A1.1 Water

Syllabus Content

1SL **Water As Medium Of Life**
The first cells originated in water and water remains the medium in which most processes of life occur.

2SL **Hydrogen Bonds As A Consequence Of The Polar Covalent Bonds Within Water Molecules**
Polarity of covalent bonding within water molecules is due to unequal sharing of electrons and hydrogen bonding due to this polarity occurs between water molecules. Draw two or more water molecules and hydrogen bonds between them with the notation shown to indicate polarity.

3SL **Cohesion Of Water Molecules Due To Hydrogen Bonding And Consequences For Organisms**
Include transport of water under tension in xylem and the use of water surfaces as habitats due to the effect known as surface tension.

4SL **Adhesion Of Water To Materials That Are Polar Or Charged And Impacts For Organisms**
Include capillary action in soil and in plant cell walls.

5SL **Solvent Properties Of Water Linked To Its Role As A Medium For Metabolism And For Transport In Plants And Animals**
A wide variety of hydrophilic molecules dissolve in water and most enzymes catalyze reactions in aqueous solution. The functions of some molecules in cells depend on them being hydrophobic and insoluble.

6SL **Physical Properties Of Water And The Consequences For Animals In Aquatic Habitats**
Include buoyancy, viscosity, thermal conductivity and specific heat capacity.
Contrast the physical properties of water with those of air and illustrate the consequences using examples of animals that live in water and in air or on land, such as the black-throated loon (*Gavia arctica*) and the ringed seal (*Pusa hispida*).

7HL **Extraplanetary Origin Of Water On Earth And Reasons For Its Retention**
The abundance of water over billions of years of Earth's history has allowed life to evolve.
Limit hypotheses for the origin of water on Earth to asteroids and reasons for retention to gravity and temperatures low enough to condense water.

8HL **Relationship Between The Search For Extraterrestrial Life And The Presence Of Water**
Include the idea of the "Goldilocks zone".

Guiding Questions

What physical and chemical properties of water make it essential for life?
What are the challenges and opportunities of water as a habitat?

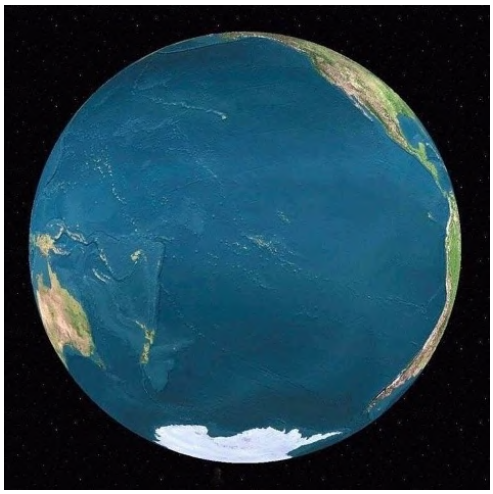
Linking Questions

How do the various intermolecular forces of attraction affect biological systems?
What biological processes only happen at or near surfaces?

1SL Water as the medium of life

Just over 70% of the Earth's surface is covered by water.

If the Earth had a smooth surface then it would be completely covered in water to a depth of more than 2.5km.



View over Pacific Ocean, sans clouds.

It is believed life arose in the oceans when:

- water became enclosed in a membrane
  - substances were dissolved in this water (solutes)
- internal conditions differed from external conditions
  - concentration gradients could form
  - isolated chemical reactions could occur

Many cells are mostly water.
Water is an excellent solvent for many chemicals.

Life requires water in a liquid state for:

- diffusion gradients to form
- collisions between chemicals including enzyme-controlled reactions
- many chemical reactions involve water

(2SL) Draw and label two water molecules below, include hydrogen bonds and polarity. (see over page)

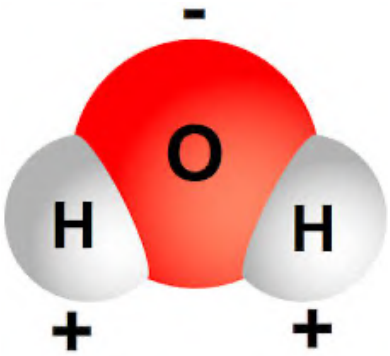
2SL Hydrogen bonds as a consequence of polar covalent bonds within water molecule

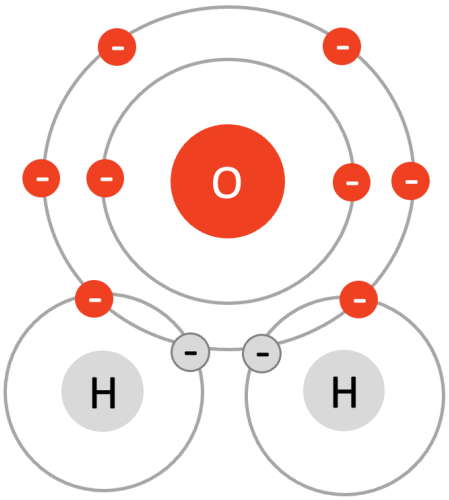
polar molecule – one part of a molecule has a positive charge and one part has a negative charge

covalent bond – form when two atoms share a pair of electrons

Polar molecules are formed by unequal sharing of negatively charged electrons.
A water molecule (H_2O) is made of two hydrogen atoms and one oxygen atom.

Unequal sharing of electrons:
- forms polar covalent bonds
- the larger oxygen atom attracts electrons more strongly
- gives oxygen a *partial* negative charge
- gives hydrogen atoms a *partial* positive charge



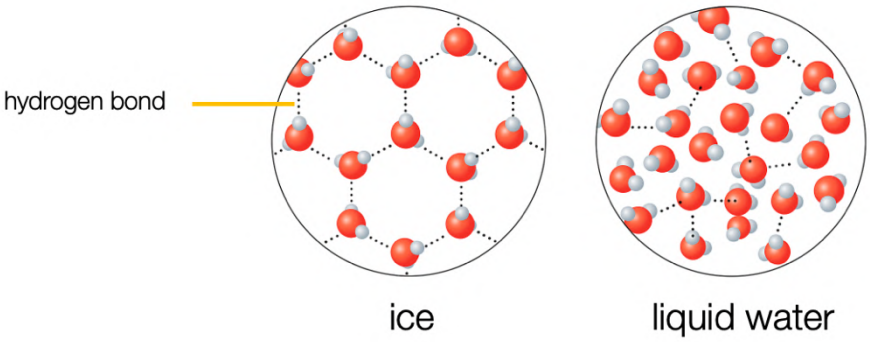


A water molecule is bent with both hydrogens on one side of the molecule.
Therefore, the oxygen forms a negative pole and the hydrogen atoms form a positive pole.

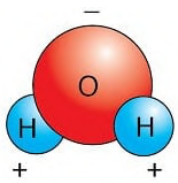
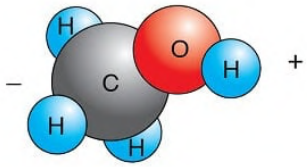
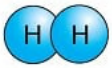
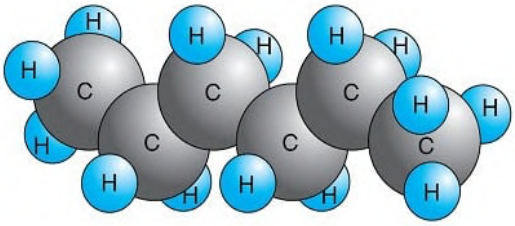
As a polar molecule - water can form intermolecular hydrogen bonds:
- between partially positive hydrogen atoms on one water molecule and the partially negative oxygen atom on another water molecule
- one hydrogen bond is weak and temporary
  - many hydrogen bonds can add up to a stronger force
- this gives water its unique properties

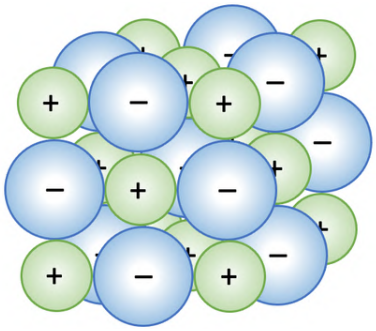
water animation a

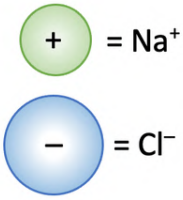
water animation b



Hydrogen bonding in ice forms a lattice structure. This makes it less dense than liquid water. Floating ice insulates aquatic habitats and prevents them from freezing solid in winter.

polar molecules	nonpolar molecules
electrons are unequally shared	electrons are equally shared - usually
have partial positive and negative charges	no charge separation within the molecule
 water  methyl alcohol	 hydrogen  hexane gasoline





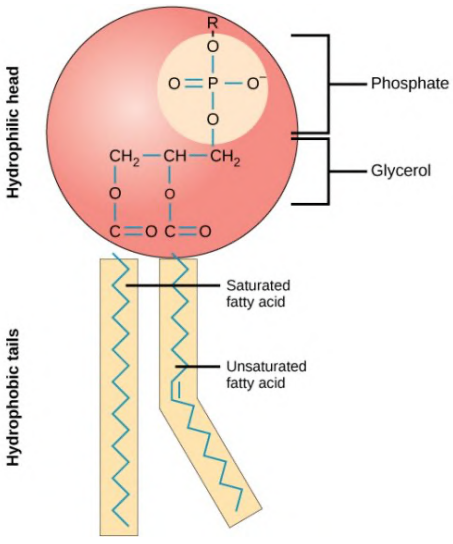
ion – a charged particle

Ionic bonds – can form due to attraction between oppositely charged particles

Ions and many ionic compounds dissolve in water and in other polar solvents - they are hydrophilic.

amphipathic molecules – have hydrophobic regions (nonpolar) and hydrophilic regions (polar or charged)

examples: phospholipids, cholesterol, channel proteins

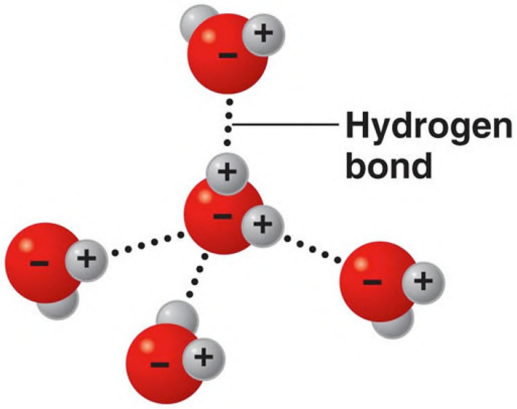


Openstax

3SL Cohesion of water due to hydrogen bonding and consequences for organisms

cohesion - the attraction of similar molecules to each other

Hydrogen bonds between water molecules allow water to stick to itself.

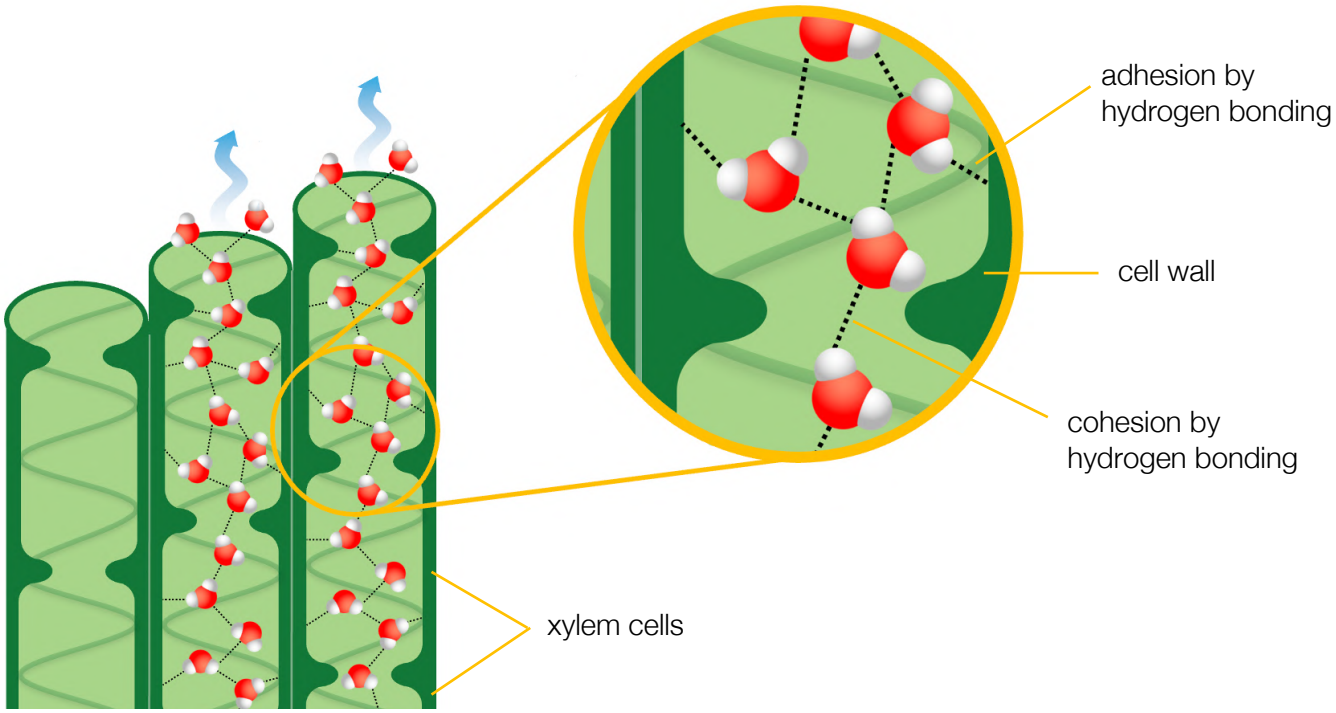


Pearson Ed 2010

Transpiration Pull

- as water evaporates off leaf cells it creates a strong pulling force
- cohesion allows a continuous column of water to be pulled under tension up the xylem
- a continuous column of water can act like a rope due to hydrogen bonds

If there were fewer hydrogen bonds per ml of water - tall trees would not be possible as the long columns of water would be too easily broken.



Surface Tension as a Habitat

Surface tension occurs because water molecules at the surface form hydrogen bonds with water molecules below and beside them, but not with the air particles above.

surface tension – the surface of a liquid acts as an elastic skin

All liquids have surface tension but few are stronger than water – one exception is liquid mercury.

To break surface tension many hydrogen bonds must be broken at the same time.
The energy for this by a small object or organism may not be available.

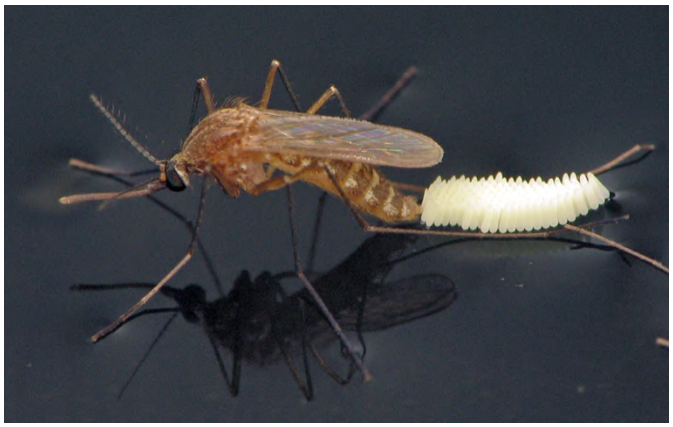
raft spider (1g)

- increases its surface area with fine hairs and 8 legs.
- detects vibrations on the water surface
- runs across it to hunt prey

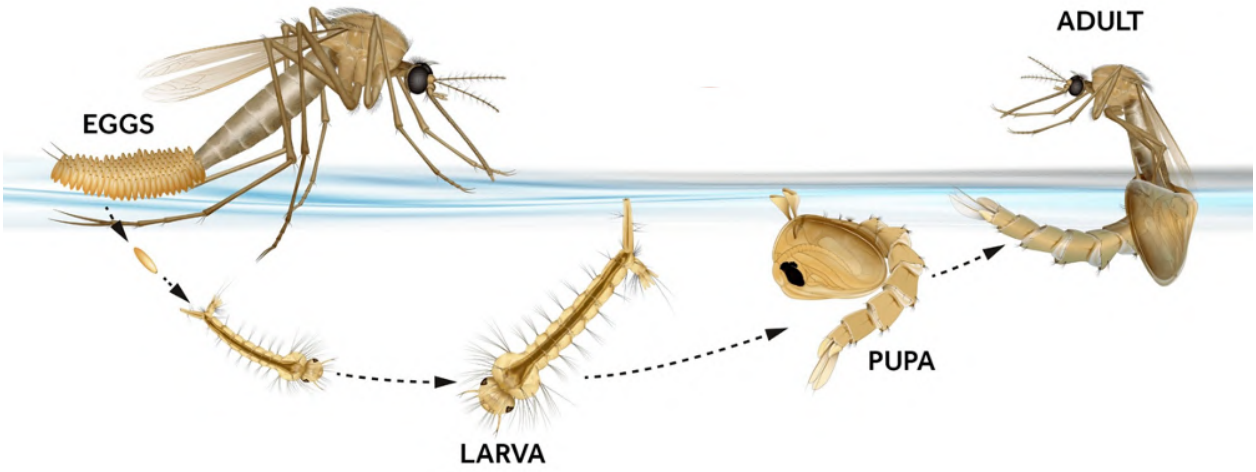
Ocrdu Wikimedia

mosquito:

- larvae hang below water surface and pierce it to siphon air
- adults stand on water surface using 6 long hydrophobic legs
- eggs laid as rafts on the water surface



Sean McCann



Aldona Griskeviciene 123RF

4SL Adhesion of water to materials and impacts for organisms

adhesion - attraction of dissimilar molecules to each other

Water sticks to solid surfaces made of polar molecules.

This can cause movement of water called capillary action.

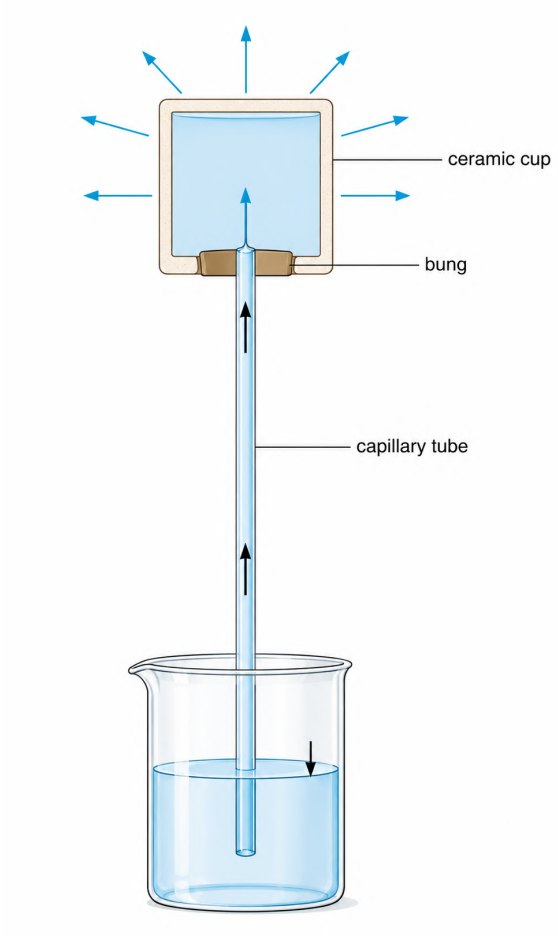
Water rises against gravity between soil particles by capillary action to reach roots.

Porous paper towel has a large surface area to create a strong capillary pulling force by adhesion.
Paper is made of cellulose fibres from the cell wall of plant cells.

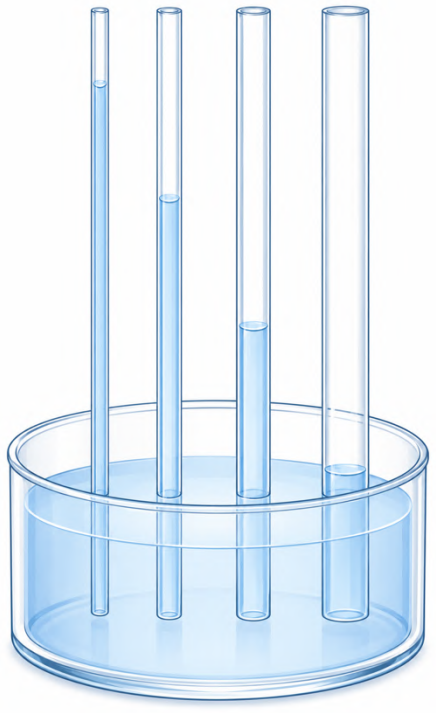
In certain trees during winter some xylem vessels may fill with air.
Capillary action of water by adhesion can help refill these with sap in the spring.

Some mosses have narrow hair like structures on their stems.
These have cellulose cell walls which attract water from fog and store it to keep the moss hydrated.

Clay pots allow water to evaporate out of them.
Water is pulled up under tension by cohesion of water molecules.
pot = leaf
capillary tube = stem
beaker = soil water



Capillary tubes showing 'capillary action' by adhesion of water to the glass.
Narrower tubing provides a larger surface area for adhesion and a smaller volume of water to be lifted against gravity resulting in a higher rise.



Transpiration Pull

Water evaporates from the cell wall surface of leaf (mesophyll) cells into air spaces.
If stomata are open the water vapour can exit the leaf allowing further evaporation to occur.

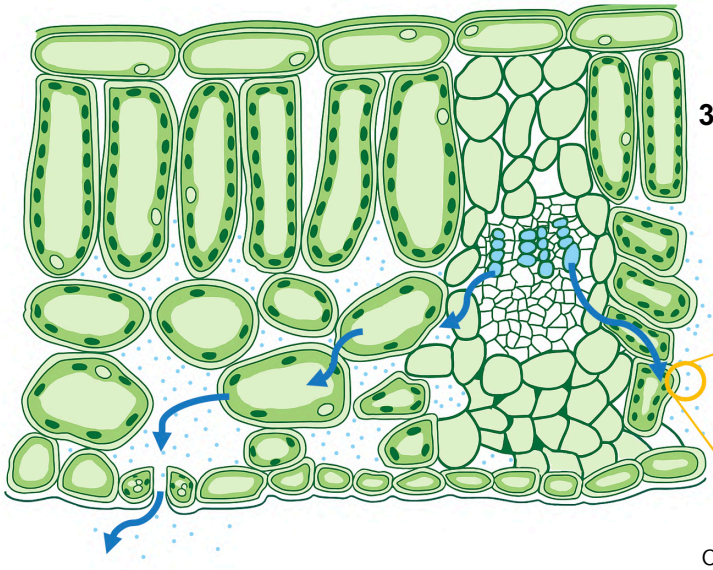
The property of adhesion causes neighboring water molecules to take the place of the evaporated water on the now exposed cell walls. This creates a tension force due to cohesion of water molecules that pulls water from the xylem up into the mesophyll cell and across its cell wall.

Negative pressure and tension forms on the water in the xylem tissue.
The thick cell walls of the xylem prevent them from buckling inwards like a collapsed paper straw.
As all the water molecules are connected by cohesion this pulling force is transmitted all the way down the continuous water column in the xylem to the roots and out into the soil water.

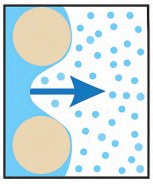
This force pulls water up the stem against gravity due to the low pressure formed in the leaf.

This is a passive process requiring no energy from the plant. The process is powered by the heat of the sun which causes evaporation of water off the surface of leaf cells and into the leaf spaces.

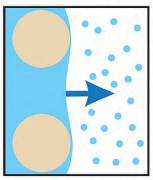
At night adhesion and cohesion help prevent the water column in xylem from falling under gravity.

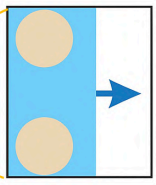


3 Tension forces are created in the leaf cells and back to the xylem due to **cohesion**.



2 **Adhesion** to exposed fibres by nearby water molecules replaces the lost water – by capillary action.





1 Water **evaporates** off the cellulose fibers of the cell wall.

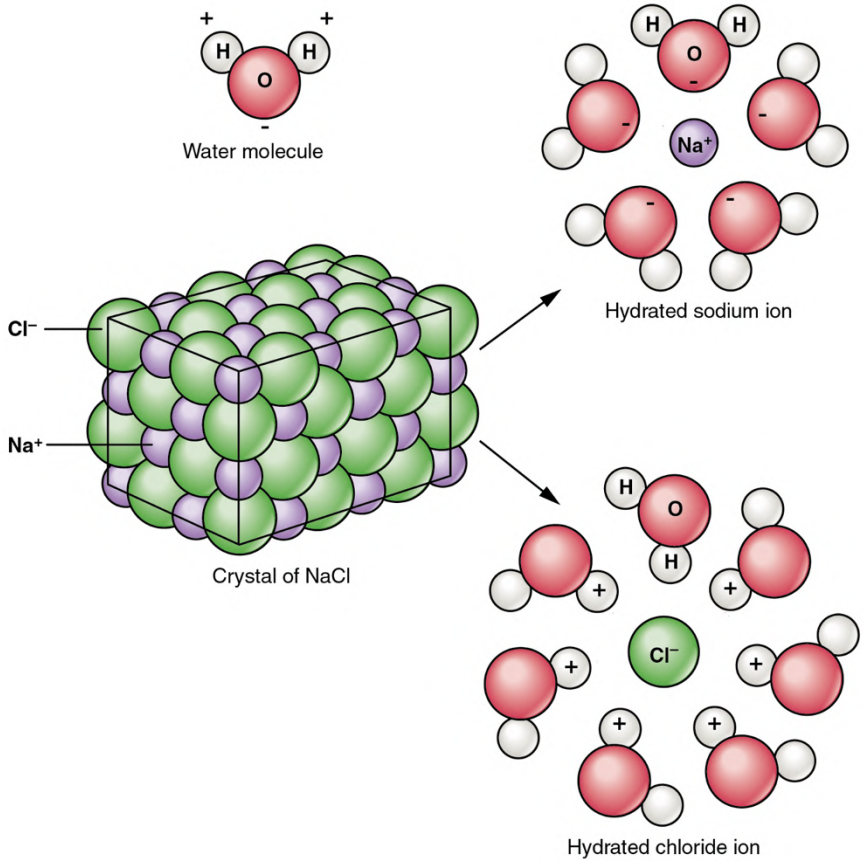
cellulose fibers allow water to move by capillary action

adapted from Pearson Ed 2008

5SL Solvent properties of water provide a medium for metabolism and transport

Water is a polar molecule:

- forms shells around charged and polar molecules
- keeps solutes separated and dissolved in solution
- forms hydrogen bonds with polar molecules



adapted from OpenStax

Water can dissolve many substances therefore it is a medium for metabolism and transport.

metabolism - is all the chemical reactions in a cell

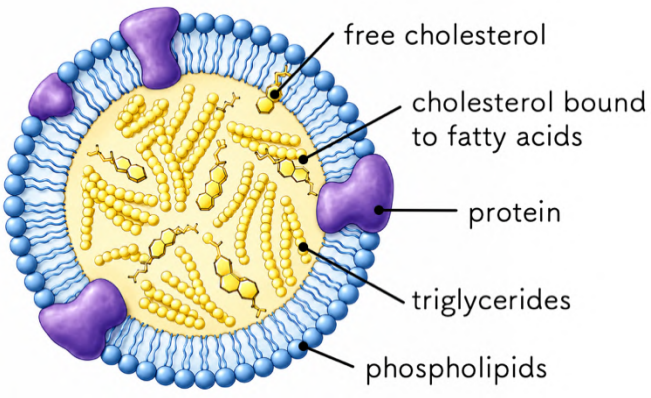
Cytoplasm contains dissolved enzymes which require water to be able to collide with their substrate. Hydrogen bonding by water helps proteins fold into shape and maintains membrane structure. Therefore, water is a required medium for metabolism.

In plants water transports mineral ions up xylem. Water allows sucrose and amino acids to flow in phloem.

Blood plasma is mainly water and carries:

- sodium chloride particles are charged and highly soluble
- glucose is highly soluble due to its many polar OH groups
- amino acids vary in solubility
- oxygen and carbon dioxide are small but are non-polar. Oxygen has low solubility in water especially if it is warm, carbon dioxide is more soluble. Both can bind to hemoglobin, CO_2 is mainly carried as bicarbonate HCO_3^- ions and carbonic acid.
- lipids are non-polar, large and insoluble in water so they are coated in a layer of phospholipids for transport in water
- vitamins and hormones are a mix of water and lipid soluble substances

Water can also carry heat energy.



a lipoprotein

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6SL Physical properties of water and the consequences for animals in aquatic habitats

buoyancy – upward force of a fluid
- the force is equal to the weight of the fluid displaced by the object

The density of pure water is 1g/cm^3 at 4°C.

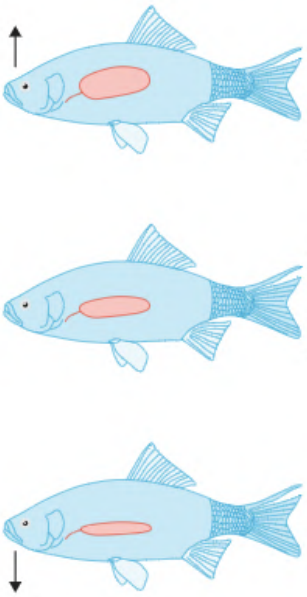
As a solid water has a lower density than 1g/cm^3 and will float on itself. This rare property ensures aquatic habitats do not freeze completely solid during winter.

Many tissues have a density close to 1g/cm^3 – this allows organisms living in an aquatic environment to be able to move without sinking or floating to the surface too easily.

Water supports delicate structures of aquatic organisms such as gills and there is less need for strong skeletons.

Bony fish use an air-filled swim bladder
- to optimize their buoyancy
- reduce energy needed to stay at the right depth

Air has low density and little supportive buoyancy.



viscosity - is resistance to flow
- more viscous fluids flow less easily – they are more sticky
- caused by internal friction in a fluid
- greater flow rate in centre and less near edges in contact with a barrier

Hydrogen bonds increase viscosity of water.
Solutes increase viscosity – blood has a higher viscosity than pure water.
Air has 50x less viscosity than liquid water.

thermal conductivity – rate at which heat passes through a material

Water has a high thermal conductivity. Water conducts heat away 25 times faster than air.
Warm blooded animals risk losing too much heat in watery habitats so require fat for insulation.
Fat and oil are 75% less conductive than water.
Air is 95% less conductive than water – making it a good insulator.

specific heat – heat required to raise the temperature of 1g of material by 1ºC

Water has a high specific heat capacity of 4.18 J/g/ºC and air is 1.01 J/g/ºC (or use kelvin J g^{-1} K^{-1})

Water is slow to heat and slow to cool – it is a thermally stable habitat. To raise the temperature of water many hydrogen bonds must be broken before there is an increase in the average movement (kinetic) energy of the water molecules.

Water can absorb and remove heat by sweating and transfer heat around the body in the blood.

Water:
- can be used as a coolant as it can absorb a lot of heat energy
- is a stable habitat as it does not change temperature easily
- helps maintain constant temperatures in warm blooded birds and mammals

water as a habitat		air as a habitat
less energy needed for support	buoyancy	more energy to get airborne
more energy to move through	viscosity	less energy to move through it
high heat loss risk – insulation by blubber	thermal conductivity	low heat loss risk – insulation by feathers/fur
temperatures more stable	heat capacity	temperatures can fluctuate

Special properties of pure water:
- colourless
- tasteless
- odourless
- pH neutral
- below 4°C water becomes less dense and moves to the surface
- as a solid it can float on liquid water
- forms hexagonal 6-sided crystals
- can form white reflective ice, snow and clouds

The following adaptations improve energy efficiency:

By permission Erkko Badermann

arctic black throated loon
- streamlined body and webbed feet to overcome water viscosity
- easily floats on the surface due to buoyancy
- an oil gland and feathers insulate against heat loss to the water

arctic ringed seal
- streamlined shape and fins overcome water viscosity
- easily keeps its nose above water due to blubber buoyancy
- blubber insulates against heat loss to the water

The water temperature in the Arctic may slowly drop to 1.8°C which is just above freezing. This is often higher than winter air temperatures which can rapidly drop to -40°C.

Alaska sealife center

7HL Extraplanetary origin of water on earth and reasons for its retention

Where did all the water come from that is on Earth?
If the planet was initially molten then water may have boiled and been lost to space, therefore, it is more likely to have arrived after the planet cooled.

A popular hypothesis is that water arrived by asteroids colliding with the earth as meteorites:
- there is evidence of an asteroid bombardment with many craters left on the Moon
- unmelted asteroids have a higher water content of up to 20% however, these are rare
- melted asteroids are some of the driest objects in space

Water in *comets* is high in deuterium unlike the water on Earth which makes them a less likely source.

Once present how was the water retained on the Earth?
1. Earth's temperature is low enough to allow water to condense from a vapour to a liquid.
   Most of the water (98%) on Earth exists as a liquid.

2. Earth is large enough to have a strong gravitational pull.
   Oceans are held tightly to the Earth's surface and gases remain within the atmosphere.
   Hydrogen and helium can escape the atmosphere but very little water vapour escapes.

Meteor Crater in Arizona is 1.2km wide 170m deep and formed by a meteorite about 50m across.

Emma Buchanan

Extra for Experts
How many asteroids would be needed every year to supply 1 386 000 000 km^3 of water if each asteroid contained a) 25% water and was 40km^3 in volume over 200 000 000 years?
b) 10% water and was 0.1km^3 in volume over 4 billion years?

8HL Relationship between the search for extraterrestrial life and the presence of water

The search is on for liquid water on other worlds to find other evolved life forms. The story of *Goldilocks and the Three Bears* is used as a metaphor for the habitable zone around a star. A planet needs to be not too close or too far from a stable star to ensure it has liquid water. A planet in the *Goldilocks zone* is just the right distance away for liquid water.

The distance depends on:

- size of the star
- size of the planet

The Sun is the right size to release energy for liquid water

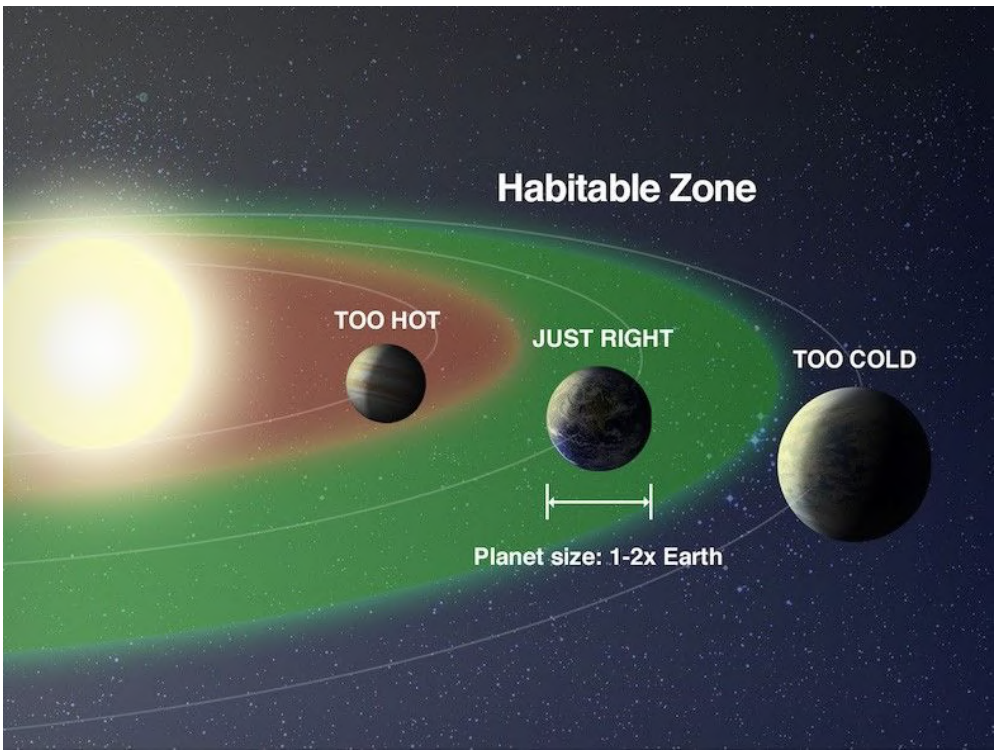
- bigger and it would release too much energy
  - even if Earth was moved further away there would be too many UV rays from a larger star
- smaller and it would not release enough energy
  - even if Earth was moved closer to be the right temperature the light would be very dim

The size of the planet has to be just right. It determines the strength of gravity to retain an atmosphere.

- too big makes a thick, hot atmosphere like Venus
- too small makes a thin, cold atmosphere like Mars

The Sun and Earth are both the right size and distance for most water to be in a liquid state.

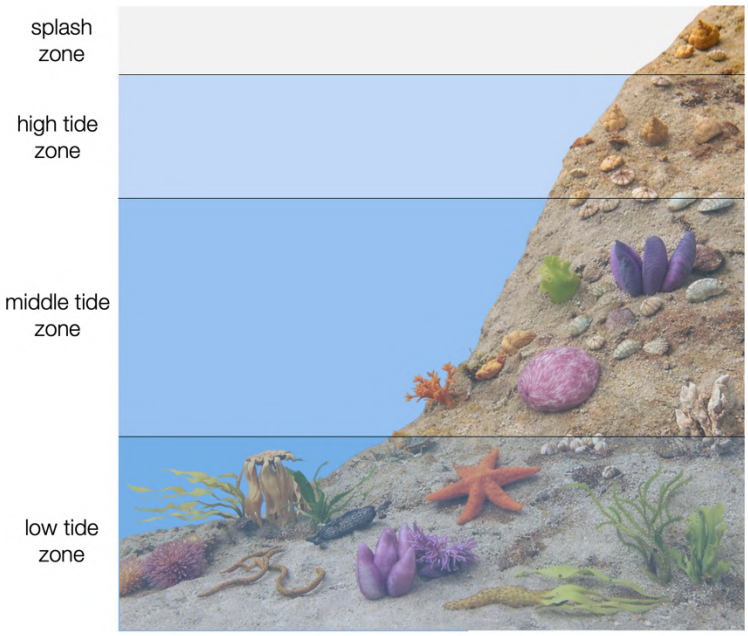
Leonard Leslie Brooke Public Domain



NASA

Optional Extension (not required for the IB examination)

The Moon:
- if closer, tides would flow over continents
- if too far away there would not be enough ocean mixing to supply nutrients and remove waste



adapted from Pearson Ed. 2005

The Earth spins once every 24 hours:
- faster and fierce winds would blow
- slower and the light side would be too hot for organisms and the dark side too cold for life

The Earth's tilt (23.5º) gives us seasons:
- smaller, a permanent ice age develops
- larger, results in wild changes in temperature

A wonderful feature that is extra special for us on our planet is the Sun which is 400x larger than the Moon but 400 times further away which means they look the same size from Earth.
This creates breath-taking eclipses and enables the corona of the Sun to be studied.