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A1.1 Water

Molecules: how the structure of water explains its role as the medium for life

Standard Level and Higher Level (2 hours); Additional Higher Level (1 hour)

What you must be able to do

Idea	You must be able to...	Level
Water as the medium	Appreciate that life began in water and that most life processes happen in water	SL HL
Polarity and hydrogen bonds	Explain polar covalent bonds; draw hydrogen bonds between water molecules	SL HL
Cohesion and adhesion	Link cohesion to surface tension and xylem transport; adhesion to capillary action in soil and cell walls	SL HL
Solvent properties	Explain how water dissolves hydrophilic substances; role of hydrophobic substances	SL HL
Aquatic habitats	Compare buoyancy, viscosity, thermal conductivity and specific heat capacity of water and air; loon and ringed seal	SL HL
Origin of water; search for life	Asteroid origin and retention of Earth's water; Goldilocks zone	HL

What is inside

1. Concept notes with 7 worked examples
2. Hydrogen-bond, capillary and solvent diagrams
3. Common mistakes; investigation (IA) ideas
4. 15 Paper 1A-style MCQs, explained
5. 3 Paper 2-style structured questions with mark schemes (one data-based)
6. Quick-reference sheet and "I can" checklist

How to read these notes

SL = Standard Level content

HL = needed at Higher Level only

red = key term green = definition

1 = one mark in the mark scheme

★ **Exam tip:** Calculators are allowed in every IB Biology paper; there is no formula booklet, so learn the few formulae you need. Paper 1: SL = 30 MCQs + 25-mark data questions (1 h 30); HL = 40 MCQs + 35 marks (2 h).

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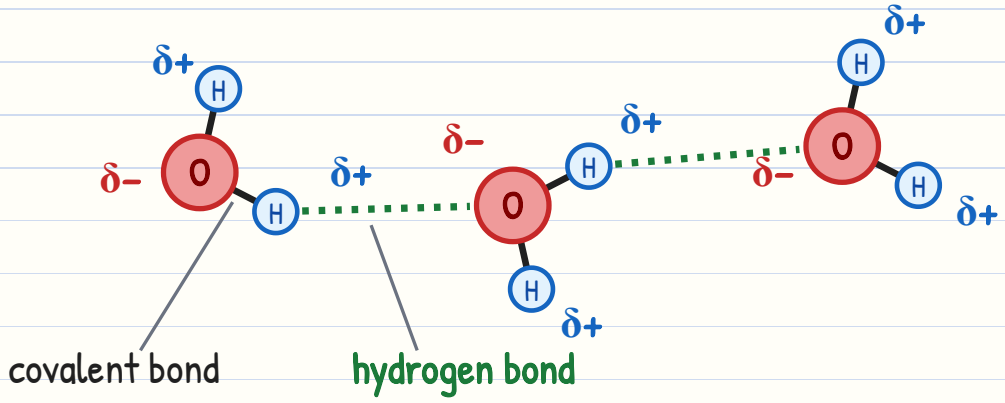
Water: the medium of life

SL HL The first cells arose in water, and water is still the **medium** in which almost all the reactions of life take place. A cell is roughly 70 to 80% water by mass. Cytoplasm, blood plasma, sap and tissue fluid are all watery solutions in which substances meet, react and are carried from place to place. Water's usefulness comes from one structural fact: the molecule is polar.

Polarity and hydrogen bonding

In an H_2O molecule oxygen shares electrons with two hydrogen atoms by **polar covalent bonds**. Oxygen attracts the shared electrons more strongly, so the electrons spend more time near O. The oxygen end therefore carries a small negative charge (**δ−**) and each hydrogen a small positive charge (**δ+**). The molecule is bent (about 104.5°), so the charges do not cancel.

The δ+ hydrogen of one molecule is attracted to the δ− oxygen of a neighbouring molecule. This attraction between molecules is a **hydrogen bond**. One water molecule can form up to four hydrogen bonds: two through its hydrogens and two through lone pairs on its oxygen.



Three water molecules. Solid lines are covalent bonds inside a molecule; dotted lines are hydrogen bonds between molecules.

	Covalent bond (O–H)	Hydrogen bond
Where	inside one molecule	between neighbouring molecules
Cause	sharing of an electron pair	attraction of δ+ H to δ− O of another molecule
Strength	strong (about 460 kJ mol^{-1})	weak (about 20 kJ mol^{-1}); constantly breaking and re-forming

Worked example 1: counting hydrogen bonds

Five water molecules each have the potential to form four hydrogen bonds. What is the largest possible number of hydrogen bonds among them? Each bond joins *two* molecules, so the total is not 5×4. Bond "ends" available $= 5 \times 4 = 20$. Each bond uses two ends, so at most $20 \div 2 = 10$ bonds (in practice fewer, because molecules at the edge of a small group cannot reach four partners).

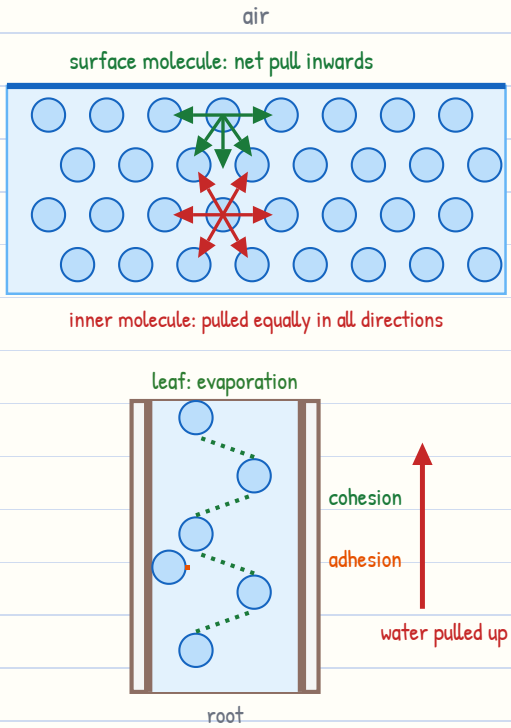
✗ Don't do this: Writing that "hydrogen bonds join the hydrogen and oxygen *atoms* in a water molecule". Those are covalent bonds. Hydrogen bonds are always **between** molecules.

Cohesion and adhesion

Definition **Cohesion** is the attraction between molecules of the same substance; in water it is due to hydrogen bonding between water molecules. **Adhesion** is the attraction of water molecules to molecules of another substance, here polar or charged materials such as cellulose and glass.

Cohesion: surface tension and xylem transport SL HL

- **Surface tension.** A molecule inside the liquid is pulled equally in all directions; a molecule at the surface has no neighbours above it, so it is pulled sideways and inwards. The surface behaves like a stretched skin. Pond skaters, water snails and some plants use the water surface as a habitat.
- **Water in the xylem.** Evaporation from leaves (transpiration) pulls water upwards. Because water molecules cohere, the water moves as a continuous column in the narrow xylem vessels, which is under **tension** (negative pressure). The column does not break even in tall trees, because the hydrogen bonds hold it together.

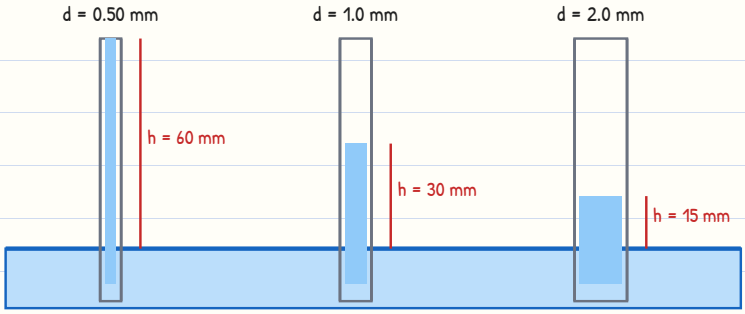


Left: net inward pull on surface molecules (surface tension). Right: cohesion and adhesion keep the xylem column unbroken.

Adhesion: capillary action SL HL

Adhesion pulls water along the walls of narrow spaces, while cohesion drags the rest of the water behind it. This **capillary action** moves water *up* a narrow tube. The narrower the tube, the higher the water climbs: the height is roughly inversely proportional to the tube diameter.

- **Soil.** Water clings to the surfaces of clay and humus particles and is drawn through the tiny pore spaces, keeping soil moist and bringing water towards roots.
- **Plant cell walls.** Cellulose is polar, so water adheres to it and is held in the walls; water is drawn through the wall network to the surface where it evaporates into the leaf's air spaces.



Capillary rise in glass tubes of different diameter: narrower tube, higher rise.

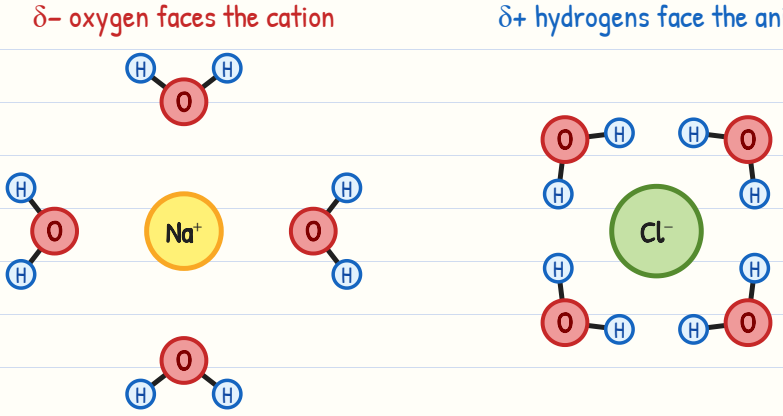
Worked example 2: speed of water movement in a stem

A cut stem stands in dye. After 12 min the dye front has risen 18 cm. Calculate the rate in cm min^{-1} and in m h^{-1}.

Rate $= 18 \div 12 = 1.5$ cm min^{-1}. In one hour: $1.5 \times 60 = 90$ cm $= 0.90$ m h^{-1}.

Water as a solvent SL HL

Water dissolves a huge variety of substances, so it is the medium for metabolism and for transport. **Hydrophilic** ("water-loving") molecules are polar or charged and dissolve because water molecules cluster round them. **Hydrophobic** ("water-fearing") molecules are non-polar, do not attract water and are insoluble.



Dissolving sodium chloride: the δ− oxygen ends of water point towards Na^+, the δ+ hydrogen ends towards Cl^-, so the ions separate and stay dispersed.

Type	Examples	Why it matters
Hydrophilic: ions	Na^+, Cl^-, K^+, Ca^{2+}, hydrogencarbonate	carried dissolved in blood plasma, sap and cytoplasm
Hydrophilic: polar molecules	glucose, amino acids, urea	transported in plasma and phloem sap; reacting molecules meet in solution
Hydrophilic: large polar molecules	most enzymes, many proteins	stay dissolved or dispersed, so most enzymes work in aqueous solution (cytoplasm, digestive juices)
Hydrophobic	fats, oils, phospholipid tails, steroids, oxygen (poorly soluble)	form membranes that separate watery compartments; waxy cuticle reduces water loss; fats carried in lipoprotein "packages"

- **Transport in animals:** blood plasma is mainly water and carries glucose, amino acids, ions, urea and hormones. Oxygen dissolves poorly, so it is carried by haemoglobin, and fats are carried inside lipoproteins whose outer layer is hydrophilic.
- **Transport in plants:** mineral ions move in xylem sap; sucrose and amino acids move in phloem sap.
- **Metabolism:** most reactions of the cell happen with the reactants dissolved in the cytoplasm.

Worked example 3: how much glucose is in the plasma?

Normal plasma glucose is about $5.0\ \text{mmol dm}^{-3}$. The molar mass of glucose is $180\ \text{g mol}^{-1}$. Estimate the mass of glucose in $3.0\ \text{dm}^3$ of plasma.

Mass per dm³ $= 5.0 \times 10^{-3} \times 180 = 0.90\ \text{g dm}^{-3}$. In $3.0\ \text{dm}^3$: $0.90 \times 3.0 = 2.7\ \text{g}$. That is less than one teaspoon of sugar, which is why blood glucose is tightly regulated.

Worked example 4: inverse proportion in capillary tubes

Water rises 30 mm in a tube of diameter 1.0 mm. Predict the rise in tubes of diameter 0.50 mm and 2.0 mm, assuming height is inversely proportional to diameter.

$h \times d$ is constant $= 30 \times 1.0 = 30\ \text{mm}^2$. For $d = 0.50$: $h = 30 \div 0.50 = 60\ \text{mm}$. For $d = 2.0$: $h = 30 \div 2.0 = 15\ \text{mm}$.

★ **Exam tip:** When asked why a substance is soluble, always link **polar or charged** to **attraction to water molecules**. "It is polar" alone does not earn the mark.

Water and air as environments SL HL

Hydrogen bonding gives water physical properties very different from air. Animals in water meet different challenges and opportunities from those on land.

Property	Water (about 20 °C)	Air (about 20 °C)	Consequence for animals
Density	1000 kg m⁻³	1.2 kg m⁻³	**Buoyancy**: water supports bodies, so aquatic animals need less skeletal support; but drag is large
Viscosity	about 1.0 mPa s	about 0.018 mPa s	moving through water is harder; streamlined bodies reduce drag
Thermal conductivity	0.60 W m⁻¹ K⁻¹	0.026 W m⁻¹ K⁻¹	water removes body heat much faster, so aquatic mammals and birds need insulation
Specific heat capacity	4.18 J g⁻¹ K⁻¹	about 1.0 J g⁻¹ K⁻¹	water temperature changes slowly, so aquatic habitats have stable temperatures

Worked example 5: specific heat capacity

How much energy is needed to warm 250 g of water by 12 °C? How does this compare with 250 g of air? Use $E = m\,c\,\Delta T$, with $c = 4.18$ for water and $1.0\ \text{J g}^{-1}\text{K}^{-1}$ for air.

Water: $250 \times 4.18 \times 12 = 12\,540\ \text{J} = 12.5\ \text{kJ}$. Air: $250 \times 1.0 \times 12 = 3000\ \text{J} = 3.0\ \text{kJ}$. Water needs $12.5 \div 3.0 = 4.2$ times as much energy: it warms and cools more slowly.

Worked example 6: comparing properties as ratios

Calculate how many times greater (a) the density and (b) the thermal conductivity of water is than that of air, using the table.

(a) $1000 \div 1.2 = 830$ times (two significant figures). (b) $0.60 \div 0.026 = 23$ times. A seal in 5 °C water loses heat by conduction far faster than in 5 °C air (up to 23 times, other things equal), which is why it needs blubber.

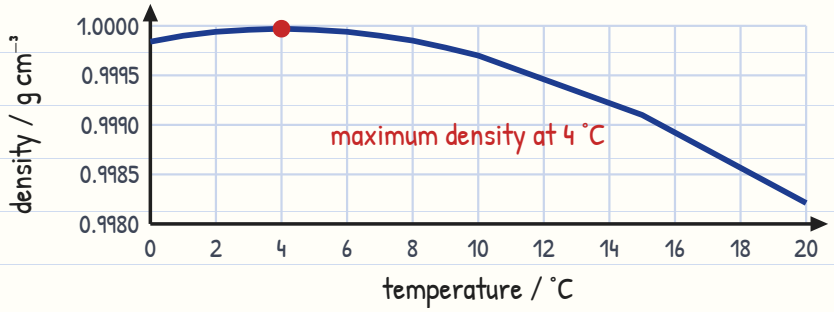
Examples: black-throated loon and ringed seal

Black-throated loon (*Gavia arctica*): a diving bird. Streamlined body; legs set far back to give thrust in water, but it is clumsy on land; bones are denser (less air-filled) than in most birds, so it is less buoyant and can dive; it needs a long take-off run over water and flies strongly once airborne.

Ringed seal (*Pusa hispida*): lives in cold Arctic water. Streamlined, tapered body reduces drag; a thick layer of fat (blubber) insulates against rapid conduction of heat into water; flippers for propulsion; it keeps breathing holes open in the ice.

Ice floats

Liquid water is densest at about 4 °C. In ice, hydrogen bonds hold molecules in an open lattice, so ice (about 0.92 g cm^{-3}) is **less dense** and floats. The ice layer insulates the water below, so lakes do not freeze solid. (Typical values only; exams give any numbers needed.)



Density of liquid water (g cm^{-3}) between 0 and 20 °C; the maximum is at 4 °C.

Water and the search for life HL

Higher Level (HL) only

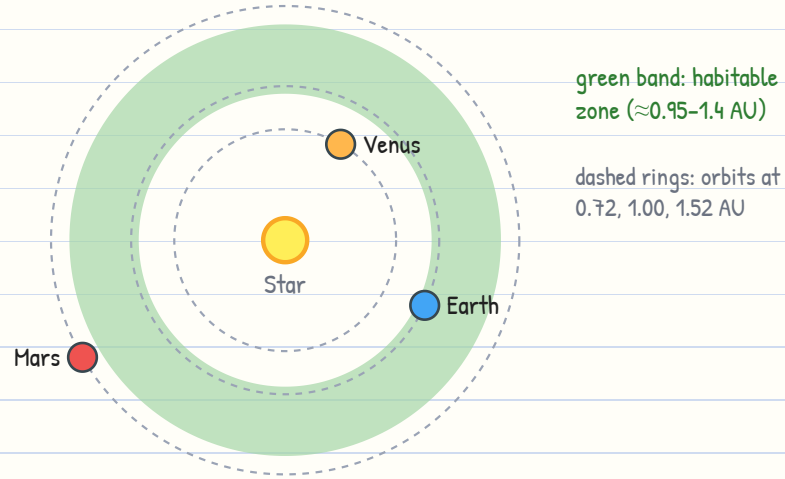
A1.1.7 Origin of water on Earth. The abundance of water over billions of years allowed life to evolve. For the exam, limit the origin of Earth's water to **asteroids**: water-rich asteroids that collided with the young Earth are thought to have delivered much of it. Earth **retained** its water for two reasons:

- **gravity**: Earth's mass is large enough to hold water vapour and other gases so they are not lost to space (smaller bodies lose them more easily);
- **temperature**: Earth cooled to below 100 °C at the surface, so water vapour **condensed** into liquid oceans rather than staying as vapour in the atmosphere.

Higher Level (HL) only

A1.1.8 The search for extraterrestrial life. Because life on Earth depends on liquid water, searches for life elsewhere look for liquid water first. The **Goldilocks zone** (habitable zone) is the range of distances

from a star where a planet's surface temperature allows liquid water: not so close that water boils away, and not so far that it freezes. Liquid water may also exist under an icy surface, so the zone is a guide, not a guarantee of life.



The Sun's habitable zone is roughly 0.95 to 1.4 AU (1 AU = the Earth–Sun distance). The exact limits depend on the model used.

Worked example 7: radiation received at different distances

The radiation a planet receives from its star is proportional to $1/d^2$, where d is the distance from the star. Compare the radiation received by Venus ($d = 0.72$ AU) and Mars ($d = 1.52$ AU) with Earth's ($d = 1.00$ AU).

Venus: $1/0.72^2 = 1/0.518 = 1.9$ times Earth's. Mars: $1/1.52^2 = 1/2.31 = 0.43$ times Earth's. Venus lies inside the hot edge and Mars near the cold edge of the zone, which fits their very different surfaces.

★ **Exam tip:** For "discuss" questions on extraterrestrial life: say why liquid water is needed (solvent, medium, stable temperature), what the Goldilocks zone is, and one limitation (a planet in the zone may still lack an atmosphere, or liquid water may exist outside the zone).

Common mistakes

Mistake	Correct idea
"Hydrogen bonds hold the hydrogen and oxygen together in a water molecule."	Those are covalent bonds. Hydrogen bonds act **between** molecules.
Confusing cohesion with adhesion	Cohesion: water to water. Adhesion: water to another surface (cell wall, glass).
"Water is polar because it has a charge."	Water is neutral overall; unequal sharing of electrons gives partial charges (δ+, δ−).
"Water boils at 100 °C because the covalent bonds are strong."	Boiling breaks hydrogen bonds between molecules, not the O–H bonds.
"Ice floats because it is colder."	Ice is less dense because hydrogen bonds hold molecules in an open lattice.

Saying oxygen "dissolves easily so no carrier is needed"	Oxygen is non-polar and poorly soluble in water, so many animals use haemoglobin.
Writing "the xylem is pushed up by root pressure" for tall trees	Water is pulled up under tension by transpiration, held together by cohesion.
Calling fats "hydrophilic"	Fats (triglycerides) are hydrophobic; their insolubility is useful for membranes and storage.

Investigation ideas (IA)

- How does tube diameter (independent variable) affect the capillary rise of water, or of different liquids? Use at least five diameters, repeat each three times, and test for an inverse relationship by plotting height against 1/diameter.
- How does the concentration of a detergent (or the temperature of water) affect the number of drops of water that can be held on a coin before it spills? Control the pipette, drop height and coin.
- How does an insulating layer (fat-like, fur-like) change the cooling rate of a warm water-filled bottle in water and in air? Record temperature every minute and compare the cooling rates.
- Does the surface of a leaf (waxy or not) change how many water drops it can hold? Count drops before run-off.

Design tips: state the independent, dependent and controlled variables; give the uncertainty of each instrument (for example ±0.5 mm for a ruler); repeat to give a mean and a measure of spread; draw a graph with error bars.

Nature of science

Hydrogen bonds cannot be seen directly; their existence is inferred from many observations (high boiling point, surface tension, the density of ice). A good model explains a wide range of observations with one simple idea.

15 multiple-choice questions

One mark each; no marks lost for a wrong answer. Questions 13 to 15 are HL only (SL students answer 1 to 12). Answers and explanations are on the next page.

1. Which feature of a water molecule is the direct cause of hydrogen bonding between water molecules?

   A Transfer of electrons from H to O to form ions
   B Unequal sharing of electrons within the molecule
   C A non-polar oxygen atom
   D Attraction between the two H atoms

2. Which statement about hydrogen bonds in liquid water is correct?

   A They are stronger than O–H covalent bonds
   B They join the two H atoms of one molecule
   C They are permanent below 100 °C
   D They are weak and constantly break and re-form

3. A pond skater can stand on the surface of a pond. Which property of water is mainly responsible?

   A Cohesion between water molecules, which produces surface tension
   B Adhesion of water to the insect's legs
   C The high specific heat capacity of water
   D The solvent properties of water

4. Water rises up a narrow glass tube above the level of the water outside it. This is mainly due to:

   A evaporation from the top of the tube
   B the low density of water
   C adhesion to the wall and cohesion between water molecules
   D hydrophobic interactions with glass

5. A dye front rises 24 cm up a stem in 8.0 minutes. What is the average rate of movement in m h^{-1}?

   A 0.18
   B 3.0
   C 18
   D 1.8

6. Which molecule is most likely to be hydrophobic and so insoluble in blood plasma?

A Glucose
B A triglyceride (fat)
C An amino acid
D A sodium ion

7. Which statement explains why sodium chloride dissolves in water?

A Water molecules are attracted to and surround the ions
B Water forms covalent bonds with the ions
C The ions are non-polar
D Hydrogen bonds join Na^+ to Cl^-

8. Compared with air, water has:

A higher density but lower viscosity and conductivity
B lower density but higher viscosity and conductivity
C higher density, viscosity and thermal conductivity
D higher density and viscosity but lower conductivity

9. How much energy is needed to raise the temperature of 200 g of water from 15 °C to 40 °C? (specific heat capacity of water = 4.18 J g^{-1} $°C^{-1}$)

A 5.0 kJ
B 20.9 kJ
C 83.6 J
D 20.9 J

10. A large lake warms and cools much more slowly than the land around it. The main property of water responsible is its:

A high viscosity
B lower density when frozen
C adhesion to surfaces
D high specific heat capacity

11. Which statement explains why ice floats on liquid water?

A Covalent bonds lengthen on freezing
B Ice molecules are lighter
C Hydrogen bonds hold the molecules in an open lattice, so ice is less dense
D Ice is colder than the water below

12. Why do mammals that live in cold water, such as the ringed seal, need a thick layer of blubber?

A Water conducts heat away from the body much faster than air
B Water has a lower specific heat capacity than air
C Water is less viscous than air
D Blubber makes the animal denser

13. HL: Which is the hypothesis, in the IB course, for how most of Earth's water arrived?

A Combustion of hydrogen with oxygen from photosynthesis
B Transport by the first living organisms
C Transfer from the Moon
D Delivery by water-rich asteroids

14. HL: Earth has kept its water for billions of years mainly because:

A the ozone layer stops evaporation
B gravity holds water vapour and temperatures let it condense
C Earth lies outside the habitable zone
D water is locked in rock

15. HL: A planet orbiting a Sun-like star receives 0.25 times the radiation that Earth receives. Its distance from the star, in AU, is:

A 0.50
B 4.0
C 2.0
D 0.25

Answers and explanations

1 B	2 D	3 A	4 C	5 D	6 B	7 A	8 C
9 B	10 D	11 C	12 A	13 D	14 B	15 C	

1. **B.** Oxygen attracts the shared electrons more strongly (polar covalent bonds), giving δ− on O and δ+ on H. The δ+ H of one molecule is attracted to the δ− O of another. Water molecules are not ionic.
2. **D.** Hydrogen bonds are weak (about 20 kJ mol^{-1} compared with about 460 kJ mol^{-1} for O–H) and exist between molecules; they break and re-form all the time in liquid water.

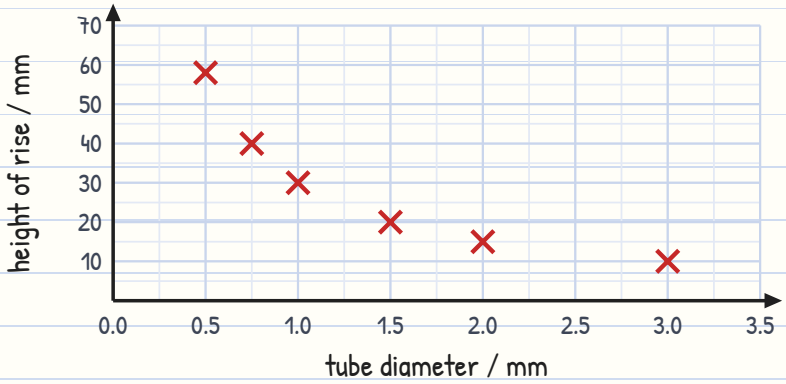
3. **A.** Surface molecules are pulled inwards and sideways by hydrogen bonds to other water molecules (cohesion), so the surface acts like a stretched skin that supports small insects.
4. **C.** Water adheres to the polar glass wall and pulls the rest of the water up by cohesion. This is capillary action. Glass is not hydrophobic and evaporation is not required.
5. **D.** 24 ÷ 8.0 = 3.0 cm min^{-1}. In one hour this is 3.0 × 60 = 180 cm = 1.8 m. The value 3.0 is the rate in cm min^{-1}; 0.18 and 18 are errors of a factor of ten in changing cm to m.
6. **B.** Triglycerides are made mostly of non-polar hydrocarbon chains, so they do not attract water. Glucose, amino acids (polar or charged groups) and ions are hydrophilic.
7. **A.** The δ− oxygen ends of water cluster round Na^+ and the δ+ hydrogen ends round Cl^-, which separates the ions from the crystal and keeps them dispersed.
8. **C.** Water is about 830 times denser, about 55 times more viscous and about 23 times more thermally conductive than air. The other combinations each contain at least one false comparison.
9. **B.** $E = m\,c\,\Delta T = 200 \times 4.18 \times 25 = 20\,900$ J = 20.9 kJ. Leaving out the specific heat capacity gives 5.0 kJ; 83.6 J (4.18 × 20) and 20.9 J (wrong unit) are not correct.
10. **D.** A large amount of energy is needed to change the temperature of water because energy is used to disrupt hydrogen bonds. This is a high specific heat capacity.
11. **C.** In ice each molecule is held by hydrogen bonds at fixed distances in an open lattice, so the same number of molecules occupies a larger volume (ice about 0.92 g cm^{-3}). The molecules themselves are identical.
12. **A.** The thermal conductivity of water is about 23 times that of air, so an uninsulated animal loses heat quickly. Blubber is an insulating layer. Water has a higher (not lower) specific heat capacity than air.
13. **D.** The guide limits the origin of Earth's water to asteroids. The other ideas have no such support (water was present before photosynthesis and life).
14. **B.** Earth's gravity prevents water vapour escaping to space, and temperatures are low enough for water vapour to condense to liquid. Earth lies inside, not outside, the habitable zone.
15. **C.** Radiation is proportional to $1/d^2$, so $0.25 = 1/d^2$, $d^2 = 4.0$ and d = 2.0 AU. A distance of 0.50 AU would give 4.0 times Earth's radiation.

Structured questions

Question 1 (8 marks) data-based, Paper 1B style

A student measured how high water rose in clean glass capillary tubes of different internal diameter at 20 °C. Each height is the mean of three readings (±1 mm).

Diameter / mm	0.50	0.75	1.0	1.5	2.0	3.0
Height of rise / mm	58	40	30	20	15	10



(a) Describe the relationship between tube diameter and height of rise. [2]

(b) Calculate the value of (height × diameter) for the 0.50 mm and 2.0 mm tubes and state what this suggests about the relationship. [3]

(c) Predict the height of rise in a tube of diameter 4.0 mm. [1]

(d) Explain, with reference to adhesion and cohesion, why water rises in a glass tube. [2]

Mark scheme

- (a) as the diameter increases the height decreases 1; the decrease is steep at small diameters and levels off at large diameters (a curve, not a straight line) 1
- (b) $0.50 \times 58 = 29$ 1; $2.0 \times 15 = 30$ 1; the product is (almost) constant, so height is inversely proportional to diameter 1
- (c) $30 \div 4.0 = 7.5$ mm (accept 7 to 8 mm) 1
- (d) water adheres to the (polar) glass wall, pulling the water at the edge upwards 1; cohesion between water molecules (hydrogen bonds) pulls the rest of the water up with it 1

Question 2 (8 marks)

Water has properties that make it suitable as the medium for life.

(a) Draw two water molecules and the hydrogen bond between them, showing partial charges. [3]

(b) Explain how cohesion allows water to be transported to the top of a tall tree. [3]

(c) Distinguish between hydrophilic and hydrophobic substances, giving one biological example of each. [2]

Mark scheme

- (a) bent molecule with O and two H, bonds shown 1; δ− on oxygen and δ+ on hydrogens 1; dotted line (hydrogen bond) from the H of one molecule to the O of the other 1
- (b) transpiration/evaporation from leaves pulls water upwards, creating tension in the xylem 1; hydrogen bonds between water molecules (cohesion) keep the water in a continuous column 1; so

the water is pulled up the xylem without the column breaking (adhesion to the xylem wall also helps support it) 1

- (c) hydrophilic substances are polar/charged and dissolve in water; hydrophobic substances are non-polar and do not dissolve 1; one example of each, such as glucose or sodium ions (hydrophilic) and fat or phospholipid tails (hydrophobic) 1

Question 3 (9 marks)

The table gives approximate values for water and air at 20 °C.

	Water	Air
Thermal conductivity / W m^{-1} K^{-1}	0.60	0.026
Density / kg m^{-3}	1000	1.2

(a) Calculate how many times greater the thermal conductivity of water is than that of air. [2]

(b) Using your answer to (a), explain why a ringed seal (*Pusa hispida*) has a thick layer of blubber. [2]

(c) Outline how the density of water affects a diving bird such as the black-throated loon (*Gavia arctica*). [1]

HL (d) State two reasons why Earth has kept its water for billions of years. [2]

HL (e) A planet orbits a star like the Sun at a distance of 1.6 AU. Calculate the radiation it receives as a fraction of that received by Earth (1.0 AU). [2]

Mark scheme

- (a) $0.60 \div 0.026$ 1; $= 23$ times 1 (23.1)
- (b) water conducts heat away from the body about 23 times faster than air 1; blubber is a poor conductor (insulator), so it reduces heat loss and keeps the body warm 1
- (c) water is much denser than air so it gives a large buoyancy force, which the bird must overcome to dive (denser bones/less air help); or drag is greater, so a streamlined body is needed 1
- (d) gravity is strong enough to retain water vapour/prevent loss to space 1; temperatures are low enough for water vapour to condense to liquid 1
- (e) radiation $\propto 1/d^2$, so $1/1.6^2$ 1; $= 0.39$ (0.391) 1

Quick reference

Water properties

polar covalent bonds → δ+ H, δ− O

hydrogen bonds between molecules → **cohesion** (surface tension, xylem), **adhesion** (capillarity), solvent action, high specific heat capacity, ice less dense

$E = m\,c\,\Delta T$ ($c = 4.18$ J g^{-1}K^{-1})

Water vs air

water is denser (buoyancy), more viscous (drag), conducts heat better (insulation needed), changes temperature slowly

HL: water from asteroids; kept by gravity and condensation; Goldilocks zone ≈ 0.95 to 1.4 AU; radiation $\propto 1/d^2$

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"I can" checklist

- ☐ I can explain polarity and draw hydrogen bonds between water molecules.
- ☐ I can link cohesion and adhesion to xylem transport, surface tension and capillary action.
- ☐ I can explain why water is a good solvent and tell hydrophilic from hydrophobic substances.
- ☐ I can compare water and air as habitats using buoyancy, viscosity, conductivity and specific heat capacity.
- ☐ HL: I can state how Earth's water arrived and was kept, and explain the Goldilocks zone.