REVISION GUIDE

Water, carbon and the *elements* of life

Water and the elements of life

A water strider stands on a pond, a redwood pulls water 100 meters into the air, and ice floats while fish swim beneath it. One small, lopsided molecule explains all three. Then: why life is built on carbon, and where its atoms come from.

7 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-1-water-and-elements

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By the end you can

- [ ] Explain how unequal sharing of electrons makes water polar, and draw hydrogen bonds between water molecules with partial charges `1.1.A`
- [ ] Explain how cohesion gives water its surface tension and lets transpiration pull a column of water up the xylem `1.1.A`
- [ ] Explain how adhesion to polar surfaces, with cohesion, moves water by capillary action `1.1.A`
- [ ] Explain why ions and polar molecules dissolve in water while nonpolar ones do not, and why that matters to a cell `1.1.A`
- [ ] Explain water's high specific heat, evaporative cooling and floating ice in terms of hydrogen bonds `1.1.A`
- [ ] Describe why carbon forms the skeleton of biological molecules, and name four functional groups `1.2.A`
- [ ] Describe which elements each class of macromolecule contains, and how organisms take carbon, nitrogen and phosphorus from their environment `1.2.A`

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

1.1.A POLARITY AND HYDROGEN BONDS

01 One lopsided molecule, and the *bonds* it makes

Almost everything a cell does happens in water, and water behaves the way it does because of the shape of one small molecule. A water molecule is an oxygen atom joined to two hydrogen atoms by **covalent bonds**. It is bent, not straight.

The two atoms in each bond do not share their electrons equally. Oxygen is more **electronegative** than hydrogen: it pulls the shared electrons toward itself. So each O–H bond is a **polar covalent bond**, and the molecule ends up with a slightly negative oxygen end and two slightly positive hydrogen ends. A molecule with charged ends like this is **polar**. The charges are partial, written δ+ and δ−: the molecule as a whole is neutral.

Opposite charges attract. The δ+ hydrogen of one water molecule is drawn to the δ− oxygen of a neighbor, and that attraction is a **hydrogen bond**. One is weak and lasts a tiny fraction of a second, but each molecule can make up to four, and in a glass of water there are trillions upon trillions, forming and breaking all the time.

Every property of water in this guide comes from these bonds: water sticking to itself and to other surfaces, dissolving so much, and soaking up heat.

KEY POINTS

- Covalent bonds hold the atoms of one molecule together; hydrogen bonds hold neighboring molecules to each other.
- Draw covalent bonds as solid lines and hydrogen bonds as dashed lines, with δ+ and δ− on the atoms.

KEY TERMS

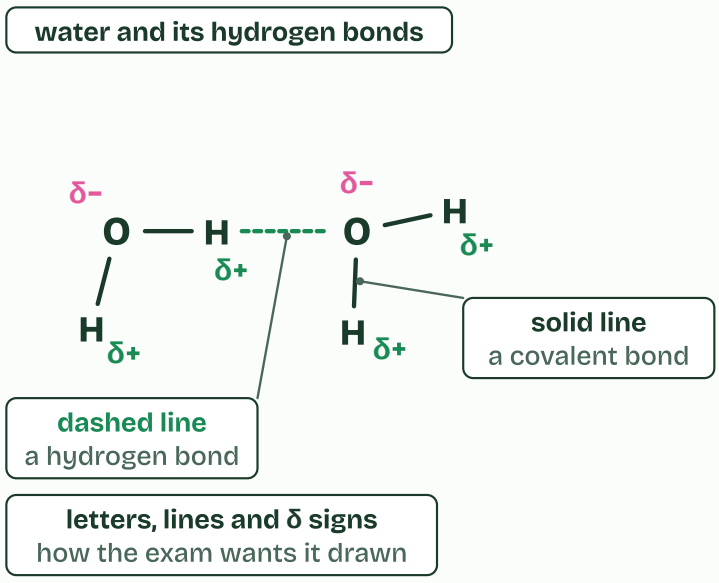
covalent bonds
A bond in which two atoms share a pair of electrons.

electronegative
How strongly an atom pulls the electrons it shares in a bond toward itself. Oxygen pulls harder than hydrogen.

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

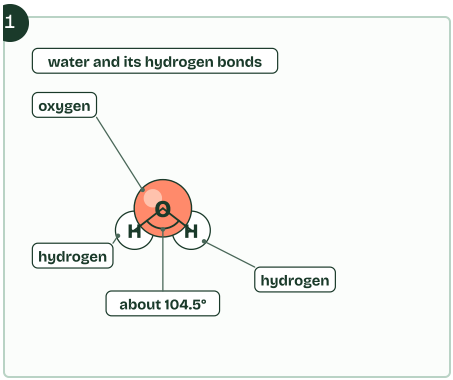
polar
Having a slightly positive end and a slightly negative end because electrons are shared unequally.

hydrogen bond
A weak attraction between a slightly positive hydrogen atom of one molecule and a slightly negative atom, such as oxygen or nitrogen, of another molecule or another part of the same large molecule.



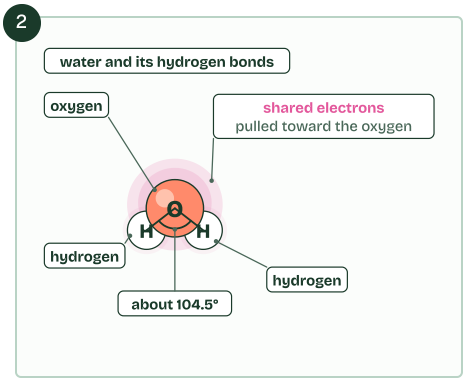
STEP BY STEP 6 STEPS

1



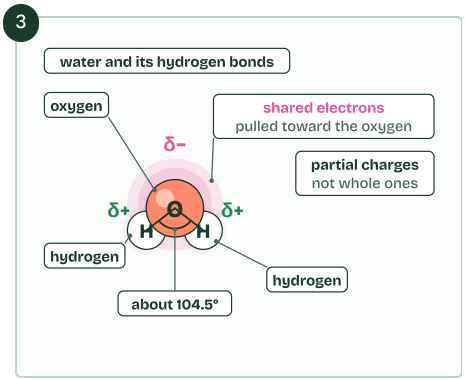
One water molecule: an oxygen with two hydrogens, **bent**, with about 104.5° between the bonds.

2



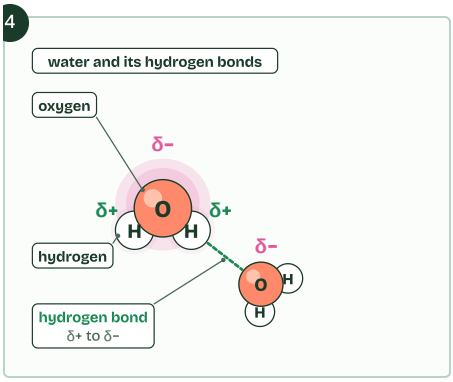
The shared **electrons** (the pink cloud) crowd round the oxygen and thin out round each hydrogen.

3



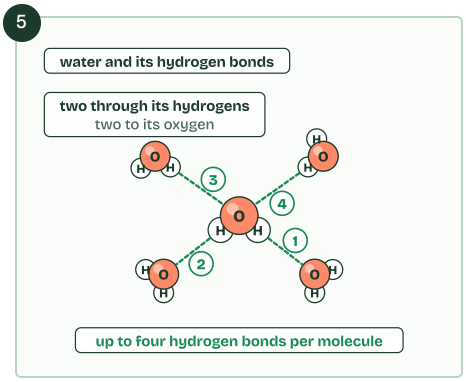
So the oxygen is slightly negative and each hydrogen slightly positive: **partial** charges, not whole ones.

4



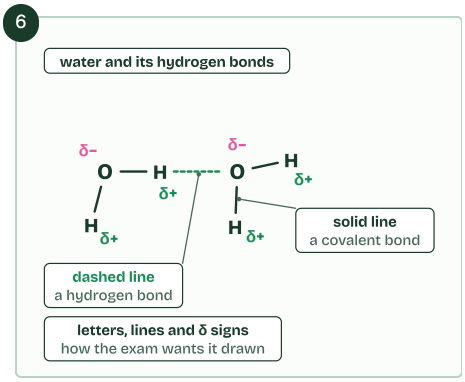
A second molecule turns its oxygen to face a hydrogen of the first, and a dashed line joins them: a **hydrogen bond**.

5

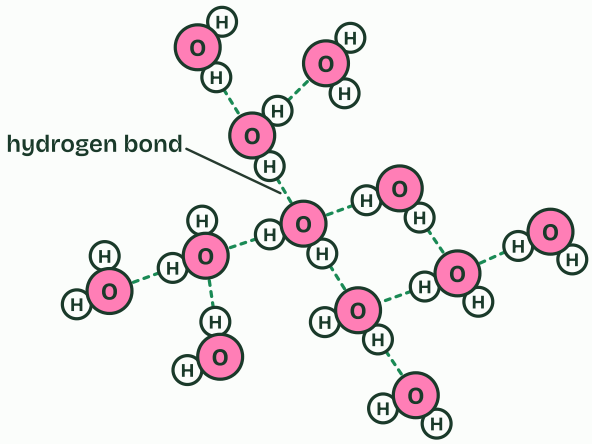


One molecule can make up to **four**: two through its hydrogens and two to its oxygen.

6



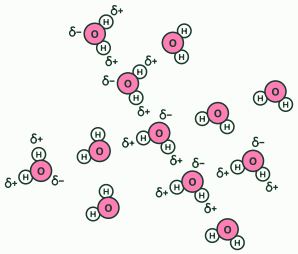
The notation the exam wants: letters, solid lines for covalent bonds, dashed lines for hydrogen bonds, and δ signs. **Draw it like this**.



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.

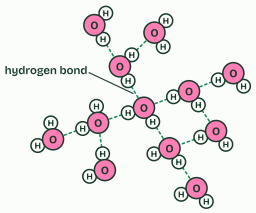
STEP BY STEP 3 STEPS

1



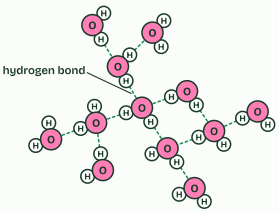
Each water molecule is **polar**: the oxygen is slightly negative and the hydrogens slightly positive.

2



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

3



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 Always	S Skip	H Hot	S Showers
Cohesion water sticks to water (chapter 2)	**Adhesion** water sticks to polar and charged surfaces (chapter 3)	**Solvent** dissolves polar and charged substances (chapter 4)	**Heat** slow to warm, cools by evaporating, floats when frozen (chapter 5)	**Surface tension** a surface that holds together (chapter 2)

WATCH OUT

"The hydrogen bond is the bond between O and H inside the molecule." That is a covalent bond. A hydrogen bond is between molecules, and it is about twenty times weaker.

PREDICT

Water boils at 100 °C. Methane, CH_4, a molecule of about the same size, is nonpolar and boils at about −160 °C. What explains the difference?

(A) Water's covalent bonds are stronger than methane's, so water molecules have to be split apart before it can boil

(B) Water molecules are held to one another by hydrogen bonds, which must be broken before they can leave as a gas

(C) Methane molecules are heavier than water molecules, so they move more slowly and need far less heat to boil

Decide before you look. Answer on page 32.

02 Water *holds on* to itself

1.1.A COHESION AND SURFACE TENSION

Because of hydrogen bonds, water molecules stick to each other. That is **cohesion**.

Cohesion is easiest to see at a surface. A molecule in the middle of a drop is pulled equally in every direction. A molecule at the surface has neighbors beside and below it but none above, so it is pulled sideways and inward. The surface holds together like a stretched film. That is **surface tension**, and water's is one of the highest of any liquid. It is why a water strider can walk across a pond and why water beads up in drops.

Cohesion also moves water up a plant. Water evaporates from leaves through tiny pores, a loss called **transpiration**. Each molecule that leaves pulls on the one behind it, because they are hydrogen bonded. The pull passes all the way down the thin tubes of **xylem** to the roots, so a whole column of water is drawn up, like a rope pulled from the top. No pump is needed: the sun's energy evaporates the water, and cohesion does the lifting.

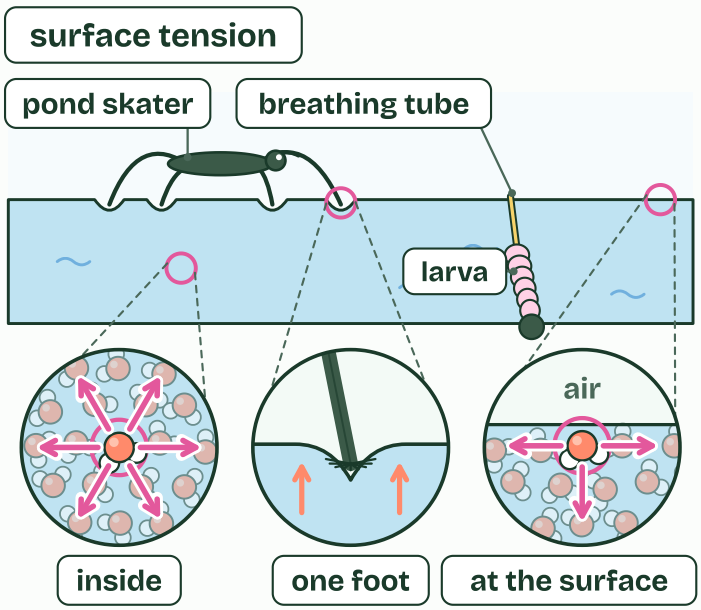
KEY TERMS

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

surface tension
The way a liquid's surface resists being broken, because the molecules at the surface are pulled together and inward.

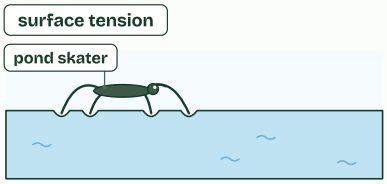
transpiration
The loss of water vapor from a plant, mostly through pores in its leaves.

xylem
The tissue of tubes that carries water and dissolved minerals up from the roots of a plant.



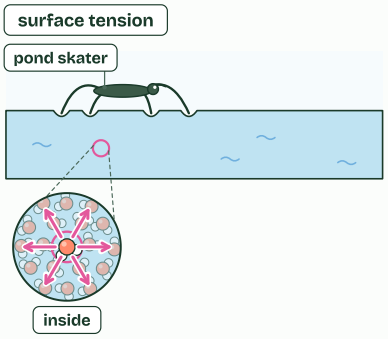
STEP BY STEP
5 STEPS

1



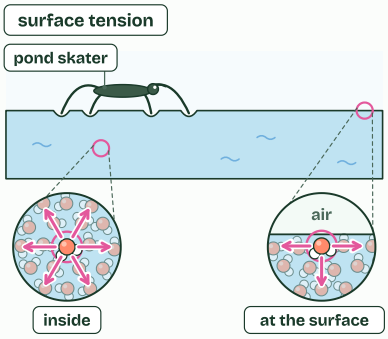
A pond skater stands on water. Its long legs spread its weight, and each foot makes a small **dimple** in the surface.

2



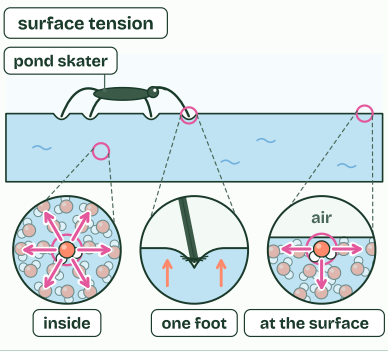
Inside the water, each molecule is pulled by its neighbors equally in **every direction**, so it stays where it is.

3



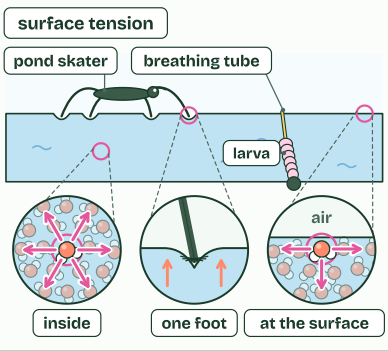
At the surface there are no neighbors above: the pull is **sideways and inwards**, and the surface holds together like a stretched film. That is **surface tension**.

4



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

5

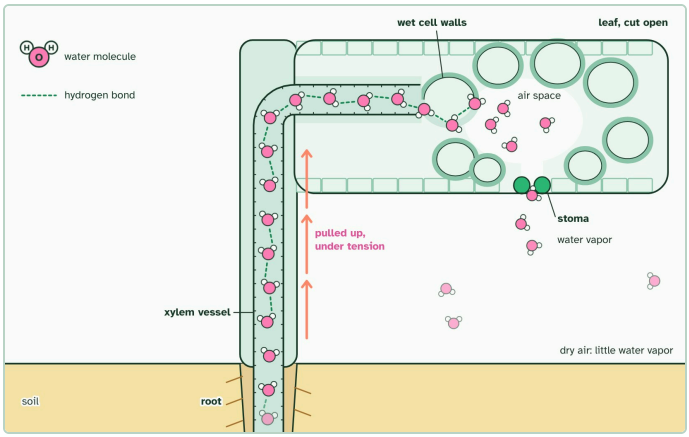


A mosquito **larva** hangs from the underside of the film and breathes through a tube that pokes through it.

ANIMATION · WATCH IT HAPPEN: PULLING WATER UP A STEM

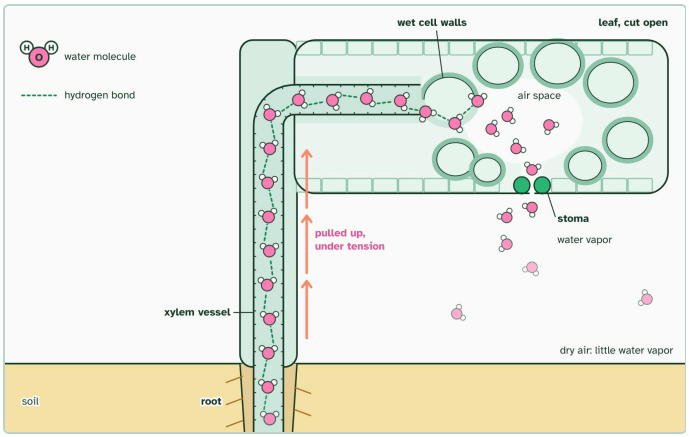
3 MOMENTS

1 FLOW: FAST



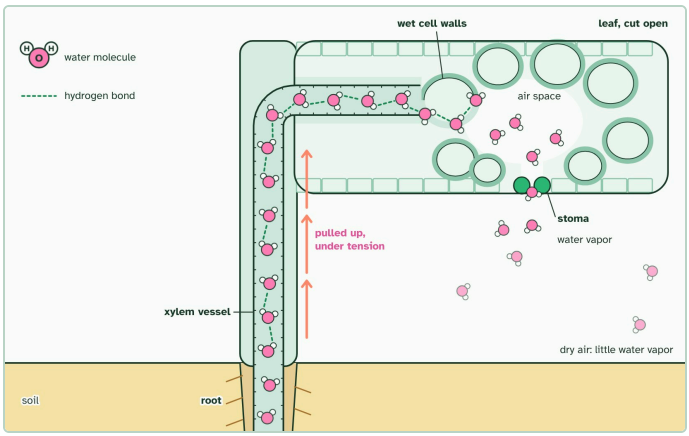
Water **evaporates** from the wet cell walls in the leaf and escapes through a stoma.

2 FLOW: FAST



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/ap-biology-unit-1-water-and-elements#cohesion

WATCH OUT

"Water is pushed up the tree from the roots." Most of it is pulled from the top. Break the column with an air bubble and the water below the break stops, because cohesion cannot pull across a gap.

EXAMPLE

The tallest trees, coast redwoods, are over 110 m tall. Every drop of water in their leaves was pulled up that far through the xylem.

PREDICT

Ground pepper floats on a bowl of water. You touch the middle of the surface with a finger dipped in dish soap. What does the pepper do?

(A) It shoots out to the edge of the bowl, pulled by the surface that is still clean all around

(B) It sinks straight to the bottom, because the soap makes the water under the pepper heavier

(C) Nothing happens: soap mixes into the water and leaves the surface pulling just as it did before

Decide before you look. Answer on page 32.

03

1.1.A ADHESION AND CAPILLARY ACTION

Water *clings* to other surfaces

Water does not only stick to itself. It is attracted to any surface that is polar or charged, and that attraction is **adhesion**. Glass is polar, so water creeps up the side of a glass tube and its surface curves up at the edge. So is **cellulose**, the stuff of plant cell walls and paper, and so are the charged particles of soil.

In a narrow tube, adhesion and cohesion work together. Water adheres to the walls and climbs them, and cohesion drags the water behind it along. That is **capillary action**, and the narrower the tube, the higher the water goes. It soaks water into a paper towel, through soil toward roots, and through the tiny gaps in plant cell walls. In xylem it helps water cling to the walls of the tubes, so the column hangs on rather than falling back.

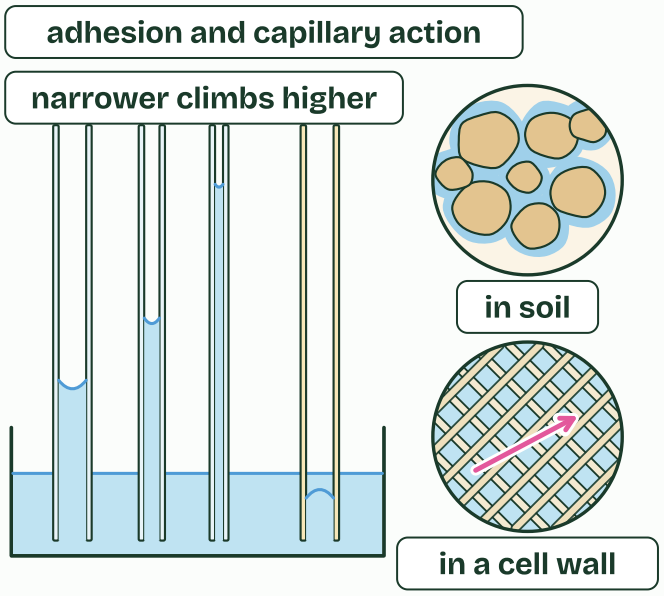
A surface that is nonpolar, such as wax, gives water nothing to cling to. Water beads up on it and runs off, which is why many leaves have a waxy coat.

KEY TERMS

adhesion
The attraction between water and a different substance that is polar or charged.

cellulose
The carbohydrate that makes plant cell walls: long chains of glucose covered in OH groups.

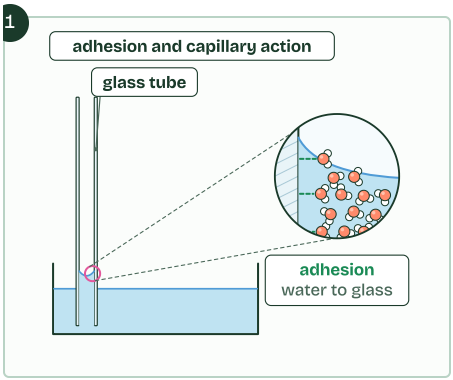
capillary action
The movement of water up or along a narrow space against gravity, caused by adhesion to the walls and cohesion between water molecules.



STEP BY STEP

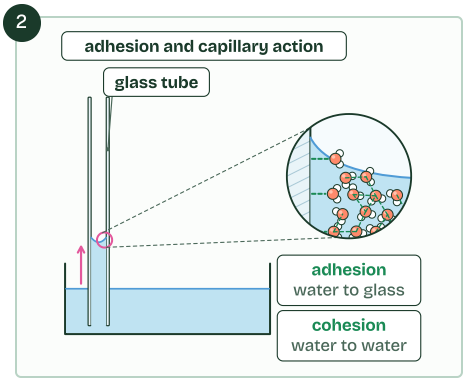
5 STEPS

1



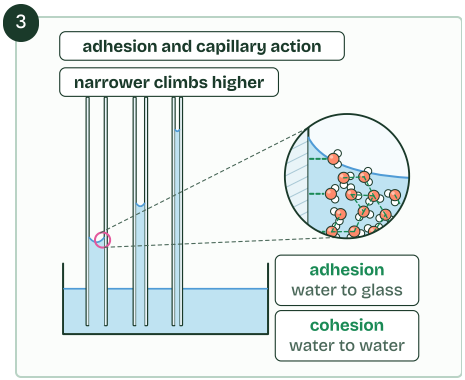
Water is attracted to the polar glass wall and forms bonds with it: **adhesion**. The water's edge curves up where it meets the glass.

2



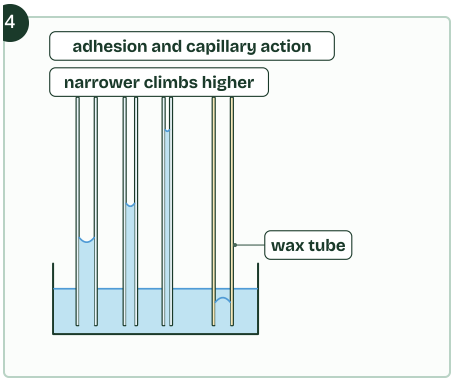
Cohesion drags more water up behind the edge, and the column rises until its weight balances the pull.

3



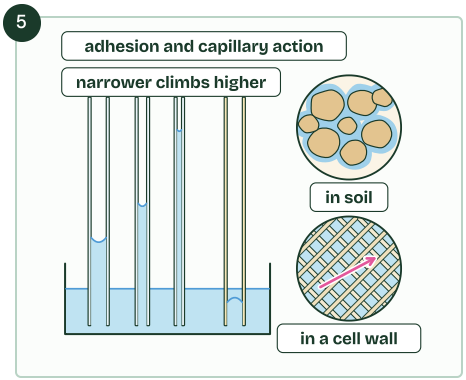
The **narrower** the tube, the higher the water climbs.

4



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

5



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 Copies	A Anything
Cohesion water clings to copies of itself: other water molecules	**Adhesion** water clings to anything polar or charged: glass, cellulose, soil

WATCH OUT

"Capillary action lifts water to the top of a tree." In tubes as wide as xylem, capillary action alone lifts water only a short way. The big lift is the pull of transpiration passed down the column by cohesion (chapter 2); adhesion keeps the column attached to the walls.

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?

(A) Nothing: water cannot climb up and out of a cup by itself, whatever the strip is made of

(B) Only red water, because the red cup was filled first and its water reached the middle first

(C) Purple water, because water creeps along the paper from both sides and the colors mix

Decide before you look. Answer on page 32.

04

1.1.A WATER AS A SOLVENT

The *solvent* a cell runs in

A **solution** is a **solute** dissolved in a **solvent**, and water dissolves more substances than almost any other liquid. Its partial charges are why.

Drop salt in water and the water molecules crowd round each ion: their δ− oxygens turn toward the positive sodium ions and their δ+ hydrogens toward the negative chloride ions. Together they pull the ions out of the crystal, and each ion moves off wrapped in a shell of water. Polar molecules such as sugars and amino acids dissolve another way: they form hydrogen bonds with water.

Substances that dissolve in water, ions and polar molecules, are **hydrophilic**, "water loving." Nonpolar substances such as fats, oils and waxes are **hydrophobic**. Water molecules bond to each other instead and squeeze the nonpolar molecules together, so oil gathers into droplets.

For a cell this is everything. The **cytoplasm** is a water solution in which enzymes and the molecules they work on move about and meet. Blood carries glucose, ions and amino acids dissolved in its water; xylem carries mineral ions. And the hydrophobic things matter just as much: the nonpolar middle of a cell membrane keeps a cell's dissolved contents in (Unit 2).

KEY TERMS

solution
A mixture in which one substance, the solute, is dissolved evenly in another, the solvent.

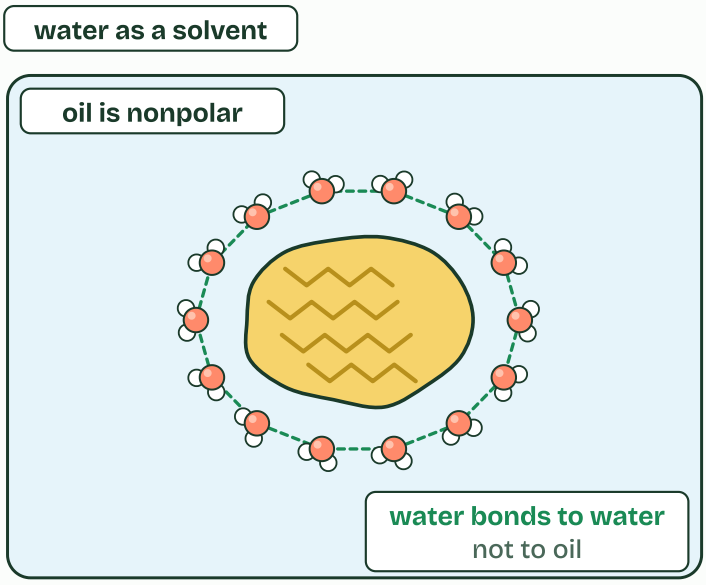
solute
A substance that dissolves.

solvent
The liquid a solute dissolves in. In living things it is almost always water.

hydrophilic
Attracted to water. Ions and polar molecules are hydrophilic.

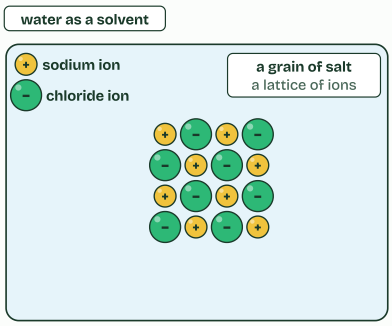
hydrophobic
Not attracted to water. Nonpolar molecules are hydrophobic.

cytoplasm
The jelly-like fluid that fills a cell, mostly water with many substances dissolved in it.



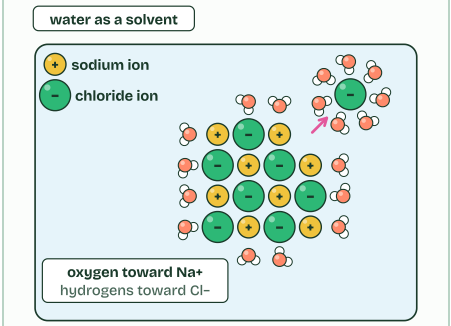
STEP BY STEP
5 STEPS

1



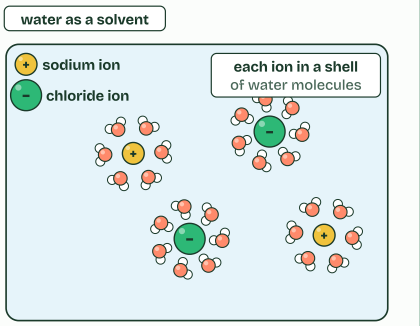
A grain of salt is a lattice of **ions**, sodium (Na^+) and chloride (Cl^-), held together by their opposite charges.

2



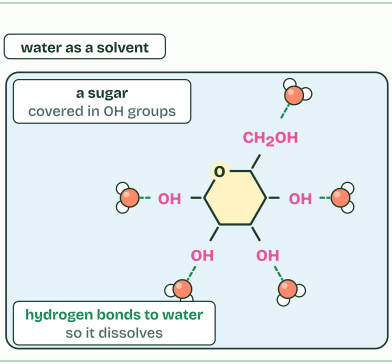
Water molecules turn to face the ions, **oxygen** toward Na^+ and **hydrogens** toward Cl^-, and together they pull ions loose.

3



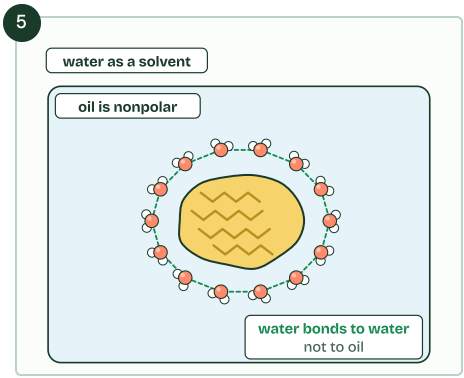
Dissolved: every ion is wrapped in its own **shell** of water molecules and drifts away from the rest.

4

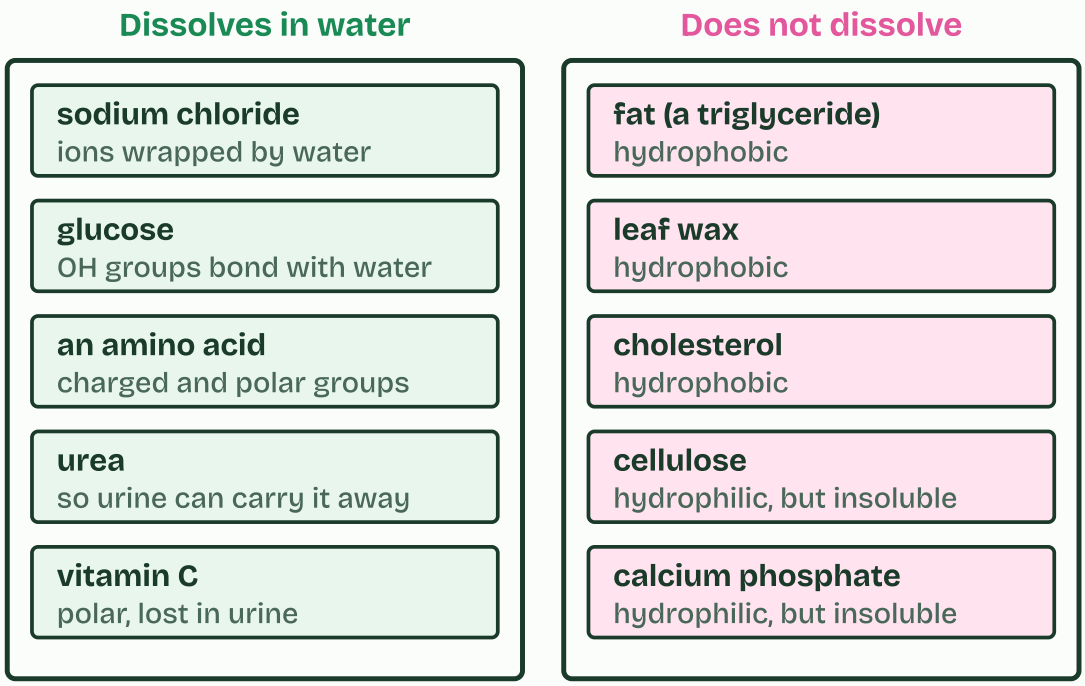


A sugar is covered in OH groups, which make **hydrogen bonds** with water, so it dissolves too.

5



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



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 dissolves everything." It is often called the universal solvent, but fats, oils, waxes and cellulose do not dissolve in it, and life depends on that.

PREDICT

Fish take all their oxygen from water, and oxygen molecules (O_2) are nonpolar. How does the oxygen get into the water?

(A) It forms hydrogen bonds with the water molecules around it, in the same way that glucose does

(B) Small nonpolar molecules dissolve a little, and a little is enough for fish with large gills

(C) It does not dissolve at all: fish split water molecules at their gills and take the oxygen out

Decide before you look. Answer on page 32.

1.1.A WATER AND HEAT

05 Slow to warm, cooled by *evaporating*, lighter as ice

Hydrogen bonds also give water three properties that shape the climate a living thing lives in.

It is slow to heat up. The **specific heat** of a substance is the energy it takes to warm a gram of it by 1 °C. Water's is unusually high, because much of the energy you put in goes into breaking hydrogen bonds before the molecules can move any faster. It also gives that energy back slowly as it cools. So a lake, a sea, or a body that is mostly water changes temperature slowly, and the cells inside it are protected from sudden swings.

It cools what it evaporates from. To leave a liquid as vapor, a molecule must break all its hydrogen bonds, and only the fastest, most energetic ones can. As they go, they take their energy with them, so what is left behind is cooler. Water's **heat of vaporization** is high, so a little evaporating water carries off a lot of heat. That is **evaporative cooling**: how sweat cools you and how transpiration cools a leaf.

Its solid floats. Most substances are denser as solids. When water freezes, each molecule locks into four hydrogen bonds that hold the molecules in an open lattice, farther apart than in the liquid. So ice is less dense than water and floats. A pond freezes from the top down, and the ice insulates the water beneath, where fish and plants survive the winter.

KEY POINTS

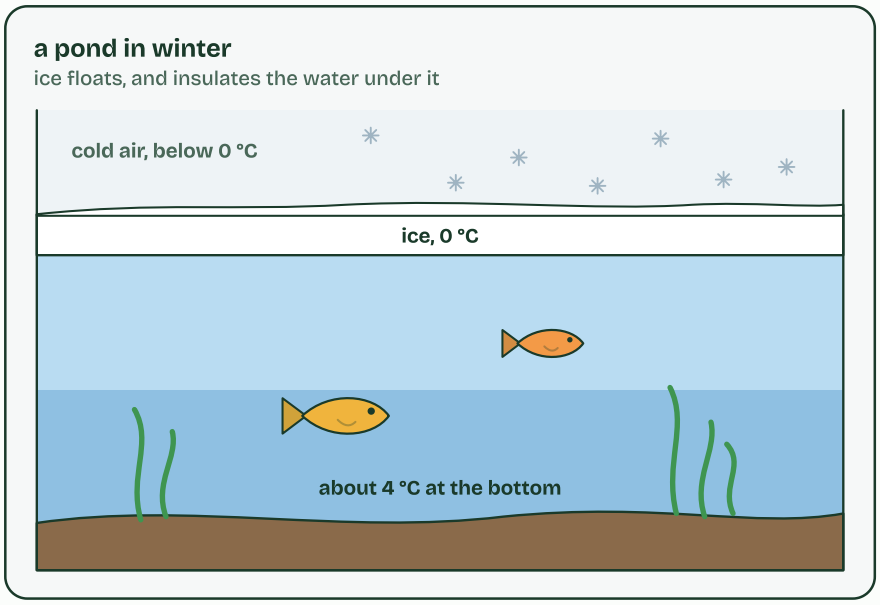
- All three trace back to one cause: energy is needed to break hydrogen bonds, and hydrogen bonds hold ice open.

KEY TERMS

specific heat
The energy needed to raise the temperature of 1 gram of a substance by 1 °C. Water's is 4.18 joules per gram per degree, one of the highest of any substance.

heat of vaporization
The energy needed to turn a gram of a liquid into vapor. Water's is high, about 2.4 kJ per gram at body temperature, because every hydrogen bond must break.

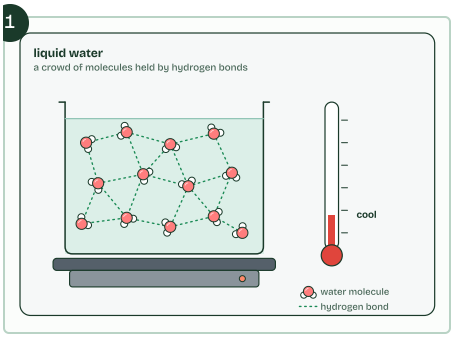
evaporative cooling
The cooling of a surface as the most energetic molecules of a liquid on it escape as vapor.



STEP BY STEP

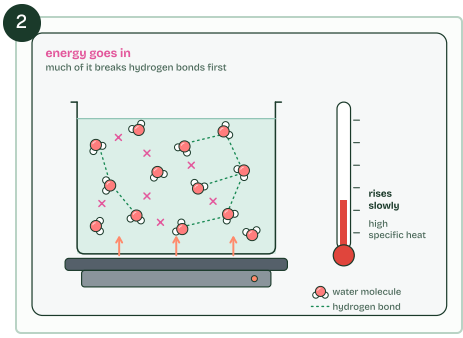
5 STEPS

1



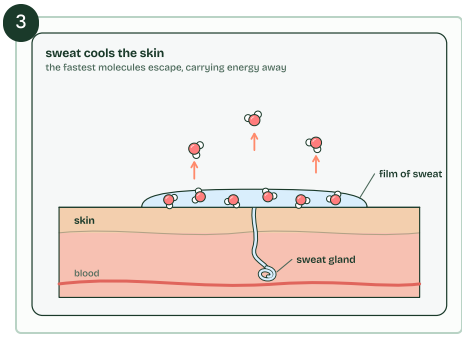
Liquid water is a crowd of molecules held by **hydrogen bonds**. Put energy in, and watch the thermometer.

2



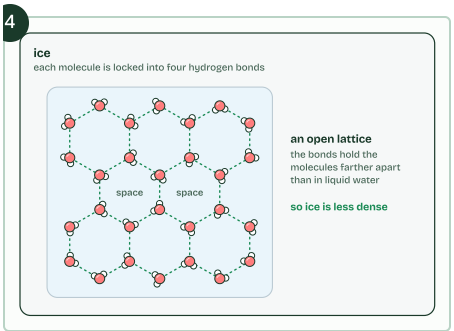
Much of the energy goes into **breaking hydrogen bonds** before the molecules can move faster, so the temperature rises slowly: a high **specific heat**.

3



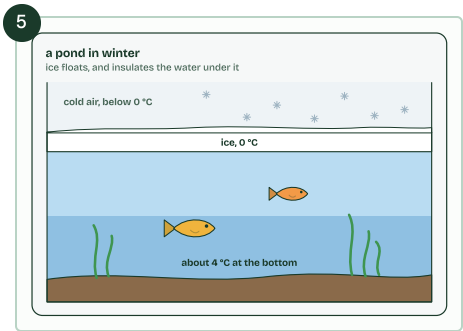
On skin, the fastest molecules break free and **evaporate**, carrying energy away. The sweat left behind, and the skin, cool.

4

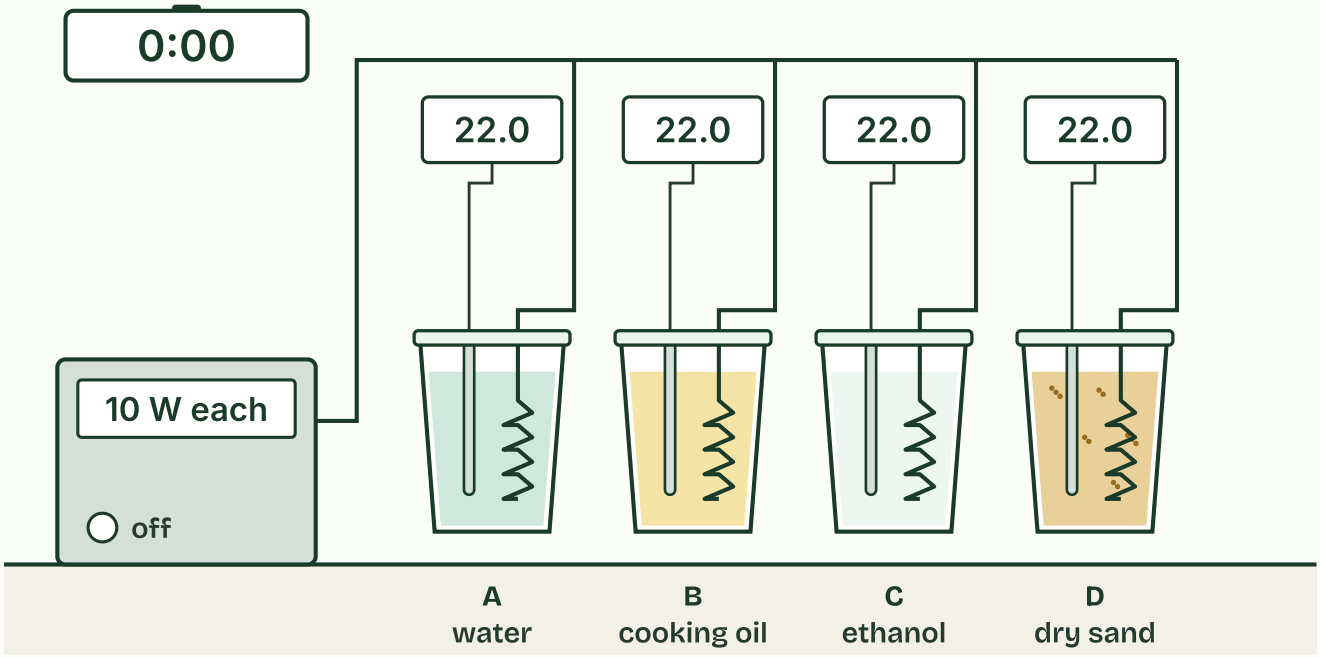


Below 0 °C each molecule locks into four hydrogen bonds. They hold the molecules **farther apart** than in the liquid, so ice is less dense.

5



So ice **floats**. It forms on top of a pond, and insulates the water under it, where life goes on through the winter.



Four cups, each with the same mass of one substance and a heater of the same power. Switch the heaters on together, read every cup every 30 seconds, and see which warms most.

WATCH OUT

"Sweat cools you because it is cold." Sweat comes out at body temperature. It cools you only as it evaporates; on a humid day, when it cannot evaporate, it drips off and cools you very little.

PREDICT

A coastal town and a town far inland are on the same line of latitude. Which has the bigger difference between summer and winter temperatures, and why?

(A) The coastal town, because sea water heats up faster than land in summer and cools faster in winter

(B) The inland town, because the sea's high specific heat lets it soak up summer heat and give it back in winter

(C) Neither: two towns on the same latitude get the same sunlight, so they have the same range of temperatures

Decide before you look. Answer on page 32.

06 Why life is built on *carbon*

1.2.A CARBON, THE BACKBONE

Take the water out of a cell and most of what is left is built round carbon. The molecules of life, carbohydrates, lipids, proteins and nucleic acids, are **organic molecules**: carbon skeletons with other atoms attached.

Carbon earns that place through the bonds it can make. A carbon atom has four electrons to share, so it forms four covalent bonds, more than hydrogen (one), oxygen (two) or nitrogen (three). It bonds strongly to other carbon atoms, so it can build chains of any length, chains with branches, and rings, and it can make double bonds as well as single ones. From one element comes an almost endless variety of shapes, and in biology, shape decides what a molecule can do.

The skeleton alone does little. What makes a molecule react is the small group of atoms attached to it, a **functional group**. Four turn up again and again in this unit, and they are where oxygen, nitrogen and phosphorus join the molecules of life (below).

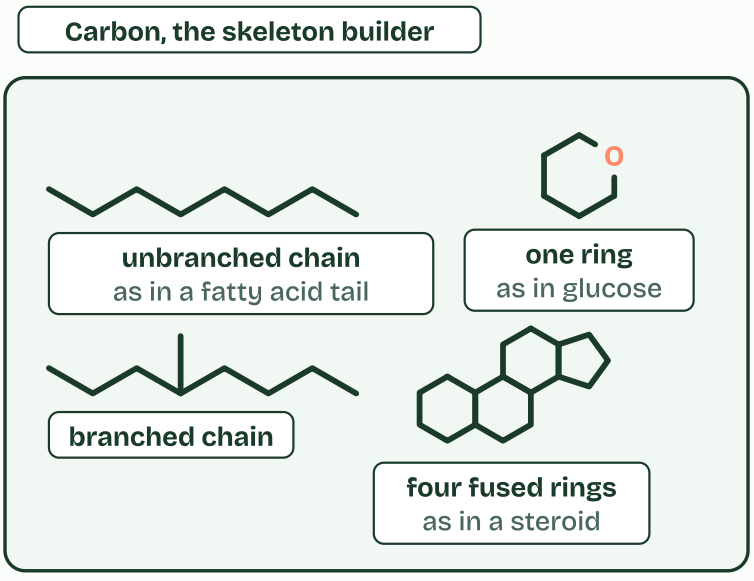
KEY POINTS

- Carbon makes four bonds; a double bond uses two of them.
- Chains, branches and rings: carbon skeletons can take many shapes.

KEY TERMS

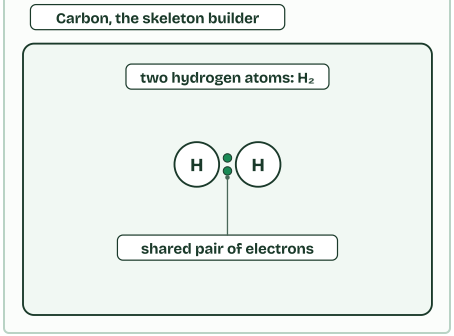
organic molecules
Molecules built on a skeleton of carbon atoms, usually bonded to hydrogen.

functional group
A small group of atoms attached to a carbon skeleton that gives the molecule its chemical behavior, such as hydroxyl, carboxyl, amino or phosphate.



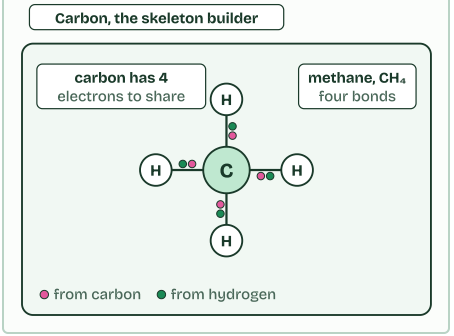
STEP BY STEP
5 STEPS

1



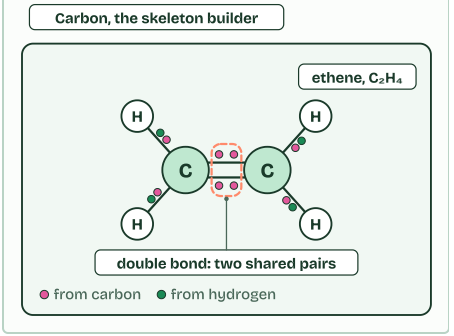
A **covalent bond** is a pair of electrons shared by two atoms.

2



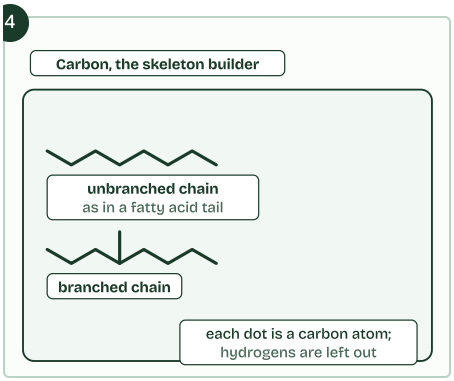
Carbon has four electrons to share, so it makes **four** bonds.

3



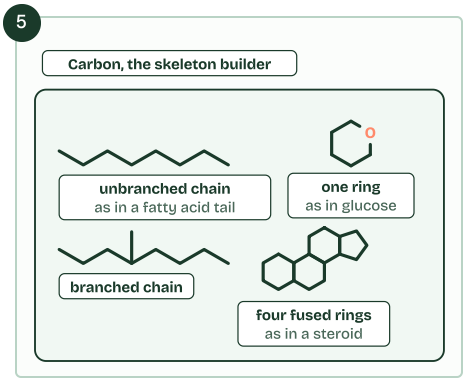
A **double bond** shares two pairs: it uses two of carbon's four.

4

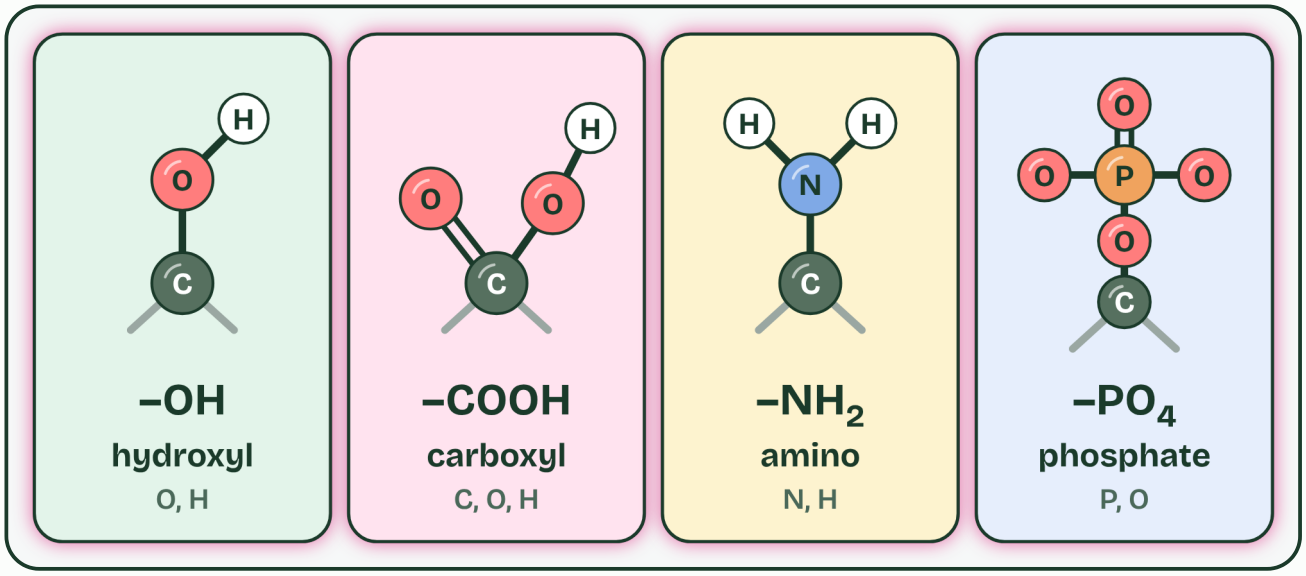


Carbon bonds to carbon, so it builds **chains**, straight or branched,

5



and **rings**, one or several fused together.



Four groups on a carbon skeleton change how the molecule behaves, and between them they bring in nitrogen and phosphorus.

Hydroxyl, –OH. Polar, so it hydrogen bonds with water. Sugars are covered in them, which is why sugars dissolve; glycerol, in fats, has three.

Carboxyl, –COOH. Acidic: it can give up an H^+ and become negatively charged. Every amino acid has one, and so does every fatty acid.

Amino, –NH2. Basic: it can pick up an H^+ and become positively charged. It is the amino in amino acid, and it brings nitrogen into proteins.

Phosphate, –PO4. Charged and very polar. It links the nucleotides of DNA and RNA, gives a phospholipid its head, and three of them make ATP.

WATCH OUT

"Organic means natural or grown without pesticides." In chemistry, organic means built on carbon, whatever made it.

PREDICT

Silicon sits just below carbon in the periodic table and can also make four bonds. Why is life built on carbon and not silicon?

(A) Silicon is too rare on Earth for living things to find enough of it to build their molecules from

(B) Carbon bonds to itself far more strongly, in long chains, rings and double bonds, so it builds far more kinds of stable molecule

(C) Silicon cannot bond with hydrogen or oxygen at all, so a living thing could never get it into its molecules

Decide before you look. Answer on page 32.

07

1.2.A ELEMENTS OF LIFE

Where the *atoms* come from

Six elements make up almost all of the mass of a living thing: carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur. The four classes of large molecule are built from them in different combinations, and the figure shows which. Learn the pattern: carbohydrates CHO, lipids CHO (with P in phospholipids), proteins CHON (with S in some), nucleic acids CHONP.

None of these atoms is made by the organism. To grow, to repair itself and to reproduce, every living thing has to take matter in from its environment and build it into new molecules. Organisms constantly exchange matter with their surroundings.

A plant, an **autotroph**, takes its carbon from carbon dioxide in the air and fixes it into sugars in photosynthesis (Unit 3). It takes nitrogen as nitrate and ammonium, and phosphorus as phosphate, from the soil through its roots. An animal, a **heterotroph**, gets all of these ready-made by eating plants or other animals. When either dies, decomposers break its molecules down and the atoms return to the air and soil, to be taken up again. Carbon, nitrogen and phosphorus all cycle this way (Unit 8).

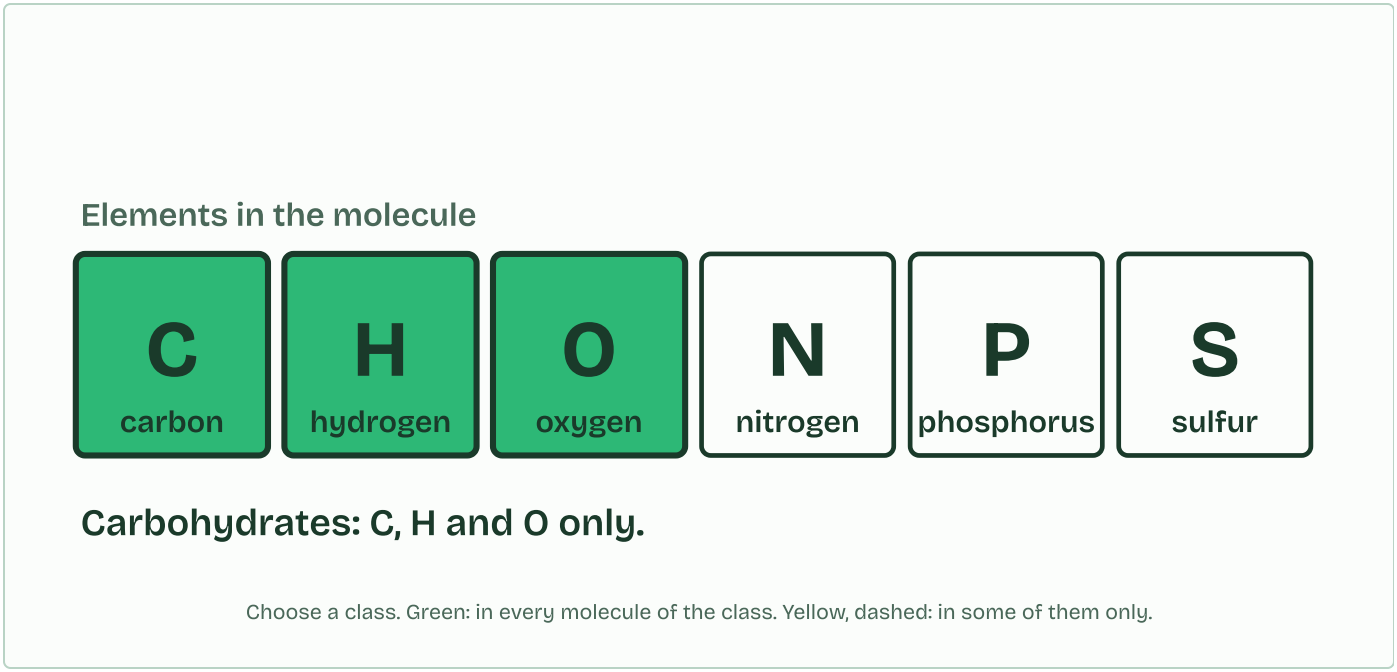
KEY POINTS

- Nitrogen is needed for proteins and nucleic acids; phosphorus for nucleic acids and phospholipids.
- Carbon is in all four classes, and in the stores (starch, glycogen, fat) every organism keeps.

KEY TERMS

autotroph
An organism that makes its own organic molecules from simple inorganic ones, such as a plant using carbon dioxide and light.

heterotroph
An organism that gets its organic molecules by eating other organisms or their products.



SWITCH IT

4 SETTINGS

1

Elements in the molecule

C carbon | H hydrogen | O oxygen | N nitrogen | P phosphorus | S sulfur

Carbohydrates: C, H and O only.

Carbohydrates

2

Elements in the molecule

C carbon | H hydrogen | O oxygen | N nitrogen | P phosphorus | S sulfur

Lipids: C, H, a little O; phospholipids add P.

Lipids

3

Elements in the molecule

C carbon | H hydrogen | O oxygen | N nitrogen | P phosphorus | S sulfur

Proteins: C, H, O and N in all; S in some.

Proteins

4

Elements in the molecule

C carbon | H hydrogen | O oxygen | N nitrogen | P phosphorus | S sulfur

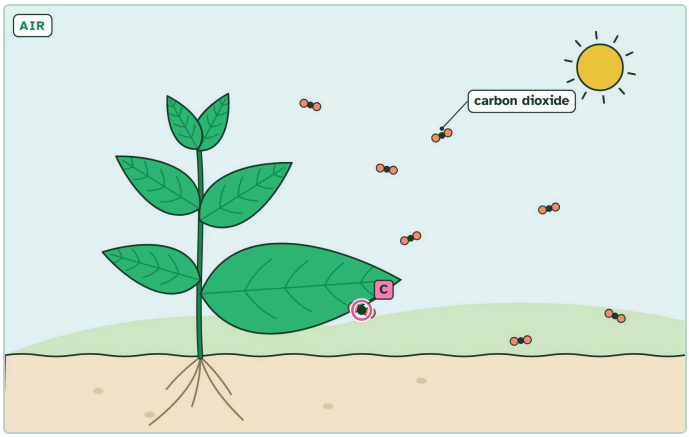
Nucleic acids: C, H, O, N and P in every one.

Nucleic acids

ANIMATION · WATCH IT HAPPEN: ONE CARBON ATOM, FROM AIR TO PLANT TO ANIMAL

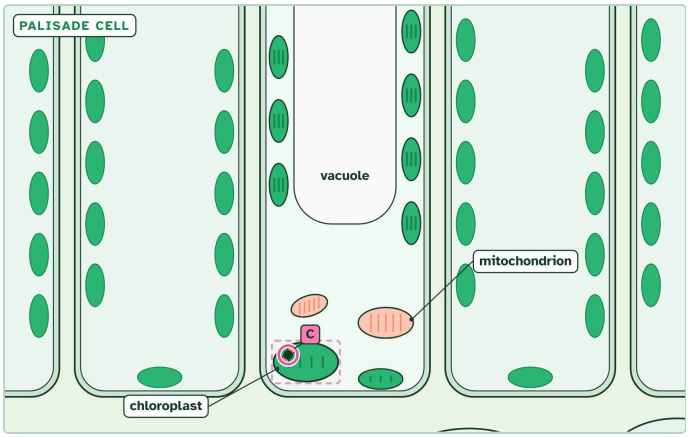
6 MOMENTS

1 AIR



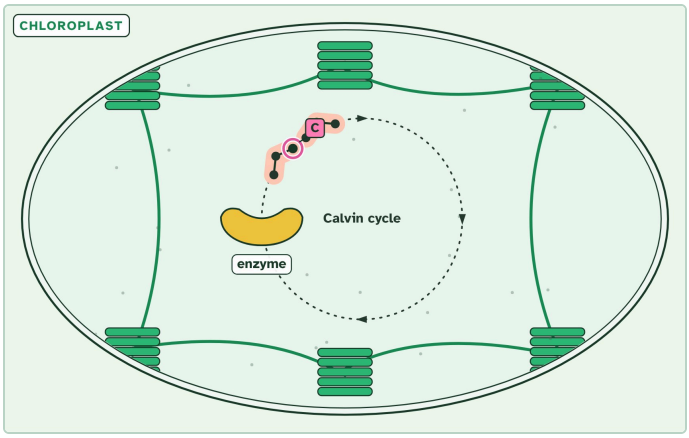
One **carbon atom**, in a molecule of **carbon dioxide** in the air.

2 CHLOROPLAST



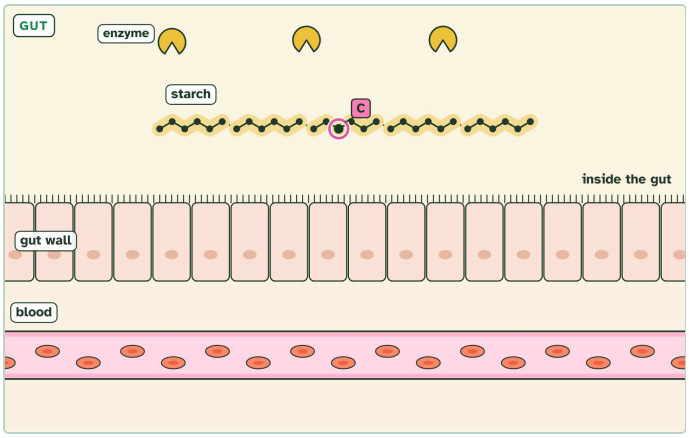
It **diffuses** in through a stoma and into a chloroplast.

3 CHLOROPLAST



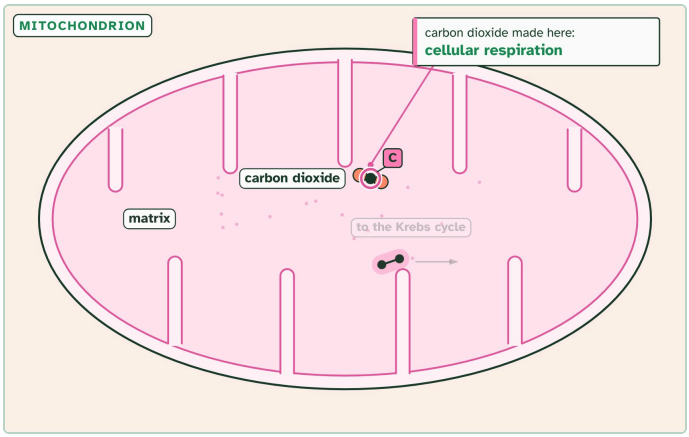
In the **Calvin cycle** it is **fixed**: an enzyme joins it to a compound already there, and the product splits in two.

4 GUT



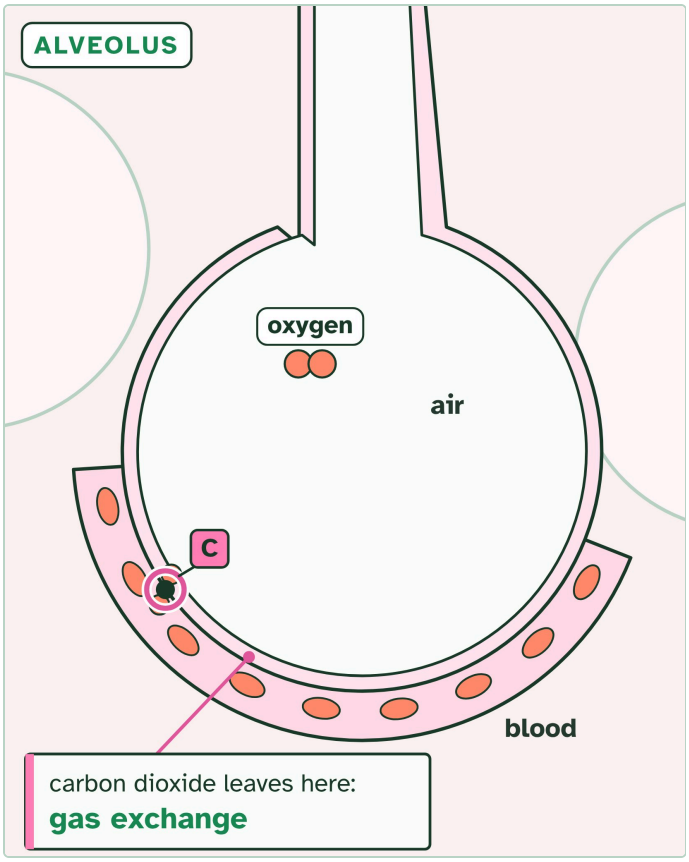
A rabbit eats the leaf. **Digestion** breaks the starch back into glucose, which passes into its blood.

5 MITOCHONDRION



The carbon dioxide is **made in the mitochondrion**: this is cellular respiration.

6 BLOOD



It leaves the body in the lungs: that is **gas exchange**, not respiration.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-1-water-and-elements#elements

REMEMBER IT

The six elements of life

C Cows	H Have	O Odd	N Names	P Personally	S Speaking
Carbon the skeleton of every organic molecule	**Hydrogen** on almost every carbon	**Oxygen** in hydroxyl, carboxyl and phosphate groups	**Nitrogen** proteins and nucleic acids	**Phosphorus** nucleic acids, phospholipids, ATP	**Sulfur** some amino acids

WATCH OUT

"Plants get their mass from the soil." Most of a plant's dry mass is carbon, and it comes from carbon dioxide in the air. The soil gives far smaller amounts of nitrogen, phosphorus and other minerals.

PREDICT

A farmer adds a fertilizer rich in nitrogen to a crop. Which molecules in the plants is that nitrogen most needed for?

(A) Starch and cellulose, because the plant needs nitrogen to join its glucose molecules into long chains

(B) Proteins and nucleic acids, because every amino acid and every base in DNA and RNA contains nitrogen

(C) The fats and oils in its seeds, because nitrogen makes up the long chains of their fatty acids

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 03
The attraction between water and a different substance that is polar or charged.

autotroph 07
An organism that makes its own organic molecules from simple inorganic ones, such as a plant using carbon dioxide and light.

capillary action 03
The movement of water up or along a narrow space against gravity, caused by adhesion to the walls and cohesion between water molecules.

cellulose 03
The carbohydrate that makes plant cell walls: long chains of glucose covered in OH groups.

cohesion 02
The attraction between molecules of the same substance. In water it is caused by hydrogen bonds.

covalent bonds 01
A bond in which two atoms share a pair of electrons.

cytoplasm 04
The jelly-like fluid that fills a cell, mostly water with many substances dissolved in it.

electronegative 01
How strongly an atom pulls the electrons it shares in a bond toward itself. Oxygen pulls harder than hydrogen.

evaporative cooling 05
The cooling of a surface as the most energetic molecules of a liquid on it escape as vapor.

functional group 06
A small group of atoms attached to a carbon skeleton that gives the molecule its chemical behavior, such as hydroxyl, carboxyl, amino or phosphate.

heat of vaporization 05
The energy needed to turn a gram of a liquid into vapor. Water's is high, about 2.4 kJ per gram at body temperature, because every hydrogen bond must break.

heterotroph 07
An organism that gets its organic molecules by eating other organisms or their products.

hydrogen bond 01
A weak attraction between a slightly positive hydrogen atom of one molecule and a slightly negative atom, such as oxygen or nitrogen, of another molecule or another part of the same large molecule.

hydrophilic 04
Attracted to water. Ions and polar molecules are hydrophilic.

hydrophobic 04
Not attracted to water. Nonpolar molecules are hydrophobic.

organic molecules 06
Molecules built on a skeleton of carbon atoms, usually bonded to hydrogen.

polar 01
Having a slightly positive end and a slightly negative end because electrons are shared unequally.

polar covalent bond 01
A covalent bond in which the electrons are shared unequally, so one end is slightly negative and the other slightly positive.

solute 04
A substance that dissolves.

solution 04
A mixture in which one substance, the solute, is dissolved evenly in another, the solvent.

solvent 04

The liquid a solute dissolves in. In living things it is almost always water.

specific heat 05

The energy needed to raise the temperature of 1 gram of a substance by 1 °C. Water's is 4.18 joules per gram per degree, one of the highest of any substance.

surface tension 02

The way a liquid's surface resists being broken, because the molecules at the surface are pulled together and inward.

transpiration 02

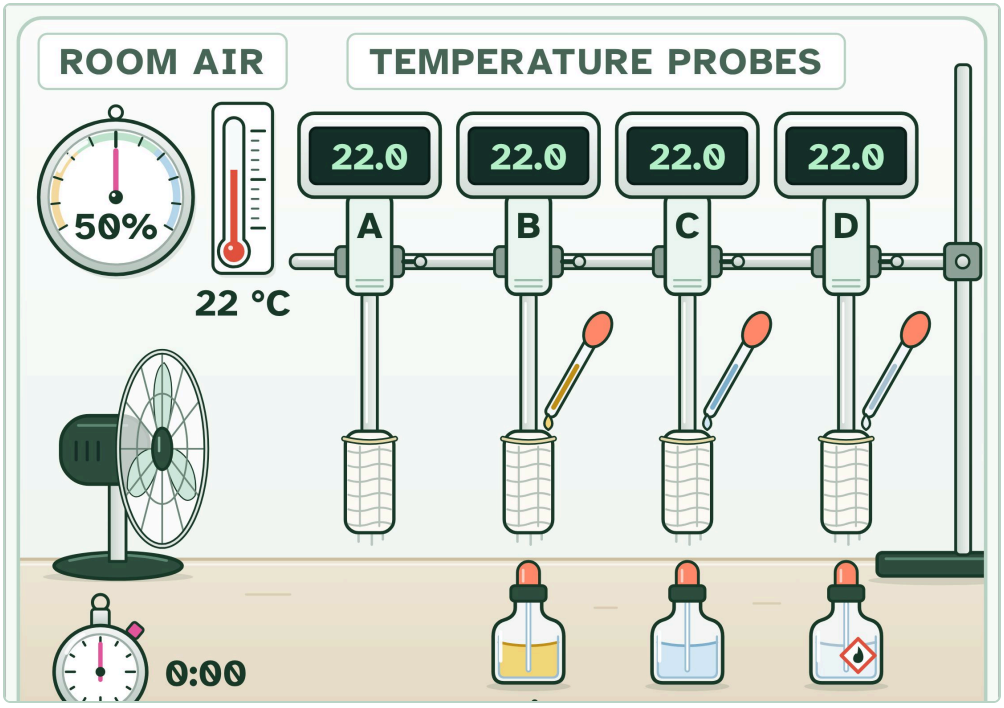
The loss of water vapor from a plant, mostly through pores in its leaves.

xylem 02

The tissue of tubes that carries water and dissolved minerals up from the roots of a plant.

Dry lab: *Wet wicks: cooling by evaporation*

Wrap thermometer probes 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.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ap-biology-unit-1-water-and-elements#lab`

Your question

What makes a wet surface cool down? Do water and ethanol 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 humidity of the room, the volume of liquid 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 down what you think 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.
- **Blow on it.** 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 and standard deviation of the largest fall for one liquid by hand, then check them against **Graph your results**.
- Graph the means with error bars, from the lab or from the CSV, and say which error bars you used.

Your question What makes a wet surface cool down? Do water and ethanol 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 humidity of the room, the volume of liquid 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.

Back to the body

Sweating cools a runner well on a dry, breezy day and poorly on a still, humid one. Use your results, and the hydrogen bonding of water, to explain why.

QUESTIONS ON THE LAB

QUESTION 1

The wicks with no liquid and with cooking oil stayed at room temperature. What do they tell you about the cooling on the other two?

(A) Nothing useful: they had no liquid that could evaporate, so they cannot be compared with the wet wicks at all

(B) The cooling comes from evaporation, not from wetting the wick or from the liquid starting out cold

(C) The probes were broken, because every probe in the same room should read the same temperature all the way through

Answer on page 33.

QUESTION 2

Ethanol cooled its 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 carries off about two and a half times as much heat as a gram of ethanol. How can both be true?

(A) Ethanol comes out of its bottle much colder than water, so its wick starts cooler and stays ahead for the whole run

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

(C) Water cannot evaporate at room temperature at all, so its probe only cools because the air around it is moving

Answer on page 33.

QUESTION 3

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

(A) Humid air is warmer than dry air, so neither liquid could cool its probe as far as it did before

(B) The wick soaked up water from the humid air and got heavier, so less of the water on it could evaporate

(C) Humid air is already full of water vapor, so many water molecules return to the wick, while there is no ethanol vapor in the room

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 1.1 and 1.2 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?program=ap&units=U1&ced=1.1,1.2&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Water boils at 100 °C. Methane, CH_4, a molecule of about the same size, is nonpolar and boils at about −160 °C. What explains the difference?

B Water molecules are held to one another by hydrogen bonds, which must be broken before they can leave as a gas

Hydrogen bonds. Boiling separates whole molecules from one another; the covalent bonds inside each molecule stay as they are. Methane has no partial charges, so nothing much holds its molecules together, and they fly apart at a very low temperature. Water's molecules cling to each other, so it takes far more energy to get them apart.

02 Ground pepper floats on a bowl of water. You touch the middle of the surface with a finger dipped in dish soap. What does the pepper do?

A It shoots out to the edge of the bowl, pulled by the surface that is still clean all around

It shoots outward. Soap molecules crowd into the surface where you touch it and get between the water molecules, so the hydrogen bonding there, and the surface tension, drop. The clean surface all around still pulls hard and drags the water, and the pepper on it, out to the edge. Detergent in a pond does the same to a water strider: with less surface tension to stand on, it sinks.

03 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, because water creeps along the paper from both sides and the colors mix

Purple water. Paper towel is cellulose, which is polar. Water adheres to its fibers and creeps along the narrow spaces between them by capillary action, with cohesion pulling the rest behind, and drips into the empty cup until the levels even out. Both colors arrive and mix.

04 Fish take all their oxygen from water, and oxygen molecules (O_2) are nonpolar. How does the oxygen get into the water?

B Small nonpolar molecules dissolve a little, and a little is enough for fish with large gills

A little dissolves. A liter of water at 20 °C holds only about 9 mg of oxygen, far less than a liter of air. Small nonpolar molecules slip in between water molecules in small amounts. Fish pass a lot of water over large gills, so it is enough. Warm water holds even less, which is why fish crowd at the surface in a heat wave.

05 A coastal town and a town far inland are on the same line of latitude. Which has the bigger difference between summer and winter temperatures, and why?

B The inland town, because the sea's high specific heat lets it soak up summer heat and give it back in winter

The inland town. The sea's water warms slowly through the summer, taking in a great deal of energy for each degree it rises, and releases it slowly through the winter. The air over the coast follows the sea, so the coastal town's summers are cooler and its winters milder. The same buffering keeps the inside of a cell, and of a body, steady.

06 Silicon sits just below carbon in the periodic table and can also make four bonds. Why is life built on carbon and not silicon?

B Carbon bonds to itself far more strongly, in long chains, rings and double bonds, so it builds far more kinds of stable molecule

Carbon's bonds to itself. Silicon is far more common than carbon in Earth's crust, so rarity is not the reason. Silicon's bonds to other silicon atoms are weak, and it bonds so strongly to oxygen that it ends up as rock and sand (silica). Carbon builds stable chains, rings and double bonds in endless variety, and its compound with oxygen, carbon dioxide, is a gas that plants can take in from the air.

07 A farmer adds a fertilizer rich in nitrogen to a crop. Which molecules in the plants is that nitrogen most needed for?

B **Proteins and nucleic acids, because every amino acid and every base in DNA and RNA contains nitrogen**

Proteins and nucleic acids. Carbohydrates and fats contain no nitrogen at all: they are built from carbon, hydrogen and oxygen. Every amino acid has an amino group, and every base in a nucleotide is nitrogen-rich, so a plant short of nitrogen cannot make enough protein or DNA to grow, which is why its leaves turn pale and yellow.

QUESTIONS ON THE DRY LAB

Q1 The wicks with no liquid and with cooking oil stayed at room temperature. What do they tell you about the cooling on the other two?

B **The cooling comes from evaporation, not from wetting the wick or from the liquid starting out cold**

They are the controls. Oil wets the wick just as water does, but it does not evaporate, and it did not cool the probe. So a wet wick on its own does not cool anything: the cooling on the water and ethanol wicks comes from molecules leaving as vapor and taking energy with them.

Q2 Ethanol cooled its 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 carries off about two and a half times as much heat as a gram of ethanol. How can both be true?

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

Ethanol escapes more easily. An ethanol molecule makes fewer hydrogen bonds than a water molecule, so many more leave each second: a fast, deep fall, until the wick runs dry and warms again. Water's molecules are held by up to four hydrogen bonds each, so they leave slowly, but every gram that goes takes more energy with it, and the cooling lasts.

Q3 Water's cooling shrank at 80% humidity, but ethanol's hardly changed. Why?

C **Humid air is already full of water vapor, so many water molecules return to the wick, while there is no ethanol vapor in the room**

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

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.