites**, contain ratios of hydrogen isotopes that are **similar to that found on Earth**, providing more support for this hypothesis
- It is possible that during an **impact with Earth**, these meteorites would have **released water vapour** which would have been **trapped by Earth's gravity**
- **Temperatures** on Earth would have been **low enough** to allow this water vapour to **condense** to form liquid water which would have been retained on the surface by gravity

Examiner Tip

Keep in mind that there are several different hypotheses about the origin of water on Earth, but you are only required to study the asteroid hypothesis

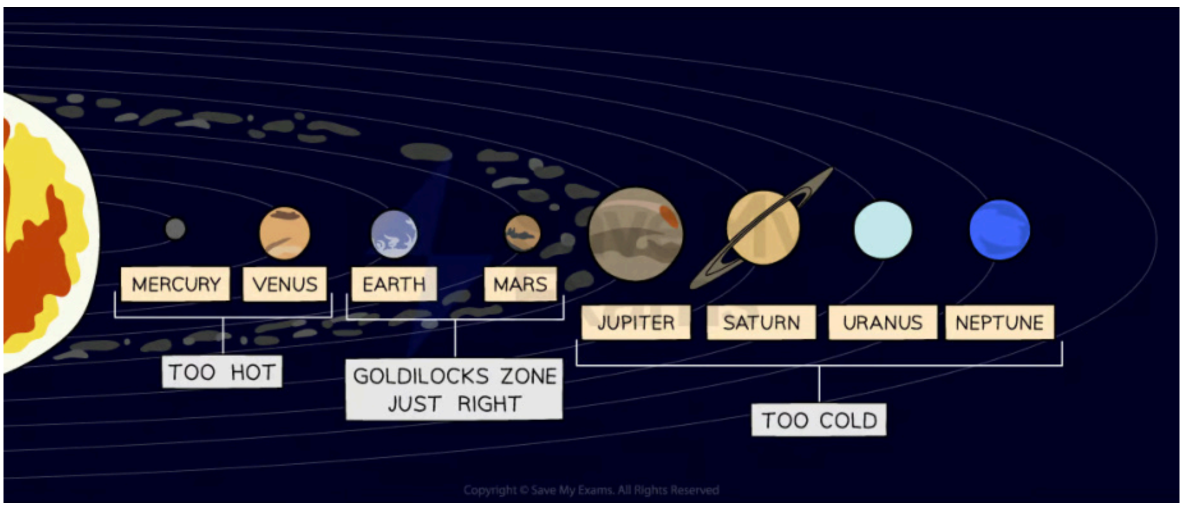
Your notes

The Presence of Water & Life

The search for extraterrestrial life and the presence of water

- Living organisms depend on **water** for their existence, so this would be a requirement for any planet to **support life**
- For water to exist in **liquid form**, the temperature on a planet should not be too hot or too cold, which in turn would depend on the **distance of that planet from its nearest star**
- The area around a star where temperatures are favourable for water to exist in liquid form is known as the **Goldilocks zone**
  - Named after the story of *Goldilocks and the three bears*

The Goldilocks zone diagram



A planet must be the correct distance from its nearest star to be located in the Goldilocks zone where temperatures are "just right" for the existence of liquid water

- In the search for life outside our solar system, scientists are looking at planets located in the Goldilocks zone of other solar systems
- These planets are called **exoplanets**
- They are able to use a technique called **transit spectroscopy**, which analyses light passing through the planet's atmosphere as it passes in front of its nearest star
- Based on the **wavelengths of light being absorbed or deflected**, an analysis can be made about the **elements and molecules present** in the atmosphere
  - If it indicates that water may be present, the planet is said to have a **water signature**
- For an exoplanet to support life it must have the following characteristics:
  - A **water signature**
  - Located in the **Goldilocks zone** of its solar system
  - Be **large enough** to support an atmosphere