A1.1 Water

Unity and diversity—Molecules

Standard level and higher level: 2 hours

Additional higher level: 1 hour

Guiding questions

• What physical and chemical properties of water make it essential for life?

• What are the challenges and opportunities of water as a habitat?

SL and HL

A1.1.1—Water as the medium for life
Students should appreciate that the first cells originated in water and that water remains the medium in which most processes of life occur.
• The first cells originated in ocean water • The chemical processes that sustain life thus evolved in **aqueous** media (i.e. with water as a solvent), so modern cells still depend on water as the medium in which most life processes occur

A1.1.2—Hydrogen bonds as a consequence of the polar covalent bonds within water molecules
Students should understand that polarity of covalent bonding within water molecules is due to unequal sharing of electrons and that hydrogen bonding due to this polarity occurs between water molecules. Students should be able to represent two or more water molecules and hydrogen bonds between them with the notation shown below to indicate polarity.

• The molecular structure of water explains the properties that make it a suitable medium for life
• **Intramolecular attractions** occur between atoms & can be covalent, ionic, or metallic
• Covalent bonds occur when two atoms equally or unequally share their electrons
  • **Non-polar covalent bonds** involve equal sharing of electrons
  • **Polar covalent bonds** involve unequal sharing of electrons
  • This occurs when an atom in a covalent bond pulls electrons more strongly towards it than the other atom
  • The atom stronger at pulling electrons has a higher electron density, so it obtains a **partial negative charge ($\delta -$)** whereas the atom with lower electron density has a **partial positive charge** ($\delta +$)
• **Intermolecular attractions** occur between particles (molecules or ions)
  • They occur between particles that have fully or partially charged atoms, causing oppositely charged atoms on nearby particles to attract each other
  • They are weaker than covalent bonds but their effect on the physical properties of substances becomes significant (non-negligible) when millions of them are occurring at the same time
  • **Hydrogen bonds** are a specific type of intermolecular attraction that occurs between a δ+ hydrogen in one molecule & a δ– oxygen or δ– nitrogen in a different molecule
  • In water, the oxygen atom strongly pulls electrons away from hydrogen, resulting in a **particularly strong** polar covalent bond with a strong δ– on oxygen & strong δ+ on hydrogen
  • The strong O–H polar covalent bond results in strong intermolecular attractions between water molecules (i.e. hydrogen bonds)

A1.1.3—Cohesion of water molecules due to hydrogen bonding and consequences for organisms

Include transport of water under tension in xylem and the use of water surfaces as habitats due to the effect known as surface tension.

- **Cohesion** occurs when molecules of the same kind attract each other by intermolecular forces
- Water exemplifies strong cohesion due to hydrogen bonding, which has consequences for organisms
- **Surface tension** is the tendency of a liquid's surface to resist rupture against an external force
  - Water molecules at the surface of liquid water form hydrogen bonds with each other
  - Since they have fewer neighboring water molecules to hydrogen bond with (because they are exposed to air on one side), they will form stronger hydrogen bonds with nearby water molecules
  - The resultant surface tension allows water to support the movement of some organisms on its surface like basilisk lizards & water striders
- Transpiration transports water up xylem vessels under tension (negative pressure)
  - The water stream moving upwards is **c**ontinuous due to **c**ohesion between water molecules (it does not break under tension)

A1.1.4—Adhesion of water to materials that are polar or charged and impacts for organisms

Include capillary action in soil and in plant cell walls.

- **Adhesion** occurs when molecules of a different kind attract each other by intermolecular forces
- Water exemplifies adhesion due to hydrogen bonding, which impacts capillary action
  - **Capillary action** is the movement of fluid through narrow or porous spaces against gravity
- Water molecules are attracted to the polar inner walls of xylem vessels, so they adhere (stick) to these narrow walls during transpiration
  - This prevents the water column from slipping downwards when the rate of transpiration decreases at night (when stomata are closed)
- Soil is porous because it contains charged particles within many narrow gaps
  - Water is attracted to these charged particles which helps it stick to the soil against the pull of gravity, creating soil moisture for plant root access

A1.1.5—Solvent properties of water linked to its role as a medium for metabolism and for transport in plants and animals

Emphasize that a wide variety of hydrophilic molecules dissolve in water and that most enzymes catalyse reactions in aqueous solution. Students should also understand that the functions of some molecules in cells depend on them being hydrophobic and insoluble.

- **Hydrophilic** molecules are polar and dissolve in water because they can form intermolecular attractions with water molecules
- **Hydrophobic** molecules are non-polar and do not dissolve in water because they cannot form intermolecular attractions with it (but they can dissolve in other hydrophobic substances)
- Most biomolecules (enzymes, sugars, DNA) are hydrophilic so they can readily dissolve in water
  - Thus, water is an effective medium (solvent) for metabolism & transport (blood & phloem)
- The functions of some molecules in cells depend on them being hydrophobic & insoluble, like the plasma membrane in cells, steroid hormones in animals, or waxy cuticle in plants (reduces water loss)

A1.1.6—Physical properties of water and the consequences for animals in aquatic habitats

Include buoyancy, viscosity, thermal conductivity and specific heat capacity. Contrast the physical properties of water with those of air and illustrate the consequences using examples of animals that live in water and in air or on land, such as the black-throated loon (*Gavia arctica*) and the ringed seal (*Pusa hispida*).

Note: When students are referring to an organism in an examination, either the common name or the scientific name is acceptable.

Property	Water	Air
Buoyancy is the net upward force on any object in any fluid (liquid or gas).	In water, buoyancy significantly offsets weight, letting organisms float more easily.	In air, buoyancy is negligible so organisms need to generate lift (i.e. by wings) to stay aloft.
Viscosity is the resistance of a substance to flow.	Organisms moving through water experience more resistance than in air since water is more viscous.	Organisms moving through air experience less drag than through water since air is less viscous.
Thermal conductivity is the ability of a substance to conduct heat.	Water has a higher thermal conductivity.	Air has a lower thermal conductivity compared to water.
Specific heat capacity is the amount of energy required to raise the temperature of 1 unit of mass by 1 K / °C.	Water has a higher specific heat capacity compared to air.	Air has a lower specific heat capacity compared to water.

- Hydrogen bonding affects the physical properties of water, which has consequences for aquatic animals
- **Black throated loon**:
  - The bird relies on water **buoyancy** to stay afloat at the surface
  - The bird's **webbed feet** and **streamlined body** helps it overcome water's viscosity
  - The bird has **oil glands** that reduce the amount of heat lost by **conduction** to water
  - The temperature of the water remains relatively stable when the air is cool due to its high specific heat capacity, which enables the bird to continue living within its **range of tolerance**
- **Ringed seal**:
  - The seal is **buoyant** enough to keep its snout above water in order to breathe air
  - The seal's **paddle-like feet** and **streamlined body** help it overcome water's viscosity
  - The seal has **thick blubber** (fatty layer) which reduces heat lost to the water
  - The relative stability of water temperature due to its high specific heat capacity enables the seal to continue living within its **range of tolerance**

Additional higher level

A1.1.7—Extraplanetary origin of water on Earth and reasons for its retention
The abundance of water over billions of years of Earth's history has allowed life to evolve. Limit hypotheses for the origin of water on Earth to asteroids and reasons for retention to gravity and temperatures low enough to condense water.

- It is unlikely that water was present when Earth was formed as a planet because temperatures were very high (above water's boiling point) so it would have evaporated & been lost to space
  - This suggests an extraplanetary origin of water on Earth
- The **asteroid theory** is one hypothesis for the origins of water on Earth
  - It posits that asteroids delivered water to Earth by collisions millions of years ago
- Water delivered by asteroids was retained on Earth for 2 reasons:
  - The **strong gravitational field** of Earth prevents most of the water from escaping into space
  - **Temperatures** on Earth allow water to be condensed to a liquid, which due to hydrogen bonding is much easier to retain than water vapor inside Earth's atmosphere
- Other theories about the extraplanetary origin of water exist

A1.1.8—Relationship between the search for extraterrestrial life and the presence of water
Include the idea of the "Goldilocks zone".

- **Goldilocks zone** is the region around a star (e.g. sun) where a planet's surface temperature allows for liquid water to exist on its surface
- Since water is the universal medium for life, it is intuitive to search for extraterrestrial life where liquid water can exist

Linking questions

• How do the various intermolecular forces of attraction affect biological systems?

• What biological processes only happen at or near surfaces?

References

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