

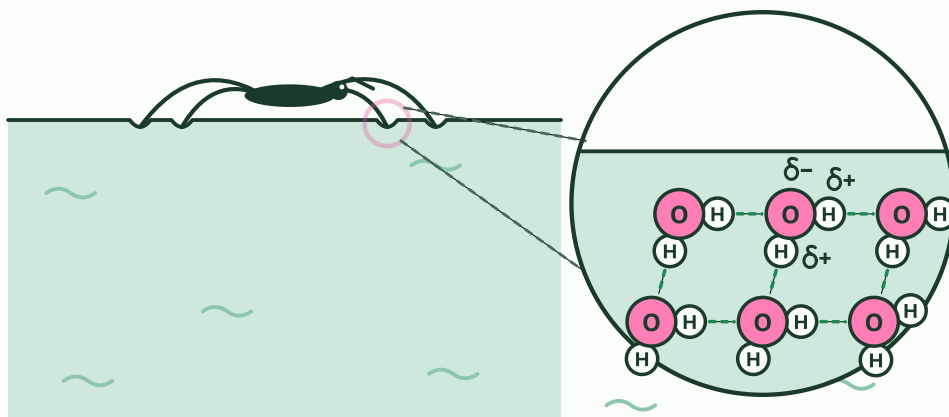
REVISION GUIDE

Why life runs on *water*

Water

Life began in water, and every cell is still mostly water. Here is why one small, lopsided molecule clings to itself and to other things, dissolves what cells need, climbs to the tops of trees, and shapes the lives of a diving bird and an Arctic seal.

Strong enough to stand on



8 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-a1-1-water



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By the end you can

- ☐ Explain why water is the medium for life: where the first cells arose, and where life's processes still happen A1.1.1
- ☐ Explain how unequal sharing of electrons makes water polar, and draw hydrogen bonds between water molecules with partial charges A1.1.2
- ☐ Explain how cohesion lets water be pulled up xylem under tension, and lets animals live on its surface A1.1.3
- ☐ Explain how adhesion draws water through soil and plant cell walls by capillary action A1.1.4
- ☐ Explain why water is the medium for metabolism and transport, and why some molecules work because they do not dissolve A1.1.5
- ☐ Compare water with air for buoyancy, viscosity, thermal conductivity and specific heat capacity, using the black-throated loon and the ringed seal A1.1.6
- ☐ Outline how asteroids may have brought Earth's water, and why gravity and cool temperatures kept it A1.1.7
- ☐ Explain why the search for life elsewhere looks for liquid water in a star's Goldilocks zone A1.1.8

Tick each one when you can do it without the book.

01

A1.1.1 WATER AS THE MEDIUM FOR LIFE

Life began in water, and still *runs* in it

The first cells appeared in water more than 3.5 billion years ago. Where exactly, in the sea or in hot pools, is still debated. What is not in doubt is that for about three billion years every living thing stayed in water, and plants and animals reached land only in the last 500 million years or so.

Water suited them because things dissolve in it. Dissolved substances can move about, meet and react, and that is how the first cells could run their chemistry. Water is the **medium** for life, and the chemistry it carries, **metabolism**, still happens in it today.

A typical cell is about 70% water by mass. Its **cytoplasm** is an **aqueous solution**, and most of the reactions of metabolism take place in it. **Blood plasma**, about 90% water, and xylem sap carry dissolved substances round bodies and plants.

Land organisms did not leave water behind. They carry it inside them, in their cells, blood and tissue fluid, and a skin or a waxy cuticle slows its loss.

KEY TERMS

medium

The material in which something happens or is carried. Water is the medium for life: cells are mostly water, and most of their chemistry happens in it.

metabolism

All the chemical reactions that go on in a living cell.

cytoplasm

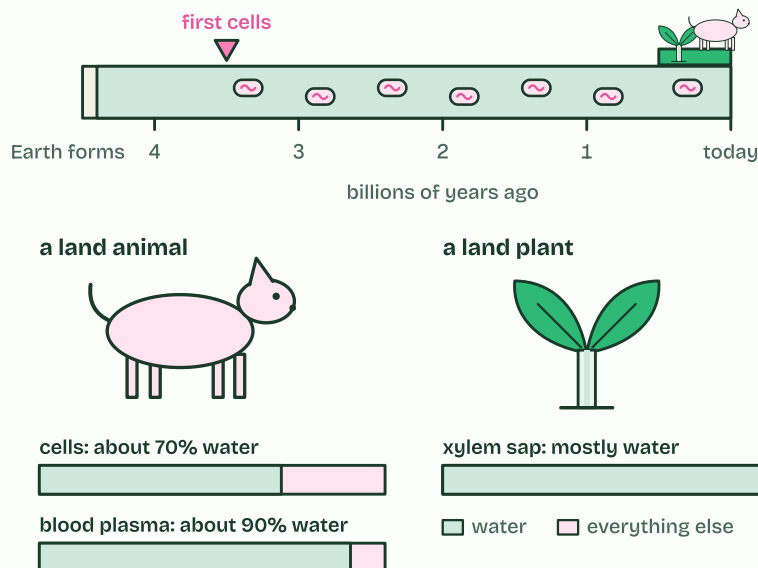
The fluid inside a cell, outside the nucleus, where many metabolic reactions take place.

aqueous solution

A mixture in which substances are dissolved in water.

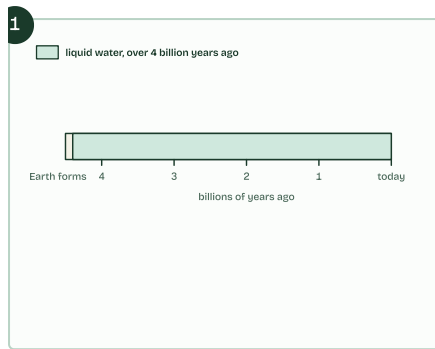
blood plasma

The pale yellow liquid part of blood. About 90% of it is water, and it carries dissolved substances round the body.

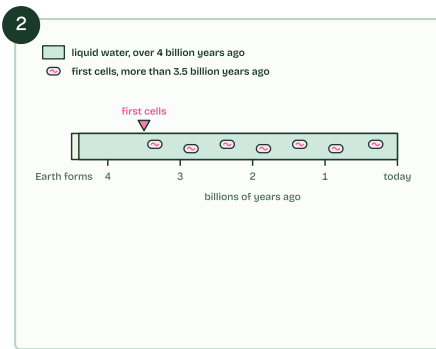


STEP BY STEP

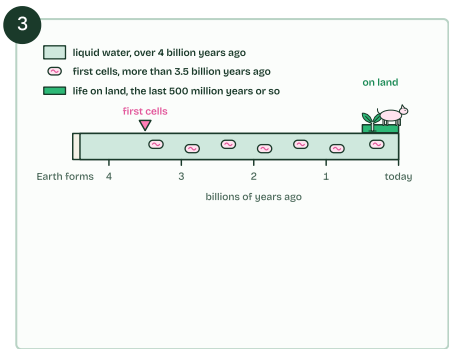
4 STEPS



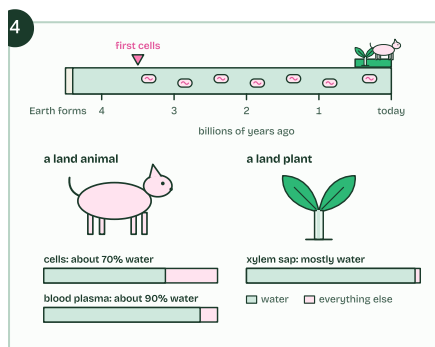
Liquid **water** appeared very early, over 4 billion years ago.



The **first cells** lived in it, more than 3.5 billion years ago, and for about three billion years every living thing stayed there.



Plants and animals reached **land** only in the last 500 million years or so.



Even there, life **carries** its water inside it: cells, blood plasma and xylem sap are all mostly water.

WATCH OUT

"Land animals live without water." They do not: they carry it inside them, and every reaction in their cells still happens in water.

IN NUMBERS

A typical cell is about 70% water by mass, an adult human about 60% and a jellyfish about 95%.

PREDICT

A packet of dry bean seeds sits in a cupboard for three years. What is happening to the metabolism inside each seed?

- (A) It runs as normal, slowly using up the seed's food store so that less is left each year
- (B) It has almost stopped: with so little water, enzymes and substrates cannot meet to react
- (C) It has stopped for good: the seeds are dead and will not grow, however much water they get

Decide before you look. Answer on page 32.

02

A1.1.2 HYDROGEN BONDS

A lopsided molecule makes *hydrogen bonds*

A water molecule is one oxygen atom joined to two hydrogen atoms by **covalent bonds**, and it is bent, with about 104.5° between the two bonds.

The sharing is unequal. Oxygen is more electronegative: it pulls on the shared electrons harder than hydrogen does, so they spend more time near the oxygen. That makes each O–H bond a **polar covalent bond**. The oxygen end gains a small negative charge and each hydrogen a small positive one: **partial charges**, written δ^- and δ^+ . The molecule is bent, so one side is negative and the other positive, and the whole thing is a **polar molecule**.

Opposite charges attract. The δ^+ hydrogen of one molecule is pulled towards the δ^- oxygen of its neighbour, and that attraction is a **hydrogen bond**. It forms between molecules, never inside one. Each is weak, about a twentieth as strong as a covalent bond, and lasts only a few trillionths of a second. But there are vast numbers, always breaking and re-forming, and one molecule can make up to four.

KEY POINTS

- Draw it the IB way: solid lines for covalent bonds, dashed lines for hydrogen bonds.
- Write δ^+ and δ^- , never a bare + or -: the molecule is neutral overall.

Why it matters: to pull water molecules apart, hydrogen bonds must be broken, and that takes energy. Water boils at 100°C , but methane, a molecule of about the same size with no hydrogen bonds, boils at -162°C . When water evaporates, its fastest molecules break their hydrogen bonds and escape, taking energy with them, so what is left behind cools. Each gram that evaporates takes about 2.4 kJ, the **latent heat of vaporisation**. That is how sweat cools skin and transpiration cools leaves.

KEY TERMS

covalent bonds

A bond in which two atoms share a pair of electrons.

polar covalent bond

A covalent bond in which the electrons are shared unequally, so one end is slightly negative and the other slightly positive.

partial charges

Charges smaller than a whole electron's, written δ^+ and δ^- . The molecule as a whole stays neutral.

polar molecule

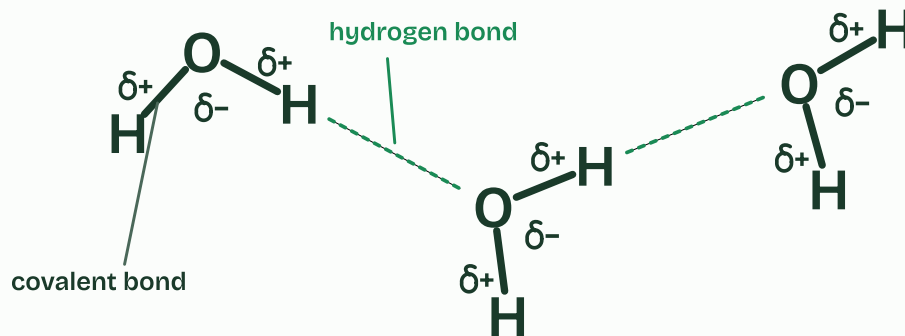
A molecule with one side slightly negative and the other slightly positive.

hydrogen bond

The weak attraction between a slightly positive hydrogen of one molecule and a slightly negative atom, here oxygen, of another.

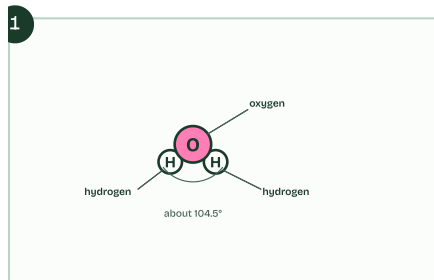
latent heat of vaporisation

The energy needed to turn 1 g of a liquid into a gas without changing its temperature.

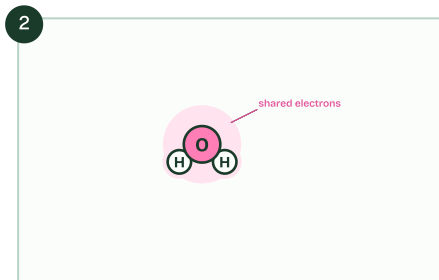


STEP BY STEP

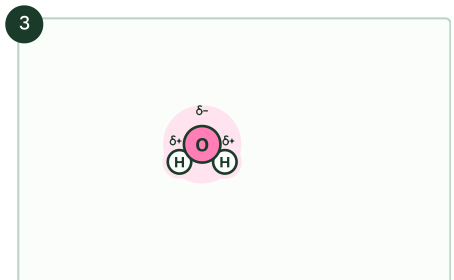
6 STEPS



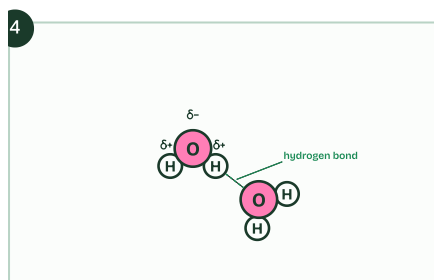
One water molecule: an oxygen with two hydrogens, **bent**, with about 104.5° between the bonds.



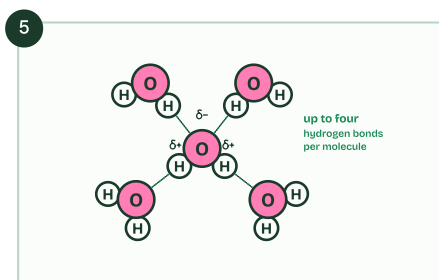
The shared **electrons** (the pink cloud) crowd round the oxygen and thin out round each hydrogen.



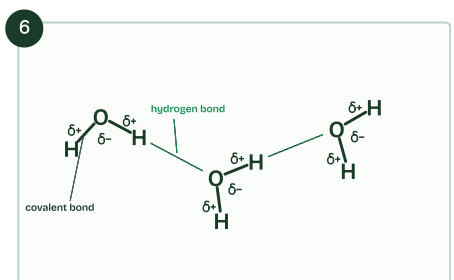
So the oxygen is slightly negative and each hydrogen slightly positive: **partial** charges, not whole ones.



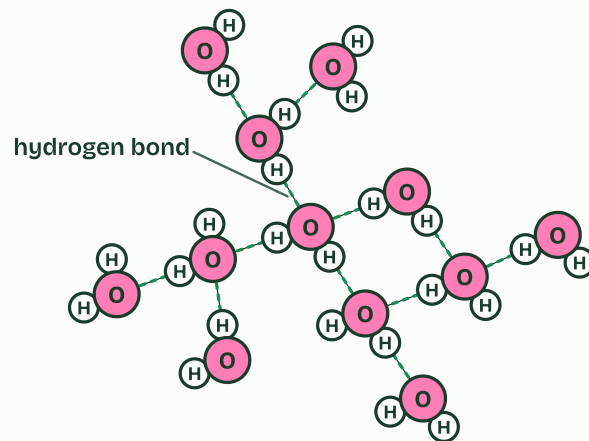
A second molecule turns its oxygen to face a hydrogen of the first, and a dashed line joins them: a **hydrogen bond**.



One molecule can make up to **four**: two through its hydrogens and two to its oxygen.



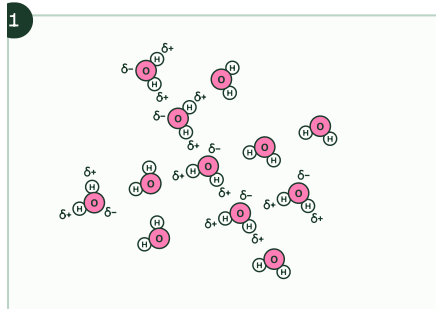
The notation the exam wants: letters, solid lines for covalent bonds, dashed lines for hydrogen bonds, and δ signs. **Draw it like this.**



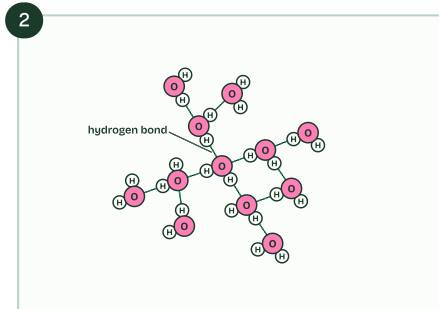
Raise the temperature: the molecules move faster and each hydrogen bond lasts a shorter time. Even so, most molecules are still held by a couple of bonds at any moment.

STEP BY STEP

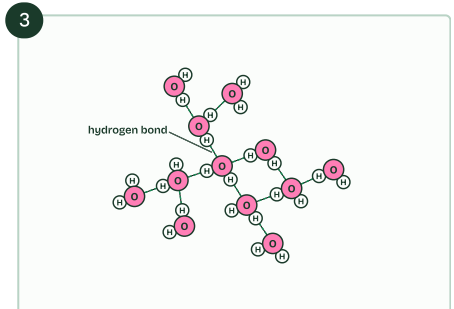
3 STEPS



Each water molecule is **polar**: the oxygen is slightly negative and the hydrogens slightly positive.



A slightly positive hydrogen is attracted to the oxygen of another molecule: a **hydrogen bond**.



Each bond lasts only a moment. They **break and form** all the time as the molecules move; in liquid water most molecules are held by several at once.

REMEMBER IT

What hydrogen bonds give water

C Cats	A Avoid	T Taking	S Showers
Cohesion water sticks to water (chapter 3)	Adhesion water sticks to polar or charged surfaces (chapter 4)	Thermal slow to warm, and takes a lot of heat to evaporate (here and chapter 6)	Solvent dissolves polar and charged substances (chapter 5)

WATCH OUT

"A hydrogen bond is the bond between O and H inside a water molecule." Those are covalent bonds. A hydrogen bond is between molecules.

WATCH OUT

" δ^+ and δ^- are the charges of ions." They are partial charges: a water molecule is neutral, so write δ , never a bare + or -.

HOW DO WE KNOW?

No one has watched a hydrogen bond form: each is far too small and lasts a few trillionths of a second. The evidence is indirect. Water boils at 100 °C, where molecules of the same size boil far lower (methane at -162 °C, hydrogen sulfide at -60 °C), and its surface tension and heat capacity are unusually high. One idea, hydrogen bonding, explains all of these at once, and X-ray and neutron studies of ice show each hydrogen pointing at an oxygen on the next molecule. A theory earns trust by explaining many observations and surviving every test so far.

LINKS

Hydrogen bonds hold the two strands of DNA together (A1.2) and help hold proteins in shape (B1.2). The same weak, numerous attractions run through the whole course.

PREDICT

Water boils in a kettle. Which bonds break as it turns to steam?

- (A) The covalent bonds inside each molecule, so the steam is hydrogen gas and oxygen gas
- (B) Both: the molecules split apart first, then the atoms join up again in the steam
- (C) The hydrogen bonds between molecules, so the steam is still made of water molecules

Decide before you look. Answer on page 32.

03

A1.1.3 COHESION

Water *holds on* to itself

Hydrogen bonds make water molecules stick to one another. That is **cohesion**.

Inside a drop, each molecule is pulled equally in every direction by its neighbours. A molecule at the surface has neighbours beside it and below it but none above, so it is pulled sideways and inwards. The surface molecules cling together and the surface acts like a stretched film that resists being broken. That is **surface tension**, and water's is higher than that of almost any other common liquid.

Small animals use the film as a habitat. A pond skater (*Gerris lacustris*) spreads its weight over long legs, and water-repellent hairs on its feet press dimples into the surface without breaking through. Mosquito larvae hang from the underside and breathe through a tube that pokes up through the film.

Cohesion also lifts water to the top of a tree. In a leaf, water evaporates from the wet walls of cells and leaves as vapour through small pores, which is **transpiration**. That pulls water out of the **xylem**. Because the molecules cohere, the whole column of water is pulled up from the roots, like a rope pulled from the top. The water is under **tension**: it is being pulled, not pushed. Cohesion keeps the column whole however tall the plant, but an air bubble breaks it, and that tube stops carrying water. (The detail of xylem vessels is B3.2.)

KEY TERMS

cohesion

The attraction between molecules of the same substance. In water it is caused by hydrogen bonds.

surface tension

The tendency of a liquid's surface to resist being broken, because the molecules at the surface are pulled together and inwards.

transpiration

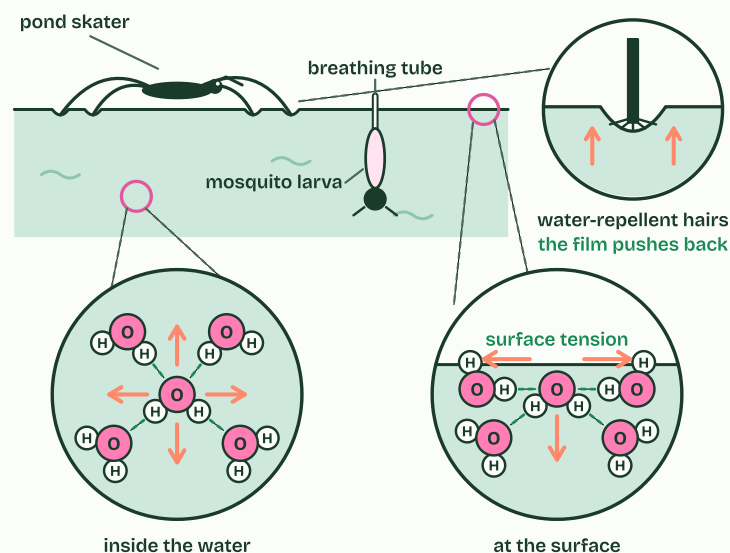
The loss of water vapour from a plant, mostly through pores in its leaves.

xylem

The tubes that carry water and dissolved minerals up a plant.

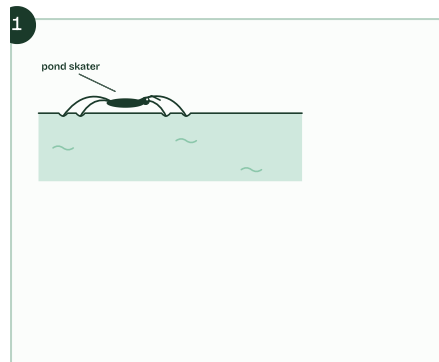
tension

A pulling force. Water in the xylem is pulled up the plant, not pushed.

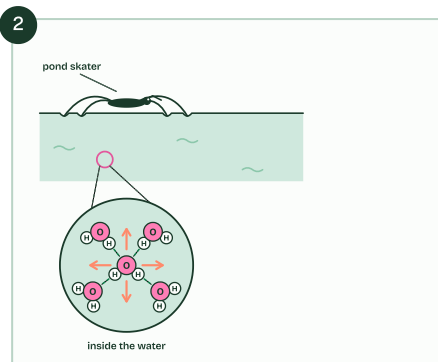


STEP BY STEP

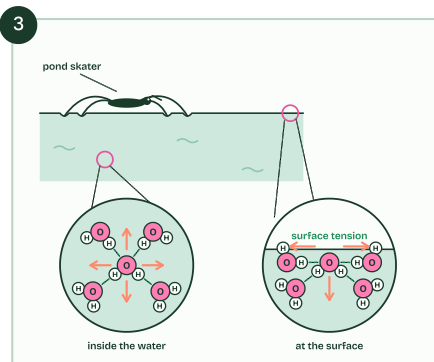
5 STEPS



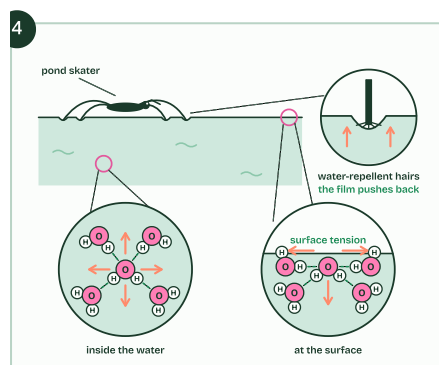
A pond skater stands on water. Its long legs spread its weight, and each foot makes a small **dimple** in the surface.



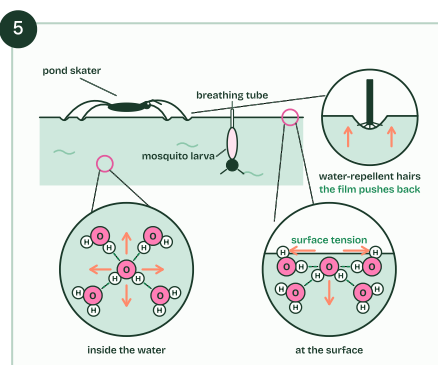
Inside the water, each molecule is pulled by its neighbours equally in **every direction**, so it stays where it is.



At the surface there are no neighbours above: the pull is **sideways and inwards**, and the surface holds together like a stretched film. That is **surface tension**.



Close up, water-repellent **hairs** on the foot press the film into a dimple without breaking it, and the film pushes back up.



A mosquito **larva** hangs from the underside of the film and breathes through a tube that pokes through it.

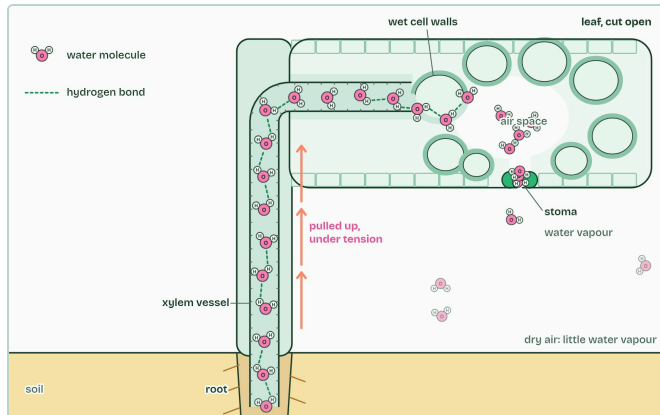
ANIMATION · WATCH IT HAPPEN: PULLING WATER UP A STEM

3 MOMENTS

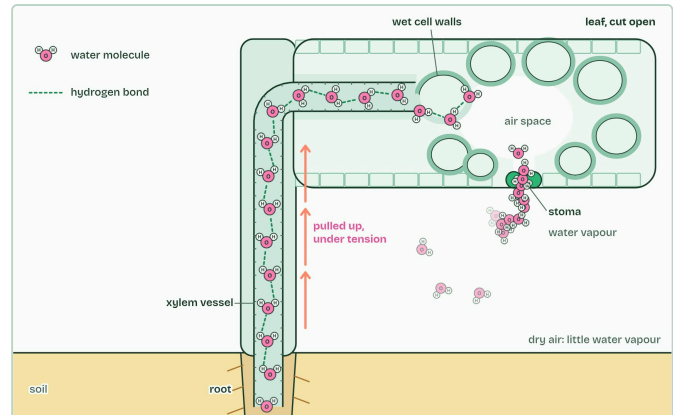
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FLOW: FAST 2

FLOW: FAST



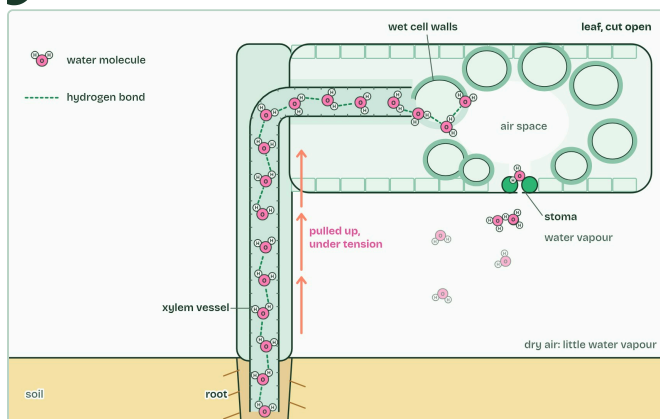
Water **evaporates** from the wet cell walls in the leaf and escapes through a stoma.



Each molecule that leaves pulls on the next: **hydrogen bonds** hold the column together.

3

FLOW: FAST



The whole column is pulled up from the roots, under **tension**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a1-1-water#cohesion

WATCH OUT

"Capillary action lifts water to the top of a tree." In a xylem vessel, capillary action alone would lift water only a metre or so at most, and far less in wider vessels. The pull comes from evaporation in the leaves, passed down the column by cohesion.

WATCH OUT

"Surface tension is a skin of different molecules," or "surface water is denser." It is the same water, held more tightly by hydrogen bonds at the surface.

EXAMPLE

The tallest living tree, a coast redwood in California, is about 116 m tall. Holding up a column of water that tall takes a pull of more than 1 MPa, about eleven times the pressure of the air, and cohesion holds.

LINKS

Processes at surfaces: the surface film is a habitat, and evaporation from wet cell walls drives the pull up the xylem.

PREDICT

Ground pepper floats on a bowl of water. You touch the middle of the surface with a finger dipped in washing-up liquid. What does the pepper do?

- ☐ (A) It shoots out to the edge of the bowl, dragged by the clean surface that is still pulling all round
- ☐ (B) It sinks to the bottom, because the soap makes the water under it heavier than the pepper grains on top
- ☐ (C) Nothing happens: the soap mixes into the water and leaves the surface pulling exactly as it was

Decide before you look. Answer on page 32.

A1.1.4 ADHESION

04 Water *clings* to polar surfaces

Water is attracted to other materials too, as long as they are polar or carry a charge. That is **adhesion**: hydrogen bonds or ionic attractions pull water on to the surface. Glass does it. So does **cellulose**, which is covered in OH groups, and so do the charged surfaces of clay and humus in soil. A waxy, non-polar surface gives water nothing to cling to, so water beads up on it instead.

Put a narrow gap between surfaces that water clings to and something useful happens. Water adheres to the walls and creeps up them, and cohesion drags the rest of the water along behind. This is **capillary action**. The narrower the gap, the higher the water rises.

In soil, rain is held in the narrow spaces between the particles by adhesion and cohesion, so it does not all drain away, and it can creep through the soil towards roots. Clay, with tiny spaces and charged particles, holds the most.

In a plant, a cell wall is a mesh of cellulose fibres with tiny gaps between them. Water soaks through the wall by capillary action and keeps it wet. In a leaf, those wet walls are where the evaporation of chapter 3 happens. (The detail of walls and leaves is B3.2.)

KEY TERMS

adhesion

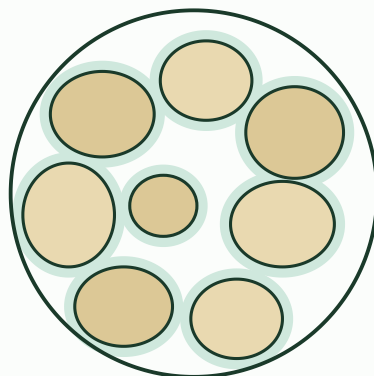
The attraction between water and a different material that is polar or charged, through hydrogen bonds or ionic attractions.

cellulose

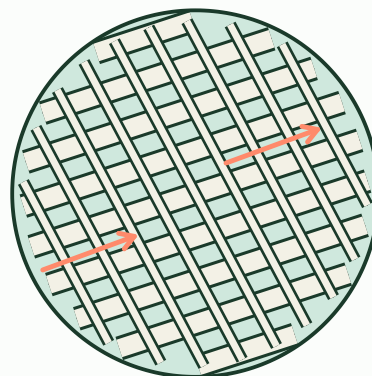
The carbohydrate that makes plant cell walls, built from long chains of glucose and covered in OH groups.

capillary action

The movement of water along a narrow space against gravity, caused by adhesion to the walls and cohesion between the water molecules.



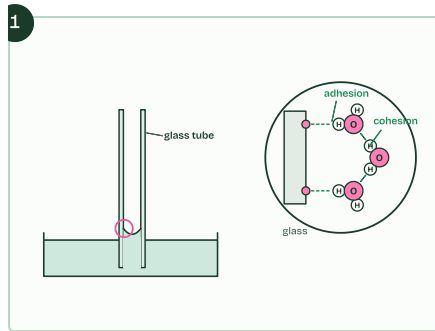
in soil
water clings to the particles
and sits in the narrow gaps



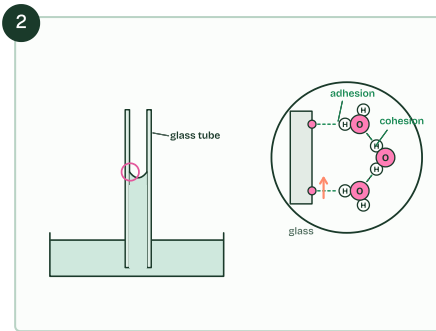
in a plant cell wall
water soaks through the gaps
between the cellulose fibres

STEP BY STEP

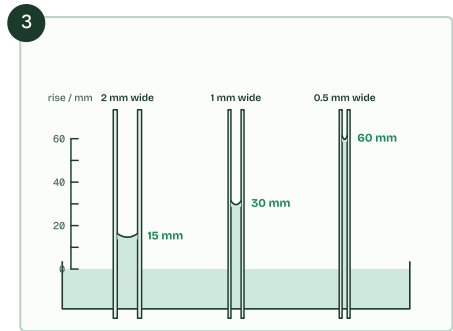
5 STEPS



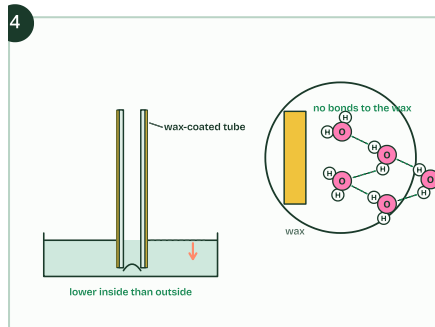
Water is attracted to the polar glass wall and forms bonds with it: **adhesion**. The water's edge curves up where it meets the glass.



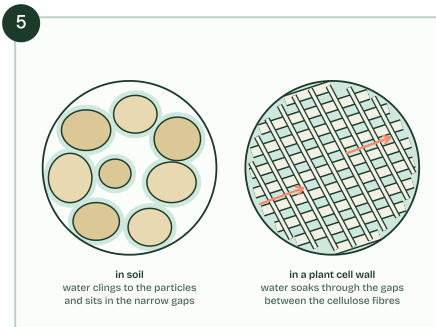
Cohesion drags more water up behind the edge, and the column rises until its weight balances the pull.



The **narrower** the tube, the higher the water climbs.



Wax has nothing for water to cling to: with no adhesion the surface curves down and sits **below** the level outside.



The same pull holds water between **soil** particles and soaks it through the gaps in a **cellulose** cell wall.

REMEMBER IT

Cohesion or adhesion?

C Clones	A Anything
Cohesion water clings to its clones: other water molecules	Adhesion water clings to anything polar or charged: glass, cellulose, soil

WATCH OUT

"Cohesion and adhesion are the same thing."
Cohesion is water to water. Adhesion is water to a different material that is polar or charged. Capillary action needs both.

EXAMPLE

A cotton towel dries you because water adheres to its cellulose fibres and creeps along the spaces between them.

LINKS

Much of biology happens at surfaces: water held on soil particles and in cell walls here, gas exchange across moist surfaces in lungs and leaves (B3.1), and reactions on membranes (B2.1).

PREDICT

Three cups in a row: red water, an empty cup, blue water. A strip of paper towel bridges each full cup and the empty one. What is in the middle cup a few hours later?

- Ⓐ Nothing: water cannot climb up and out of a cup by itself, whatever the paper strip is made of
- Ⓑ Only red water, because the red cup was filled first and so its water got into the middle cup first
- Ⓒ Purple water, rising until the levels even out, because water creeps along paper from both sides

Decide before you look. Answer on page 32.

05

The *solvent* cells run in

A1.1.5 WATER AS A SOLVENT

A **solution** is a **solute** dissolved in a **solvent**. Water dissolves a wide variety of substances: ions such as Na^+ , K^+ and Cl^- , and polar molecules such as glucose, amino acids and urea.

It does so because of its own charges. Water molecules crowd round an ion with their δ^- oxygens turned towards positive ions and their δ^+ hydrogens towards negative ions, and pull the ions apart. Polar molecules dissolve by forming hydrogen bonds with water. Each dissolved particle ends up wrapped in water molecules, which is called **solvation**. A positive ion such as Na^+ is a cation and a negative ion such as Cl^- is an anion.

Substances that are polar or charged are **hydrophilic**. Substances that are non-polar, such as fats, oils and waxes, are **hydrophobic**: water molecules bond to each other instead, which pushes the non-polar molecules together, as oil forms droplets.

That makes water the medium for metabolism. Most **enzymes** catalyse reactions in aqueous solution, in the cytoplasm and in the fluids inside organelles, where dissolved enzymes and substrates move about and collide. It also makes water the medium for transport. Blood plasma carries glucose, amino acids, ions, urea and hormones dissolved in it, and xylem sap carries mineral ions such as nitrate and potassium from roots to leaves. Phloem sap carries dissolved sugars. Fats cannot travel dissolved, so in blood they ride inside lipoproteins, packages of lipid and protein that are soluble.

Some molecules work because they are hydrophobic and insoluble. The wax on a leaf stops water escaping. Fat stores energy, and insulates, without dissolving into the cell's water (the seal's insulating fat, in chapter 6). The non-polar tails of phospholipids make membranes a barrier to water-soluble substances (B1.1 and B2.1). Ten substances to sort are below.

KEY TERMS

solution

A mixture of a solute dissolved in a solvent.

solute

A substance that dissolves in a solvent.

solvent

The liquid that a solute dissolves in. Water is the solvent in cells.

solvation

The surrounding of dissolved ions or molecules by water molecules (or another solvent).

hydrophilic

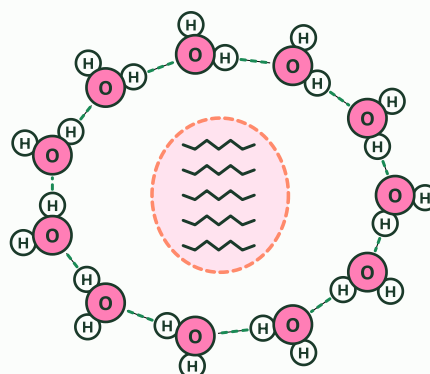
Attracted to water. Polar and charged substances are hydrophilic.

hydrophobic

Not attracted to water. Non-polar substances are hydrophobic.

enzymes

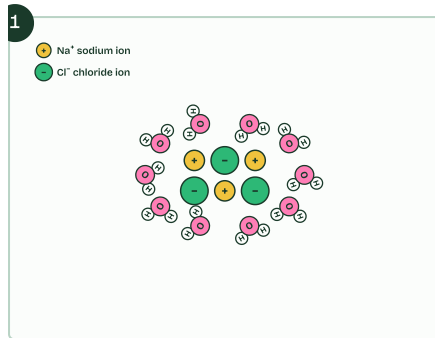
A protein that speeds up a chemical reaction in a cell without being used up.



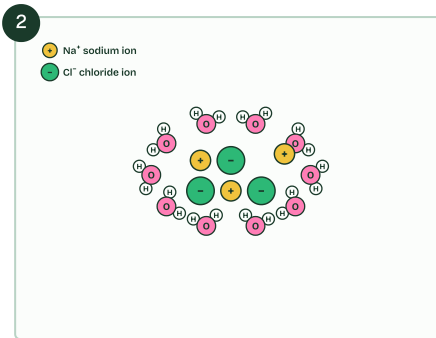
oil is non-polar
water bonds to water, not to oil

STEP BY STEP

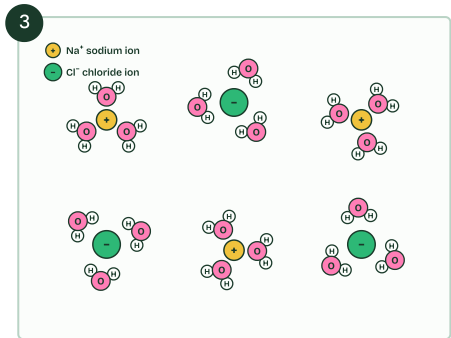
5 STEPS



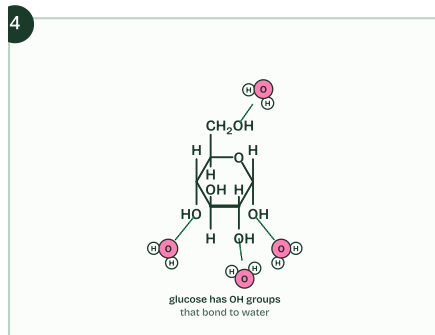
A grain of salt is a lattice of **ions**, sodium (Na⁺) and chloride (Cl⁻), held together by their opposite charges.



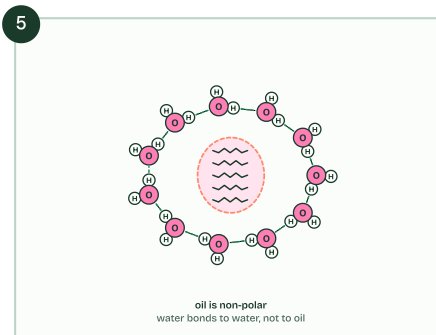
Water molecules turn to face the ions, **oxygen** towards Na⁺ and **hydrogens** towards Cl⁻, and together they pull ions loose.



Dissolved: every ion is wrapped in its own **shell** of water molecules and drifts away from the rest.



A sugar is covered in OH groups, which make **hydrogen bonds** with water, so it dissolves too.



Oil molecules are **non-polar**. Water bonds to water, not to oil, so the oil is pushed together into a droplet.

Dissolves in water

sodium chloride
ions wrapped by water

glucose
OH groups bond with water

an amino acid
charged and polar groups

urea
so urine can carry it away

vitamin C
polar, lost in urine

Does not dissolve

fat (a triglyceride)
hydrophobic

leaf wax
hydrophobic

cholesterol
hydrophobic

cellulose
hydrophilic, but insoluble

calcium phosphate
hydrophilic, but insoluble

Ten substances sorted: five dissolve in water and five do not. The five that do not are useful because of it: wax keeps water in the leaf, fat stores energy and insulates, cholesterol is part of membranes, cellulose makes cell walls that must not dissolve, and calcium phosphate makes bones that last.

WATCH OUT

"Water is the universal solvent." It dissolves more substances than any other common liquid, but not everything: fats, waxes, cellulose and bone mineral do not dissolve, and life depends on that.

WATCH OUT

"Hydrophilic means soluble." Cellulose is hydrophilic, and it is insoluble.

PREDICT

Fish get all their oxygen from water. Oxygen molecules (O_2) are non-polar. How does the oxygen get into the water?

- (A) It does not get in as a gas at all: fish split water molecules at the gills and take the oxygen from them
- (B) It forms hydrogen bonds with the water molecules round it, in just the same way that glucose does
- (C) Small non-polar molecules dissolve a little, and a little is enough to reach the gills

Decide before you look. Answer on page 32.

06

A1.1.6 WATER AS A HABITAT

Life in water, life in *air*

Water is a habitat as well as a medium, and living in it is very different from living in air. Four properties decide most of the difference. The values here are for 20 °C.

KEY POINTS

- **Buoyancy.** Water is over 800 times as dense as air, so it pushes up on a body with almost as much force as the body weighs. Air hardly supports a body at all.
- **Viscosity.** Water is about 55 times as viscous as air, and far denser, so a body moving through it meets much more **drag**. Streamlined shapes save energy.
- **Thermal conductivity.** Water conducts heat about 23 times as fast as air, so a warm body loses heat far faster in water than in air at the same temperature. Animals in cold water need thick insulation.
- **Specific heat capacity.** It takes about 4.2 J to warm 1 g of water by 1 °C, about four times as much as for 1 g of air, and a litre of water holds about 3,500 times as much heat for each degree as a litre of air. Much of the energy goes into breaking hydrogen bonds before the molecules can move faster. So lakes and seas change temperature slowly, from day to night and season to season, and make a stable habitat.

Two animals show the contrast. The black-throated loon (*Gavia arctica*) is a diving bird that breeds on large northern lakes, winters at sea and chases fish underwater. The ringed seal (*Pusa hispida*) is the commonest Arctic seal. It lives on and under the sea ice, keeps breathing holes open with its claws, and is kept warm in the water by a thick layer of **blubber**. The figure sets water against air for each property, and shows what it means for each animal.

KEY TERMS

buoyancy

The upward push of a fluid on an object in it. In water it is almost as large as the object's weight; in air it is tiny.

viscosity

How much a fluid resists flowing past or round an object.

drag

The force that resists movement through a fluid.

thermal conductivity

How fast heat flows through a material. Water conducts heat much faster than air.

specific heat capacity

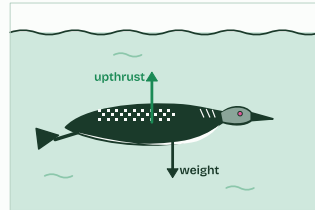
The energy needed to warm 1 g of a substance by 1 °C. Water's is unusually high.

blubber

A thick layer of fat under the skin of a seal or whale that insulates it.

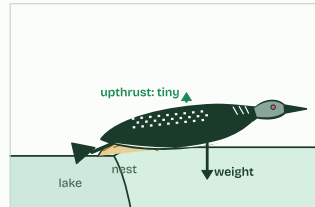
Black-throated loon

In water



Water holds it up so well that it must work to sink: its bones are denser than most birds', and it squeezes air from its feathers before a dive.

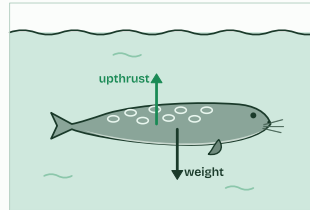
In air



Air holds up almost nothing: its heavy body needs a long run across the water to take off, and it cannot take off from land.

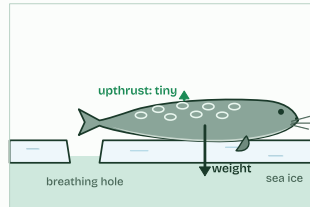
Ringed seal

In water



Water carries its weight, so its flippers drive and steer instead of holding it up.

In air



On the ice nothing holds it up: it hauls its whole weight along on its belly.

Water against air for the black-throated loon and the ringed seal: the same four properties, in each medium, and what each means for the animal.

SWITCH IT

1	2	3	4
Black-throated loon Water holds it up so well that it must work to sink: its bones are denser than most birds', and it squeezes air from its feathers before a dive. In air Air holds up almost nothing: its heavy body needs a long run across the water to take off, and it cannot take off from land.	Black-throated loon Water is thick and heavy to push through: a streamlined body, and big webbed feet and tail, drive it after fish. In air Air slips past easily, but legs and tail for back for swimming make it clumsy on land, so it needs light at the water's edge.	Black-throated loon Water would draw heat from its skin fast: dense, oil-filled feathers trap a layer of air, which conducts heat poorly. In air Air draws heat away slowly: the same feathers keep it warm with less effort.	Black-throated loon Its lake changes temperature only slowly, day to night and week to week. In air Air warms and cools quickly on land: the temperature swings between day and night.
Ringed seal Water carries its weight, so its flippers drive and steer instead of holding it up. In air On the ice nothing holds it up: it hauls its whole weight along on its belly.	Ringed seal A smooth torpedo shape, no air flaps and flat fur cut the drag: side-to-side sweeps of its head flippers push it along. In air Air gives almost no drag, but flippers built for water make poor legs on the ice: it's a skin.	Ringed seal Wet fur loses its trapped air, so a thick layer of blubber under the skin keeps its heat in. In air Air draws heat away far more slowly than water: even when the air is colder than the sea.	Ringed seal Under the ice the sea stays near -1.8 °C all year: winter and summer. In air On the ice the air may fall below -30 °C in winter and rise above 1 °C in summer.

Buoyancy

Viscosity

Heat flow

Heat capacity

REMEMBER IT

The four properties A1.1.6 compares

B Big Buoyancy water holds a body up	V Vessels Viscosity water resists movement: more drag	T Turn Thermal conductivity water draws heat from a body fast	S Slowly Specific heat capacity water's temperature changes slowly
---	--	--	---

WATCH OUT

"Thermal conductivity and specific heat capacity are the same." Water is high in both: it drains heat from a warm body quickly, while its own temperature hardly changes.

WATCH OUT

"Fur keeps a seal warm in the water." Fur insulates by trapping air, and wet fur loses it. In water, blubber does the job.

EXAMPLE

Same bird, two names: in Britain and Ireland *Gavia arctica* is the black-throated diver. In an exam, either the common name or the scientific name is accepted.

PREDICT

Ringed seal pups are born in snow caves on the sea ice, with thick woolly fur but almost no blubber. What happens to a young pup that has to stay in the sea for a long time?

- Ⓐ It stays warm: the thick woolly fur traps heat in water just as it does in air, so it needs no blubber
- Ⓑ It chills fast: soaked fur holds no air, and water draws heat away about 23 times faster than air does
- Ⓒ It warms up: the sea under the ice is warmer than the winter air above it, so the pup gains heat from it

Decide before you look. Answer on page 32.

07

A1.1.7 HL THE ORIGIN OF EARTH'S WATER

Water from *space*, kept by gravity

Water has been abundant on Earth for billions of years, and that gave life the time it needed to arise and evolve. So where did it come from?

Earth formed about 4.5 billion years ago, and it was hot. Much of its water is thought to have come from space. **Asteroids** crashed into the young planet, and some of them had water locked inside their minerals. That is the **hypothesis** this statement asks for.

Bringing water was only half of it. Earth also kept it, for two reasons.

KEY POINTS

- **Gravity.** Earth is massive enough for its gravity to hold water vapour and the rest of the atmosphere. The Moon, with about a hundredth of Earth's mass, could not, and has almost no water: only a little ice in craters that sunlight never reaches.
- **Temperatures low enough for water to condense.** Earth is far enough from the Sun, and cooled enough, for water vapour to **condense** into liquid water. It rained out to form oceans that have lasted about four billion years.

KEY TERMS

asteroids

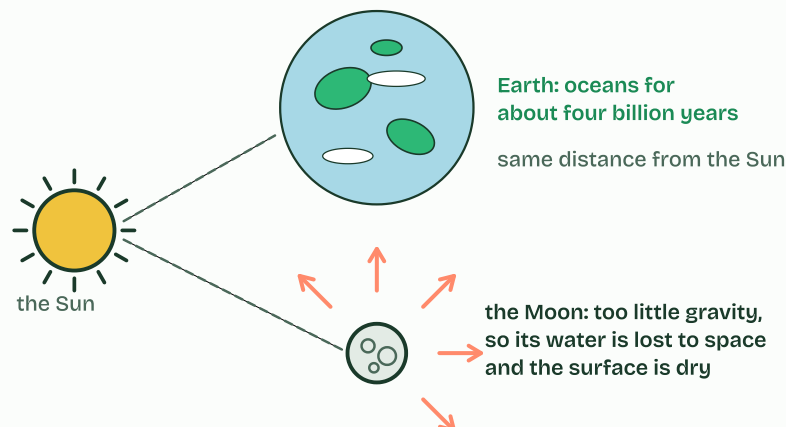
A rocky body left over from the formation of the Solar System, most of them orbiting the Sun between Mars and Jupiter.

hypothesis

An explanation that can be tested with evidence, but has not been proved.

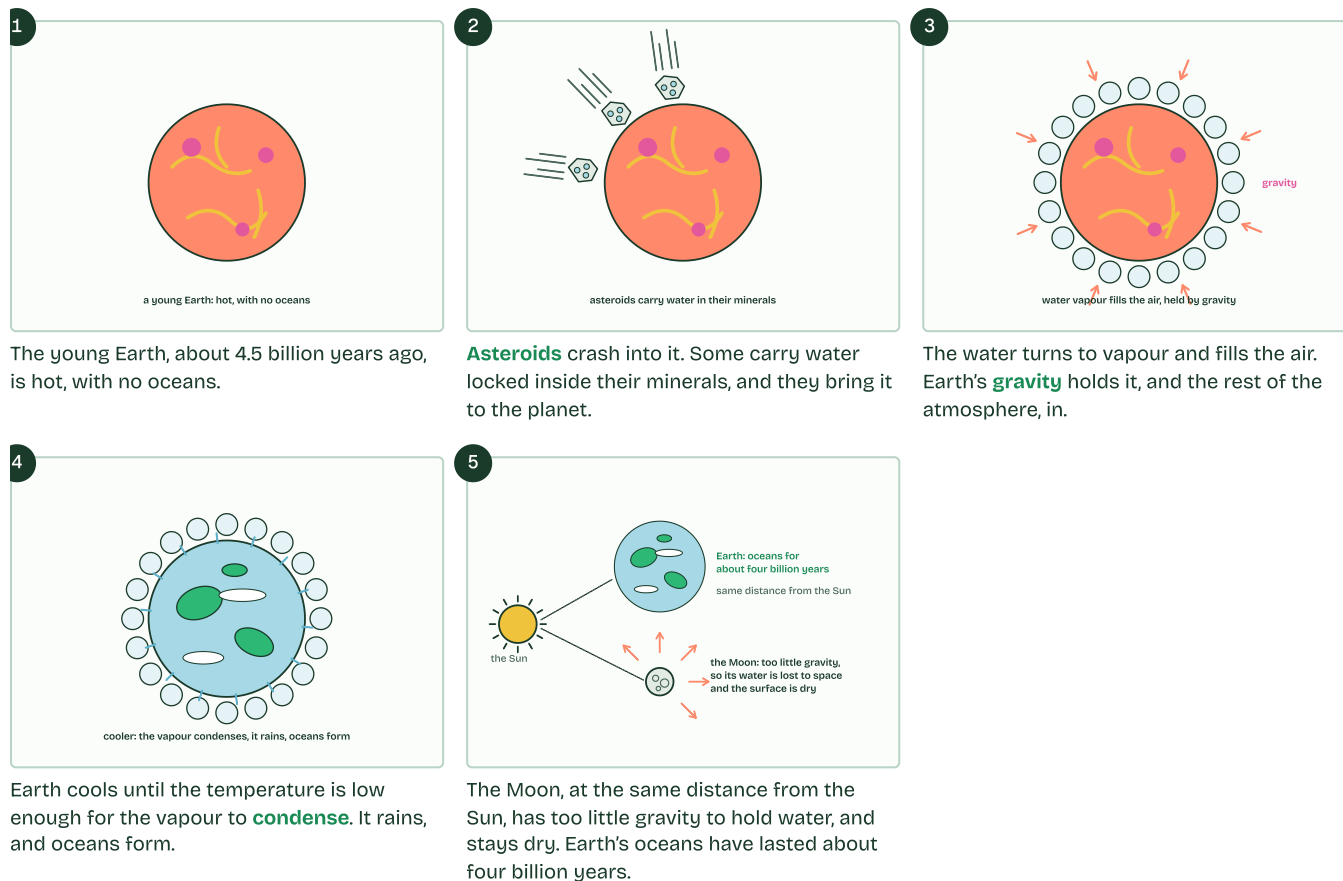
condense

Change from a gas to a liquid.



STEP BY STEP

5 STEPS



REMEMBER IT

Why Earth kept its water

G

Grip

Gravity

holds water vapour and air to the planet

C

Chill

Cool enough to condense

temperatures low enough for vapour to become liquid

WATCH OUT

"Earth kept its water because it has an atmosphere." The atmosphere is itself held by gravity. The two reasons to learn are gravity and temperatures low enough to condense water.

HOW DO WE KNOW?

No one saw it happen, so the hypothesis is tested with evidence. Hydrogen comes in a light form and a heavy form (deuterium), and the ratio of heavy to light hydrogen in water depends on where in the early Solar System the water formed. Water locked in some meteorites, which are fragments of asteroids, has almost the same ratio as Earth's oceans. That supports the asteroid hypothesis.

PREDICT

Venus is almost the same size and mass as Earth, but closer to the Sun. Why are there no oceans on Venus?

- ☐ A It is too hot for water vapour to condense into liquid, so any water stayed in the air as vapour
- ☐ B Its gravity is too weak to hold on to water vapour, so all of the vapour escaped into space long ago
- ☐ C No asteroids carrying water ever reached it, so it never had any water at all to form its oceans from

Decide before you look. Answer on page 32.

08

A1.1.8 HL THE SEARCH FOR LIFE ELSEWHERE

Not too hot, not too cold: the *Goldilocks* zone

All the life we know needs liquid water as its medium (chapters 1 and 5), so the search for **extraterrestrial** life starts by looking for liquid water.

The **Goldilocks zone**, also called the habitable zone, is the band of distances round a star where a planet's surface is warm enough for water not to freeze and cool enough for it not to boil away, so water could stay liquid. Too close and it is too hot. Too far and it is too cold. The zone depends on the star: a brighter, hotter star has its zone farther out, and a dimmer, cooler star has it closer in.

Earth lies inside the Sun's zone. Venus, closer, is far too hot. Mars, just outside the zone and much smaller than Earth, is cold, with a thin atmosphere and its water frozen. Astronomers have now found more than 5,000 planets round other stars, called **exoplanets**. The rocky ones in their star's zone are the first targets in the search for life, and space agencies share their missions and data to look for them.

The zone is a model, and every model has limits. Being in the zone does not mean a planet has water: it must have received some and kept it (chapter 7). And liquid water can exist outside the zone, under ice warmed from inside, as on Jupiter's moon Europa and Saturn's moon Enceladus. Searching only the zone could miss life, like looking for lost keys only under the street light because the light is better there.

KEY TERMS

extraterrestrial

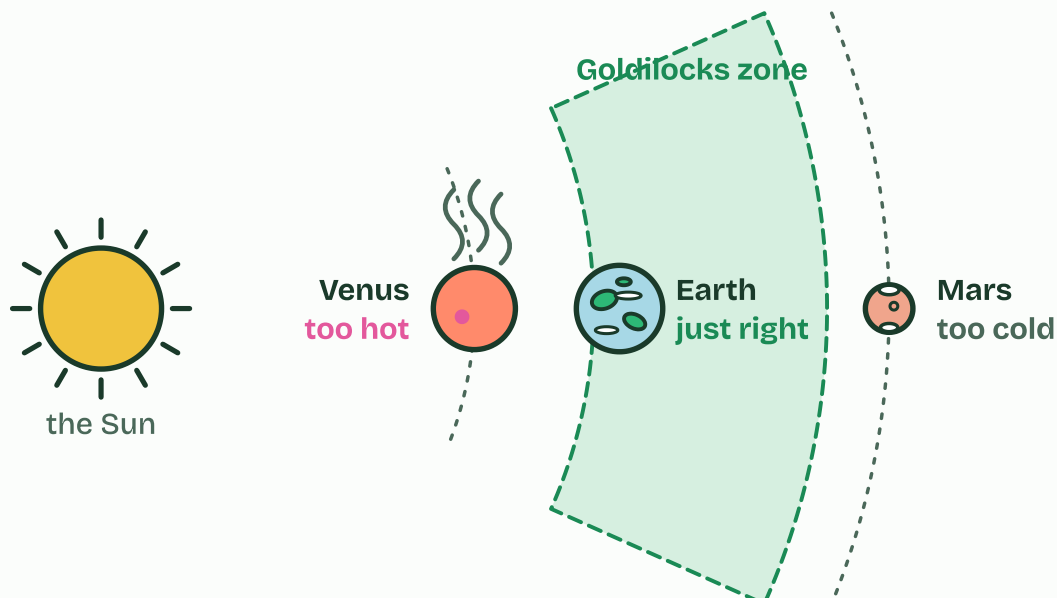
Beyond Earth.

Goldilocks zone

The band of distances from a star at which a planet's surface could be warm enough for water not to freeze and cool enough for it not to boil away. Also called the habitable zone.

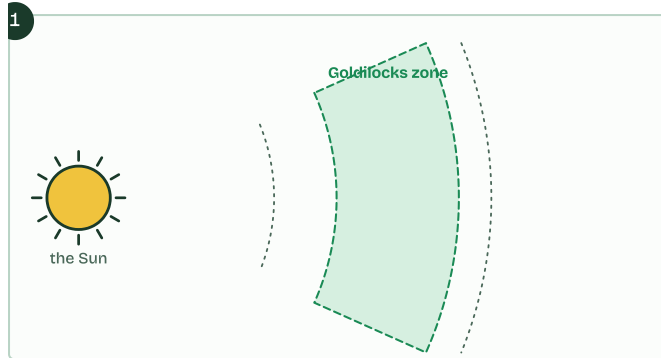
exoplanets

A planet that orbits a star other than the Sun.

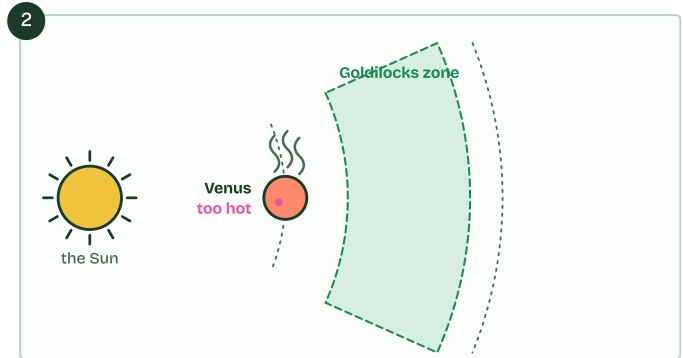


STEP BY STEP

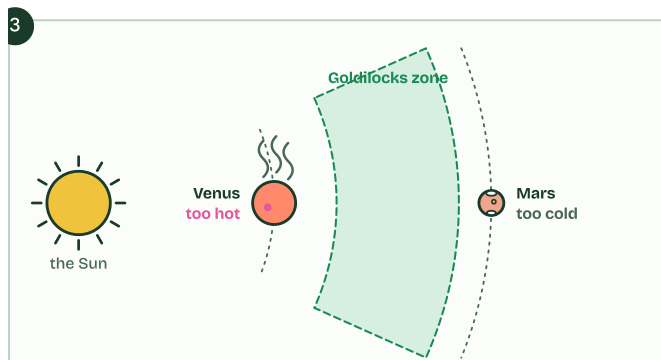
4 STEPS



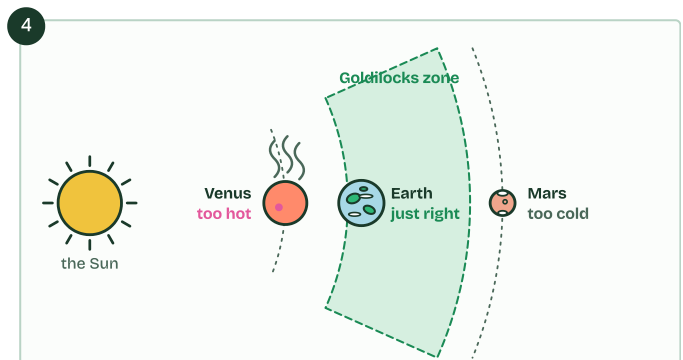
A star warms the planets round it. The pale band is its **Goldilocks zone**: the distances at which a planet's surface could keep liquid water.



Venus is closer than the zone's inner edge. It is **too hot**: water would boil away as vapour.



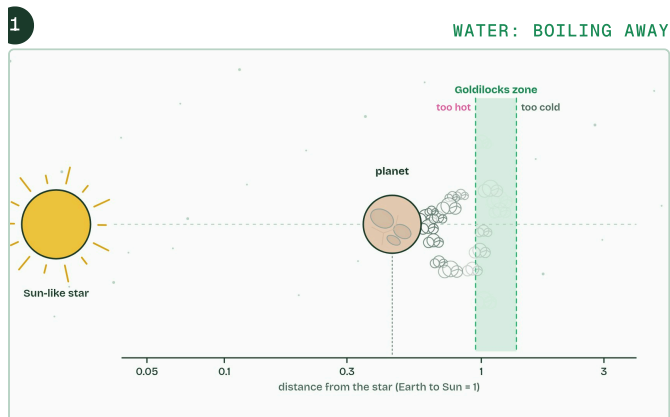
Mars is beyond the outer edge, and small. It is **too cold**: its water is frozen and its air is thin.



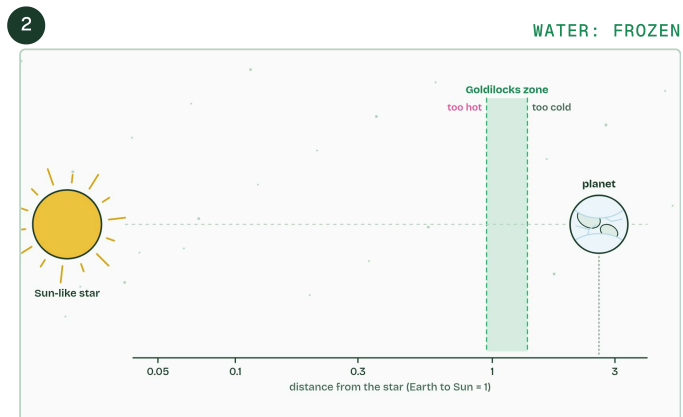
Earth is inside the zone: **just right** for liquid oceans.

ANIMATION · WATCH IT HAPPEN: FINDING THE ZONE

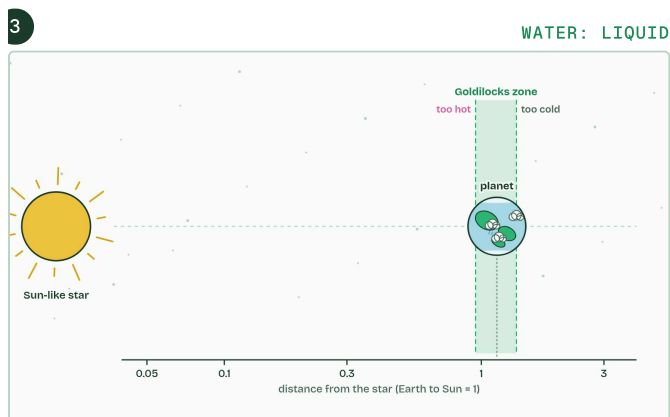
3 MOMENTS



Too close, and water boils away.



Too far, and it freezes.



In between, in the **Goldilocks zone**, water can stay liquid.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a1-1-water#goldilocks

WATCH OUT

"Every star's Goldilocks zone is at Earth's distance."
It moves with the star's brightness.

WATCH OUT

"A planet in the zone has water, so it has life." The
zone says where liquid water could exist on the
surface, and nothing more.

PREDICT

A star gives out much less energy than the Sun. Where would its Goldilocks zone be?

- ☐ A Farther out than Earth's orbit, to make up for the dim light by catching more of it as it spreads
- ☐ B At Earth's distance, because the zone is set only by the freezing and boiling points of water itself
- ☐ C Much closer to the star, so that a planet there still receives enough energy to keep water liquid

Decide before you look. Answer on page 33.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

adhesion 04

The attraction between water and a different material that is polar or charged, through hydrogen bonds or ionic attractions.

aqueous solution 01

A mixture in which substances are dissolved in water.

asteroids 07

A rocky body left over from the formation of the Solar System, most of them orbiting the Sun between Mars and Jupiter.

blood plasma 01

The pale yellow liquid part of blood. About 90% of it is water, and it carries dissolved substances round the body.

blubber 06

A thick layer of fat under the skin of a seal or whale that insulates it.

buoyancy 06

The upward push of a fluid on an object in it. In water it is almost as large as the object's weight; in air it is tiny.

capillary action 04

The movement of water along a narrow space against gravity, caused by adhesion to the walls and cohesion between the water molecules.

cellulose 04

The carbohydrate that makes plant cell walls, built from long chains of glucose and covered in OH groups.

cohesion 03

The attraction between molecules of the same substance. In water it is caused by hydrogen bonds.

condense 07

Change from a gas to a liquid.

covalent bonds 02

A bond in which two atoms share a pair of electrons.

cytoplasm 01

The fluid inside a cell, outside the nucleus, where many metabolic reactions take place.

drag 06

The force that resists movement through a fluid.

enzymes 05

A protein that speeds up a chemical reaction in a cell without being used up.

exoplanets 08

A planet that orbits a star other than the Sun.

extraterrestrial 08

Beyond Earth.

Goldilocks zone 08

The band of distances from a star at which a planet's surface could be warm enough for water not to freeze and cool enough for it not to boil away. Also called the habitable zone.

hydrogen bond 02

The weak attraction between a slightly positive hydrogen of one molecule and a slightly negative atom, here oxygen, of another.

hydrophilic 05

Attracted to water. Polar and charged substances are hydrophilic.

hydrophobic 05

Not attracted to water. Non-polar substances are hydrophobic.

hypothesis 07

An explanation that can be tested with evidence, but has not been proved.

latent heat of vaporisation 02

The energy needed to turn 1 g of a liquid into a gas without changing its temperature.

medium 01

The material in which something happens or is carried. Water is the medium for life: cells are mostly water, and most of their chemistry happens in it.

metabolism 01

All the chemical reactions that go on in a living cell.

partial charges 02

Charges smaller than a whole electron's, written δ^+ and δ^- . The molecule as a whole stays neutral.

polar covalent bond 02

A covalent bond in which the electrons are shared unequally, so one end is slightly negative and the other slightly positive.

polar molecule 02

A molecule with one side slightly negative and the other slightly positive.

solute 05

A substance that dissolves in a solvent.

solution 05

A mixture of a solute dissolved in a solvent.

solvation 05

The surrounding of dissolved ions or molecules by water molecules (or another solvent).

solvent 05

The liquid that a solute dissolves in. Water is the solvent in cells.

specific heat capacity 06

The energy needed to warm 1 g of a substance by 1 °C. Water's is unusually high.

surface tension 03

The tendency of a liquid's surface to resist being broken, because the molecules at the surface are pulled together and inwards.

tension 03

A pulling force. Water in the xylem is pulled up the plant, not pushed.

thermal conductivity 06

How fast heat flows through a material. Water conducts heat much faster than air.

transpiration 03

The loss of water vapour from a plant, mostly through pores in its leaves.

viscosity 06

How much a fluid resists flowing past or round an object.

xylem 03

The tubes that carry water and dissolved minerals up a plant.

Dry lab: *Wet wicks: cooling by evaporation*

Wrap thermometers in wicks soaked in different liquids, switch a fan on or off, change the humidity, and find out what makes a wet surface cool, and for how long.

Set up the bench

Air round the probes

Still Fan on

Humidity of the room

20% 50% 80%

Room temperature

18 °C 22 °C 26 °C

Liquid on each wick

0.05 mL 0.1 mL 0.2 mL

One, two or four drops from the dropper.

Probes to use

☒ A no liquid

☒ B cooking oil

☒ C water

☒ D ethanol

The same every run: cotton wicks of one size, the same four probes, the fan blowing on every probe alike, and the liquids kept in closed bottles in the room.

0:00

22.0 22.0 22.0 22.0

A B C D

no liquid cooking oil water ethanol

► Run

Speed Normal Faster

Write your hypothesis for each wick first (the tasks are under the lab). Then press **Run**: the drops go on at 0:00, and each probe is read every 30 seconds for 10 minutes.

Temperature on each probe

temperature / °C

24

22

20

18

16

14

12

Each probe's readings draw here as the run goes.



Run it online: change the variables, run the trials, and the table and graph fill in as you go.

biologybybradford.com/guides/ib-biology-a1-1-water#lab

Your question

What makes a wet surface cool down? Do different liquids cool it by different amounts, at different speeds, or for different lengths of time?

What you can change

The liquid on each of four wicks (none, cooking oil, water, ethanol), the air (still, or a fan), the room's humidity, the volume of liquid put on each wick and the room temperature.

What to record

Each probe's temperature every 30 seconds for 10 minutes. From each run: the starting temperature, the lowest, the largest fall and when it came. Repeat each set-up at least three times: the runs scatter, as real readings do.

Find out

- **Is it the cold, or the evaporation?** Before you run, write a hypothesis for what each wick will do, and why. Then run all four wicks in still air at 50% humidity, three times. Which wicks cool at all?
- **Water against ethanol.** From the same runs: which cools faster? Which cools further? Which keeps cooling longer? Look at the whole ten minutes, not just the start.
- **The wet hand again.** Switch the fan on and run three times. What changes for each liquid?
- **A muggy day.** Fan off. Run at 20% and at 80% humidity, three times each. Whose cooling depends on the humidity?

Record

- For every run: the settings, and each probe's start, lowest, largest fall and when the lowest came.
- Change one setting at a time and keep the rest the same.
- Repeat each set-up at least three times. Work out the mean, SD and SE of the largest fall for one liquid by hand, then check them against **Graph your results**.
- Draw a graph with error bars, from the lab or from the CSV, and say which error bars you used.

QUESTIONS ON THE LAB

QUESTION 1

Ethanol cooled the probe faster and further than water, then warmed up again, while water's cooling lasted the whole run. Yet each gram of water that evaporates takes about 2.4 kJ of heat with it, and each gram of ethanol only about 0.9 kJ. How can both be true?

- (A) Ethanol comes out of its bottle colder than water does, so its wick starts off cooler and stays ahead of the water for the whole run
- (B) Ethanol molecules escape far more easily, so more grams leave each second; water leaves slowly, but each gram takes more heat
- (C) Hydrogen bonds forming between water molecules on the wick release heat, which keeps on warming the water probe all through the run

Answer on page 33.

QUESTION 2

Water's cooling shrank at 80% humidity, but ethanol's hardly changed. Why?

- (A) Humid air is warmer than dry air, so neither liquid on its wick can cool the probe nearly as far as it did before
- (B) The wick soaks up water from the humid air and gets heavier, so much less of the water held on it is able to evaporate
- (C) Humid air holds water vapour already, so fewer water molecules leave than come back; it holds no ethanol vapour

Answer on page 33.

QUESTION 3

Blowing on a wet hand makes it feel colder. Why does moving air speed up the cooling?

- (A) Moving air carries the vapour away from the wet surface, so more molecules leave it than return to it
- (B) Moving air is colder than still air, so it draws heat out of the wet surface faster than still air can
- (C) Moving air pushes heat into the water, so its molecules gain energy and evaporate from the skin faster

Answer on page 33.



Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A1.1 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

[biologybybradford.com/exam-maker/sit?
topics=A1.1&level=HL&paper=quiz&marks=15&src=ep](https://biologybybradford.com/exam-maker/sit?topics=A1.1&level=HL&paper=quiz&marks=15&src=ep)

Answers

PREDICTIONS IN THE CHAPTERS

01 A packet of dry bean seeds sits in a cupboard for three years. What is happening to the metabolism inside each seed?

B It has almost stopped: with so little water, enzymes and substrates cannot meet to react

Almost stopped. A dry seed holds only about a tenth of its mass as water, too little for most reactions. Soak it, and within hours water floods in, its enzymes start working and the seed begins to germinate. Metabolism needs water as its medium, which is what this statement means.

02 Water boils in a kettle. Which bonds break as it turns to steam?

C The hydrogen bonds between molecules, so the steam is still made of water molecules

Only the hydrogen bonds. Boiling and evaporation separate whole molecules from one another, and the covalent bonds, about twenty times stronger, stay as they are. Breaking all those hydrogen bonds is why water needs so much heat to boil or evaporate, and why sweat cools you. The dry lab puts a number on it.

03 Ground pepper floats on a bowl of water. You touch the middle of the surface with a finger dipped in washing-up liquid. What does the pepper do?

A It shoots out to the edge of the bowl, dragged by the clean surface that is still pulling all round

It shoots outwards. Soap molecules crowd into the surface where you touch it and weaken the hydrogen bonding there, so the surface tension falls in the middle. The clean surface all round still pulls strongly and drags the water, and the pepper on it, to the edges. Detergent in a pond does the same to a pond skater: with less surface tension to stand on, it sinks.

04 Three cups in a row: red water, an empty cup, blue water. A strip of paper towel bridges each full cup and the empty one. What is in the middle cup a few hours later?

C Purple water, rising until the levels even out, because water creeps along paper from both sides

Purple water. Paper towel is cellulose. Water adheres to its fibres and creeps up and along the strip by capillary action, cohesion pulling the rest behind, and drips into the empty cup until the levels even out. Both colours arrive and mix. The same process keeps the walls of a leaf's cells wet and moves water through soil.

05 Fish get all their oxygen from water. Oxygen molecules (O_2) are non-polar. How does the oxygen get into the water?

C Small non-polar molecules dissolve a little, and a little is enough to reach the gills

A little dissolves. A litre of water at 20 °C holds only about 9 mg of oxygen, about a thirtieth of the oxygen in a litre of air. Small non-polar molecules such as oxygen slip in between water molecules in small amounts. It is enough for fish, which pass a great deal of water over large gills. Warm water holds even less, which is why fish gasp at the surface in a heatwave.

06 Ringed seal pups are born in snow caves on the sea ice, with thick woolly fur but almost no blubber. What happens to a young pup that has to stay in the sea for a long time?

B It chills fast: soaked fur holds no air, and water draws heat away about 23 times faster than air does

It chills fast. The woolly fur keeps a pup warm in the snow cave because it traps air, a poor conductor of heat. Soaked, it holds water instead, and the pup has almost no blubber yet. The sea, at about -1.8 °C, is indeed warmer than the winter air, but water draws heat away so much faster that the pup loses heat far more quickly in it. That is why the snow caves matter.

07 Venus is almost the same size and mass as Earth, but closer to the Sun. Why are there no oceans on Venus?

A It is too hot for water vapour to condense into liquid, so any water stayed in the air as vapour

Too hot. Venus's gravity is nearly as strong as Earth's, so gravity is not the problem. Its surface is about 460 °C today, so its water stayed as vapour and has since been lost. A planet needs both: enough gravity, and temperatures low enough for water to condense.

Q8 A star gives out much less energy than the Sun. Where would its Goldilocks zone be?

C **Much closer to the star, so that a planet there still receives enough energy to keep water liquid**

Much closer. A planet must be near a dim star to receive enough energy to keep water liquid. Round red dwarfs, the commonest stars in our galaxy, the zone is so close that a planet's year there lasts only days or weeks.

QUESTIONS ON THE DRY LAB

Q1 Ethanol cooled the probe faster and further than water, then warmed up again, while water's cooling lasted the whole run. Yet each gram of water that evaporates takes about 2.4 kJ of heat with it, and each gram of ethanol only about 0.9 kJ. How can both be true?

B **Ethanol molecules escape far more easily, so more grams leave each second; water leaves slowly, but each gram takes more heat**

Ethanol escapes more easily. Each ethanol molecule forms fewer hydrogen bonds, and part of it is a non-polar chain, so far more molecules leave each second: a fast, deep fall, until the wick runs dry and warms up again. Water's molecules are held by up to four hydrogen bonds each, so they leave slowly, but every gram that goes takes about two and a half times as much heat. The same few drops of water keep cooling for over an hour. The oil wick shows the liquids were not cold to begin with.

Q2 Water's cooling shrank at 80% humidity, but ethanol's hardly changed. Why?

C **Humid air holds water vapour already, so fewer water molecules leave than come back; it holds no ethanol vapour**

Evaporation depends on how much of that liquid's vapour is already in the air. Humid air is full of water vapour, so many water molecules return to the wick, and the net loss, and the cooling, is small. The room holds no ethanol vapour, so ethanol evaporates almost as fast as ever. It is why sweat cools you poorly on a muggy day.

Q3 Blowing on a wet hand makes it feel colder. Why does moving air speed up the cooling?

A **Moving air carries the vapour away from the wet surface, so more molecules leave it than return to it**

The probe with no liquid, in the fan's wind, stays at room temperature, so the air itself is no colder. Next to a wet surface the air fills with vapour, and some of it goes back into the liquid. Moving air sweeps it away, so evaporation, and cooling, go faster. That is the wet hand you blew on at the start.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.