AP BIOLOGY · UNIT 1 · TOPIC 1.1

Structure and Properties of Water

Learning objective 1.1.A Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.

Name: Date: Period:

Use the tool **Two Facts About a Bent Molecule**. Part 1 uses **One molecule**, Part 2 uses **Turn up the heat**, and Parts 3, 4 and 5 use **What follows from it**. Nearly every property of water traces back to two facts about one molecule: oxygen pulls harder on shared electrons than hydrogen does, and the molecule is **bent** rather than straight. At each step, trace the property back to those two facts.

Part 1 · The two facts

Use the three buttons on the first tab. Record the values from the readout in the table.

Quantity	Value	What it tells you
Electronegativity of oxygen		
Electronegativity of hydrogen		
Difference		
Bond angle		

1. Using the electronegativity values and the bond angle in the table, explain why a water molecule is polar.

2. Each C=O bond in carbon dioxide is polar, yet the carbon dioxide molecule has no net dipole.
(a) Explain how a molecule with polar bonds can be nonpolar.

(b) Identify the property, other than bond polarity, that determines whether a molecule is polar.

3. (a) Describe a hydrogen bond between two water molecules.

(b) Explain how a hydrogen bond differs from the covalent bonds within a water molecule.

Part 2 · What heating actually does

Go to **Turn up the heat**. A water molecule can hydrogen bond to **4** neighbors: two through its hydrogens and two through its lone pairs. At each temperature, record the four values the tool reports: the thermal energy RT, the bonds per molecule, the predicted count and the fraction intact.

Temperature	Thermal energy RT	Bonds per molecule	Predicted	Fraction intact
0 °C				
25 °C				
37 °C				
50 °C				
75 °C				
99 °C				

4. Describe the effect of heating water from 0 °C to 99 °C on the number of hydrogen bonds per molecule.

5. Based on the Part 2 table, most hydrogen bonds in water are still intact at 99 °C. Explain what happens to a water molecule as water boils.

6. The Bonds per molecule column comes from a simulation, and the Predicted column comes from a separate calculation that was never given the simulation's results. Explain why the agreement between the two columns supports the model.

Part 3 · Specific heat and evaporative cooling

Open the panels headed **Specific heat, worked through** and **Evaporative cooling, worked through**. Both start from the same idea: energy put into water goes into breaking hydrogen bonds before it goes anywhere else.

Substance	Specific heat (J/g/°C)	Rise on 41,800 J into 1 kg
Water, H_2O		
Methane, CH_4		
Ammonia, NH_3		
Hydrogen sulfide, H_2S		

7. (a) Explain why water has a high specific heat.

(b) Describe one biological consequence of water's high specific heat.

8. Using a value from the evaporative cooling panel, explain why sweating cools an animal effectively.

Part 4 · Ice, and why it is strange

Open **Why ice floats, and why that is surprising**. Almost every other substance contracts when it freezes. Record the two densities and the two bond counts before you explain the difference.

State at 0 °C	Density (g/cm³)	Hydrogen bonds per molecule	Molecules packed closer or further apart?
Liquid water			
Ice			

9. At 0 °C, ice has more hydrogen bonds per molecule than liquid water. Explain why ice is nonetheless less dense than liquid water.

10. Explain how ice floating on a lake affects the organisms living in the lake during winter.

Part 5 · Everything else follows

Go to **What follows from it** and step through the seven properties. For each, record how hydrogen bonding causes it and one biological consequence. Notice that the cause is the same for all seven.

Property	Why hydrogen bonding causes it	One biological consequence
Cohesion		
Adhesion		
Surface tension		
High specific heat		
High heat of vaporization		
Ice floats		
Solvent for polar substances		

11. Explain how cohesion and adhesion together let a tree move water from its roots to its leaves.

12. Hydrogen sulfide (H_2S) has nearly twice the molecular mass of water, yet it boils at −60 °C, while water boils at 100 °C.
(a) Explain why molecular mass cannot account for the high boiling point of water.

(b) Identify the property of water that does account for its high boiling point.

13. Explain why water dissolves salt but not oil.

What the model simplifies

A water molecule is treated as having exactly four possible hydrogen bonds, each independently intact or broken at any instant. Real liquid water has a continuous distribution of geometries, and whether a given pair counts as bonded depends on where the line is drawn, which is why published bond counts differ between studies.

The thermal model's two parameters (the enthalpy and entropy of breaking one bond inside the liquid) are calibrated to measured bond counts near 0 °C and 100 °C rather than derived from first principles. The familiar figure of about 20 kJ/mol is the energy of an isolated hydrogen bond between two molecules in the gas phase; inside the liquid a molecule that loses a bond reorients and partly bonds elsewhere, so the effective cost is several times smaller. Building the tool with the gas-phase number produced a model in which every bond stayed intact at every temperature.

Boiling itself is not modeled, and the bond count is shown only up to 99 °C. Beyond that the liquid is no longer the thing being described, and a model that switches everything off at exactly 100 °C teaches the wrong lesson about what boiling is.

The specific-heat panel splits added energy between breaking bonds and increasing molecular motion in a fixed proportion, which is illustrative rather than measured. The direction is right and the exact split is not.

Boiling points, specific heats, densities, electronegativities and the heat of vaporization are measured constants from standard references, not outputs of the model; every calculation built on them is shown in full so it can be checked.