

Water

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

A drop can stand on a leaf while water inside the same plant moves up a narrow stem. A seal can swim in water that would cool an unprotected human rapidly. These observations connect water's molecular structure with the conditions organisms face.

This handout teaches water as life's medium, polarity and hydrogen bonding, cohesion and adhesion, solvent behaviour, and the consequences of water's physical properties for animals. Sections marked **AHL** are for Higher Level only.

Prerequisites: atoms, molecules, shared electrons, positive/negative charge and energy transfer. All numerical datasets below are original, invented teaching examples unless a physical constant is explicitly given.

Water molecules and the medium for life

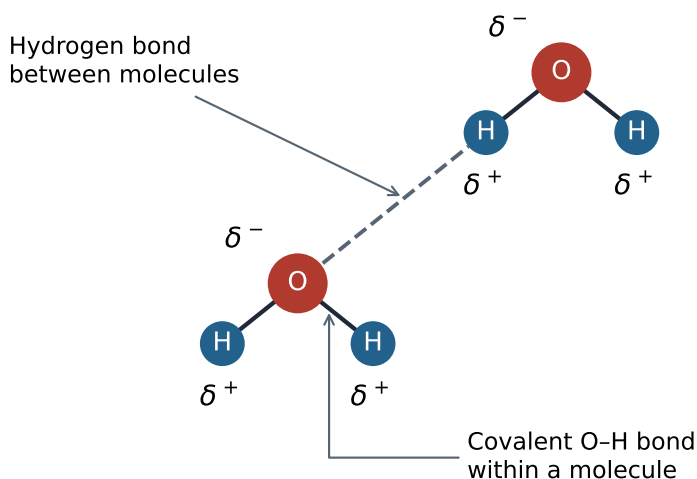
The earliest cells arose in an aqueous environment. Water remains the main medium for most cellular reactions: reactants can dissolve, move and meet enzymes in the watery contents of cells. Blood plasma and plant transport fluids also carry dissolved substances. Living on land does not remove this dependence; terrestrial organisms maintain internal aqueous environments and must replace water losses.

Water is not simply empty space between molecules. Its interactions affect protein folding, membrane organization, transport and temperature. A dry seed may survive with greatly reduced activity, but this does not mean its active metabolism is independent of water.

■ From shared electrons to partial charges

In each O–H **polar covalent bond**, electrons are shared unequally: oxygen attracts the shared electrons more strongly than hydrogen. Oxygen has a partial negative charge, δ^- ; the hydrogens have partial positive charges, δ^+ . These are partial charges within a neutral molecule, not evidence that ordinary water consists entirely of separate hydrogen and oxygen ions.

Water has a bent shape. Its bond polarities do not cancel, so the molecule has a positive side and a negative side. A **hydrogen bond** is an attraction between a partially positive hydrogen bonded to an electronegative atom and a suitable electronegative atom on another molecule. In water, this is commonly represented as an attraction between H on one molecule and O on another.



Solid O–H bonds join atoms within a molecule; the dashed attraction joins different molecules.

When drawing water, label O and both H atoms, show the partial charges, and place the dashed hydrogen bond between the appropriate H and O on different molecules. Do not draw it between two hydrogens or use the same symbol for a covalent bond and a hydrogen bond.

Individual hydrogen bonds are weaker than covalent O–H bonds. In liquid water they continually form and break as molecules move. Many interactions together produce strong effects at the scale of a droplet or a column of water. Heating increases molecular motion and changes these interactions. Ordinary boiling separates intact water molecules; it does not normally decompose them into hydrogen and oxygen by breaking their covalent bonds.

Cohesion, surface tension and water transport

Cohesion is attraction between molecules of the same substance. Hydrogen bonding contributes to cohesion between water molecules. Inside a liquid, a molecule has neighbours in many directions; at the surface the environment is different. Creating more surface requires energy, so the surface tends to resist stretching. This is **surface tension**. The surface is still liquid, not a solid skin.

A pond skater can use the water surface as a habitat. Its water-repellent legs spread the load and deform the surface, allowing surface-tension forces to help support it. This does not mean any animal can walk on water: mass, contact shape, wetting and the liquid's surface properties all matter. Detergent can alter surface tension and wetting, so it changes the system rather than merely colouring the water.

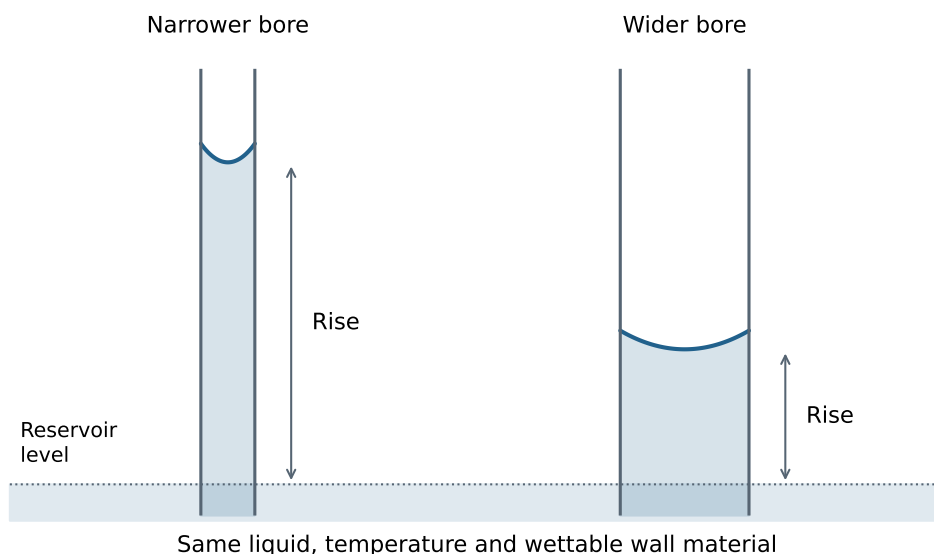
In a plant's **xylem**, evaporation from leaf surfaces helps create tension, meaning a

pulling stress or pressure below the surrounding reference pressure. Cohesion helps the water column transmit this pull through the plant. Water molecules do not actively climb because they “want” to reach the leaves. The explanation links evaporation, tension and an interconnected column of water. A gas-filled break can interrupt that column; cohesion is strong but not unlimited.

Adhesion and capillary action

Adhesion is attraction between different substances. Water can interact with polar or charged groups on plant cell-wall materials and soil particles. It does not adhere equally to every surface; a nonpolar waxy surface may resist wetting.

In a narrow wettable space, adhesion at the wall and cohesion within the liquid help produce **capillary action**: water can rise against gravity, with a curved meniscus. In an ideal wettable tube, a narrower bore can support a higher equilibrium rise. The upward surface-tension force is eventually balanced by the weight of the raised water. Surface chemistry and tube radius matter; “narrow” alone does not guarantee that a liquid rises.



The sketch compares equilibrium rises under the same conditions; it is not a scale drawing of a whole plant.

Capillary spaces in soil and plant cell walls help retain and distribute water. Distinguish this from explaining the entire height of water transport in a tall tree. Adhesion helps maintain contact with walls and cohesion links the column, but transpiration-driven tension is central to long-distance ascent. A glass-tube demonstration does not by itself prove a complete biological transport mechanism.

Water as a solvent: what dissolves and why?

A solvent is the medium in which a solute dissolves. Water’s partial charges interact with ions and with suitable polar groups. Around a dissolved positive ion, the oxygen sides of nearby water molecules tend to face the ion; around a negative ion, the hydrogen sides tend to face it. The ions become surrounded by water rather than turning into water molecules.

Hydrophilic substances interact favourably with water. Many ions, sugars and other small polar molecules dissolve sufficiently to move in aqueous transport fluids. Glucose carried in blood plasma can reach tissues; mineral ions move in xylem sap. Dissolved reactants can diffuse and participate in enzyme-controlled metabolism. Solubility still depends on the substance, temperature and concentration: “polar” does not mean unlimited solubility.

Hydrophobic substances interact poorly with water and often aggregate rather than dissolve. Lipids provide useful examples. The nonpolar regions of membrane lipids avoid water while their polar regions interact with it, helping organize a boundary around the cell’s aqueous interior. Hydrophobic regions also contribute to protein folding. Insolubility can therefore be biologically useful; water need not dissolve everything to support life.

Do not confuse dissolving with melting, reacting or forming a suspension. Fine insoluble particles can make a cloudy mixture without becoming molecularly dissolved. A clear solution is also not necessarily pure water: dissolved ions or molecules may be invisible.

Water and air as animal habitats

Compare each physical property with the biological consequence it actually explains. Several properties operate at once, so one adaptation can have more than one benefit or cost.

Property	Water versus air	Main consequence
Buoyancy	Larger at equal displaced volume	Supports body weight
Dynamic viscosity	Higher	Resists motion
Thermal conductivity	Higher	Faster heat exchange
Specific heat capacity	Higher per kilogram	Buffers temperature change

■ Support and movement

Buoyancy is an upward force caused by the surrounding fluid's pressure distribution. For a simple fully submerged object, it equals the weight of displaced fluid. Floating at rest involves balance between weight and upthrust. A greater upthrust does not mean an animal has no mass or that every animal automatically floats.

A ringed seal uses flippers for propulsion and has a streamlined body suited to movement through water. When swimming, it must overcome drag; buoyancy helps support its weight but does not remove resistance to motion. A loon, such as the black-throated loon, also moves between an aquatic habitat and air. Webbed feet provide propulsion in water, while wings provide aerodynamic forces in flight. The same animal faces different support and resistance conditions in the two media.

Viscosity is not identical to density. Drag depends on speed, size, shape and the flow conditions as well as the fluid's properties. Do not claim that one numerical viscosity ratio must equal the ratio of swimming and flying energy costs.

■ Heat movement and temperature stability

Thermal conductivity describes heat transfer down a temperature gradient through a material. Specific heat capacity describes energy needed to change a mass's temperature. These are different quantities. High conductivity can increase heat exchange; high heat capacity can reduce the temperature change caused by a given energy input.

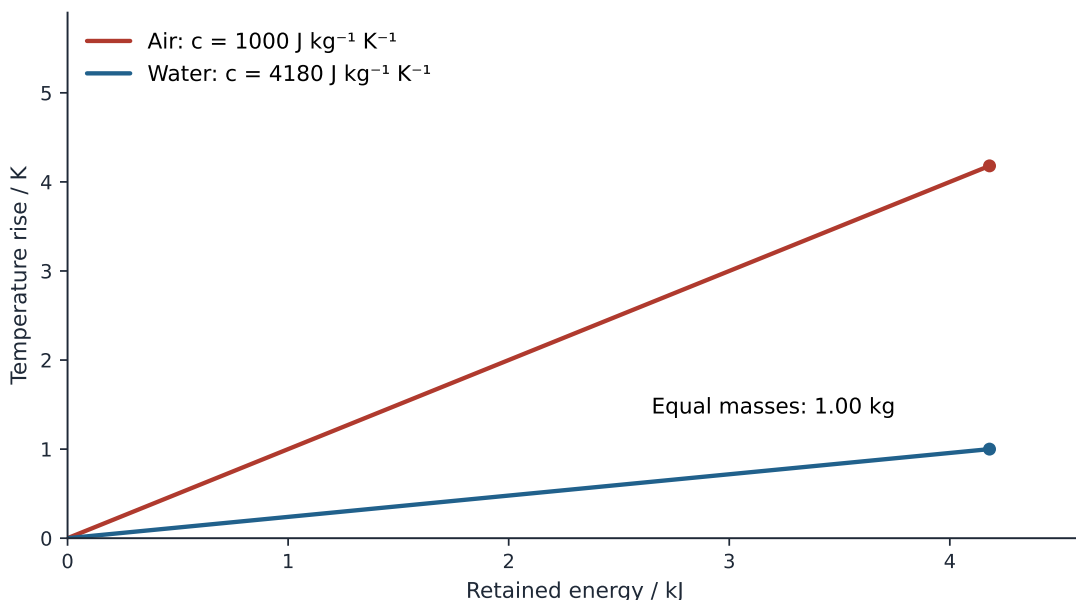
A ringed seal's blubber helps reduce heat loss in cold water. A layer of insulating material slows transfer; it does not make the animal's body completely waterproof to heat. Air trapped by suitable dry feathers can also provide insulation in a bird. Actual heat loss depends on water movement, insulation, body size and the temperature difference, not conductivity alone.

■ Worked example: an equal energy input

Use the given approximate specific heat capacities: water $c = 4180 \text{ J kg}^{-1} \text{ K}^{-1}$ and air $c = 1000 \text{ J kg}^{-1} \text{ K}^{-1}$. Suppose 4180 J is retained by 1.00 kg of each, without phase changes or losses.

$$\Delta T = \frac{Q}{mc}.$$

Water warms by $4180/(1.00 \times 4180) = 1.00 \text{ K}$; air warms by $4180/(1.00 \times 1000) = 4.18 \text{ K}$. This is an **equal-mass** comparison. Equal volumes contain very different masses, so they would give a different comparison. It is not a calculation of a seal's cooling rate.



For equal mass and retained energy, the larger specific heat capacity gives the smaller temperature rise.

Hydrogen bonding helps explain the energy required to warm water: energy changes molecular motion and intermolecular arrangements. Water therefore helps buffer organisms and habitats against rapid temperature changes. It does not keep temperature perfectly constant or remove the need for temperature regulation.

Investigate a water property fairly

To compare spreading, place equal-volume drops of water on clean samples of two surfaces at the same temperature. Define a measurement such as contact angle from a side photograph. Keep drop volume, surface preparation, time after placement and camera geometry consistent. Use repeated trials and report the scatter.

Contact angle describes wetting under these conditions; it is not a direct numerical measurement of cohesion alone. If investigating detergent concentration, change that concentration systematically while holding the surface fixed. A result can support an explanation involving surface interactions, but a difference might also arise from contamination or unequal volumes. Match the conclusion to what the method measured and give a specific improvement for each limitation.

AHL: Earth's water and the search for life

One hypothesis proposes that water-bearing asteroidal material delivered water during Earth's early history. Finding water-related minerals in asteroids supports the plausibility of such a source, but does not mean a single asteroid supplied all Earth's oceans. Distinguish the proposed source from the conditions that allowed water to

remain over geological time.

Earth's gravity helps retain material, including an atmosphere, rather than allowing it all to escape readily. Conditions cool enough for water vapour to condense allow liquid reservoirs to form. Gravity alone is insufficient if surface conditions keep water in vapour form or promote its loss; temperature alone is insufficient to explain retention on a small body. Long-term water availability gave biological evolution a persistent medium.

The **habitable zone** around a star, sometimes called the Goldilocks zone, is a range where surface liquid water could be possible on a suitable planet. It is not a fixed universal distance, because stars differ. Atmosphere, pressure and other planetary properties also affect whether liquid water actually persists. Being in the zone does not prove that water is present or that the planet supports life.

Liquid water is a useful search target because known life depends on it as a reaction medium. It is evidence of possible suitable conditions, not a detection of life. Water, an energy source and suitable chemistry must be considered together. Subsurface liquid water may also occur outside a star's surface-habitable zone, so the zone is a search guide rather than the only possible location worth investigating.

Practice

All numerical observations below are invented. Use the stated models and constants.

1. Explain why a land animal still needs an internal aqueous medium. Give one metabolic role and one transport example.
2. Draw two water molecules. Label their partial charges, distinguish covalent and hydrogen bonds, and explain why the molecule is polar but electrically neutral overall.
3. Explain how hydrogen bonding contributes to cohesion and how this helps transmit a pull through xylem. Identify where the pulling stress originates.
4. A student calls a pond surface “a solid skin that holds up all insects”. Correct both parts using surface tension and the conditions for support.
5. Distinguish cohesion from adhesion. Explain capillary rise in a wettable narrow tube and why this alone is not a full explanation of tall-tree water transport.
6. Explain how water can surround sodium and chloride ions. Contrast this with a hydrophobic region of a membrane lipid, and explain why insolubility can be useful.
7. Explain one consequence each of buoyancy and viscosity for a swimming seal. Why does buoyancy not eliminate drag?
8. Compare thermal conductivity and specific heat capacity. Explain how cold water can cool a warm animal rapidly while a large lake can resist rapid temperature change.

9. Using $c = 4180 \text{ J kg}^{-1} \text{ K}^{-1}$, calculate the energy retained when 0.200 kg water warms by 5.0 K. State two energy transfers omitted if this is used as a simple heating experiment model.
10. Equal 0.500 kg samples retain 2090 J. Use $c_{\text{water}} = 4180$ and $c_{\text{air}} = 1000$ in $\text{J kg}^{-1} \text{ K}^{-1}$. Calculate both temperature rises and explain why the comparison must specify equal mass.
11. A spreading experiment gives contact angles 68° , 71° and 69° on surface A, and 108° , 112° and 110° on B. Find each mean, identify which is more readily wetted, and give two controls and one limitation.
12. **AHL.** Distinguish the asteroidal-source hypothesis from two reasons Earth could retain water. Why would a claim that “gravity produces liquid water” be incomplete?
13. **AHL.** A planet is reported to orbit in its star’s habitable zone. Explain what this suggests and what it does not establish. Why might a moon outside that zone still interest a search for life?

■ Worked answers

1. Enzyme-controlled reactions usually occur in an aqueous environment where reactants can move and meet. Blood plasma carries dissolved substances such as glucose to tissues. Life on land still depends on maintaining water within cells and transport fluids.
2. Each O bears δ^- and each H δ^+ . Solid O–H bonds are within molecules; a dashed bond links an appropriate H on one to O on another. Oxygen attracts shared electrons more strongly; the bent arrangement gives a molecular polarity, while the molecule’s total positive and negative charges still balance.
3. Intermolecular attractions link water molecules. Evaporation from leaf surfaces generates tension; cohesion helps transmit that pulling stress through the connected water column. The molecules are not using metabolic energy to crawl upwards.
4. Surface tension is a property of a liquid surface, not a solid layer. It can provide supporting forces for a suitable small animal with appropriate mass, contact geometry and water-repellent legs; it cannot support every insect or unlimited weight.
5. Cohesion acts between water molecules; adhesion acts between water and another material. At wettable walls, surface interactions can support a rise until the raised water’s weight balances the upward force. Narrow spaces in walls and soil matter, but long-distance ascent also requires transpiration-driven tension in a cohesive column.
6. Water’s oxygen side tends to face Na^+ ; its hydrogen sides tend to face Cl^- . Non-polar lipid regions do not interact similarly and tend to avoid the aqueous phase. This helps membrane lipids organize a boundary rather than disperse completely in water.

7. Buoyancy provides an upward force that supports some or all of the seal's weight under the relevant conditions; viscosity contributes to resistance during movement. Upward support and resistance to forward motion are different effects, so swimming still requires propulsion.
8. Conductivity concerns heat transfer across a temperature gradient; specific heat capacity relates warming to retained energy per mass. Water can carry heat from a warm body while its large mass and heat capacity limit its own warming. Insulation and currents affect the transfer rate.
9. $Q = mc\Delta T = 0.200(4180)(5.0) = 4180 \text{ J}$, or 4.18 kJ before final significant-figure rounding (about 4.2 kJ to two significant figures). Energy absorbed by the container and transferred to the wider surroundings are omitted.
10. Water: $2090/(0.500 \times 4180) = 1.00 \text{ K}$. Air: $2090/(0.500 \times 1000) = 4.18 \text{ K}$. Their ratio is 4.18. Equal volumes contain unequal masses, so substituting equal volumes would not preserve this result.
11. A: $(68 + 71 + 69)/3 = 69.3^\circ$; B: $(108 + 112 + 110)/3 = 110^\circ$. A is more readily wetted. Control drop volume and temperature; prepare and photograph surfaces consistently. Contact angle measures wetting, not cohesion alone; contamination or camera geometry could bias it.
12. **AHL.** Asteroidal material is a proposed source of water. Gravity helps retain material; sufficiently cool conditions allow condensation. Gravity does not itself supply water or ensure suitable temperature and pressure for a persistent liquid phase.
13. **AHL.** Its orbital region may permit surface liquid water under suitable planetary conditions. The report does not establish an atmosphere, actual liquid water or life. A moon outside the surface-habitable zone could have a subsurface liquid-water habitat maintained by internal heating.

Exam tips

- Link molecular structure $\rightarrow$ property $\rightarrow$ named biological consequence. Distinguish cohesion/adhesion, viscosity/density and conductivity/heat capacity.
- Label partial charges and both bond types. Boiling normally leaves covalent O–H bonds intact.
- State comparison conditions and calculation units; match experimental conclusions to measured outcomes.
- **AHL.** Liquid water suggests possible suitable conditions; a habitable-zone position does not detect life.

References: IB A1.1; NOAA insulation; NASA habitable zones.