A1.1 Water

Unity and diversity—Molecules

Standard level and higher level: 2 hours

Additional higher level: 1 hour

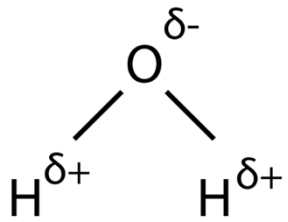
Guiding questions

• 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.
Many chemical reactions occur in solutions, like **aqueous solutions** where water is the **solvent** (liquid that dissolves **solutes**). Water is the primary solvent in the human body where most reactions that help sustain life occur. The first cells originated in water, which enabled the formation of the phospholipid bilayer and the creation of an internal compartment for many controlled biochemical reactions.

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.
Covalent bonds can involve equal or non-equal sharing of electrons. • Equal sharing of electrons results in **non-polar covalent bonds** (net charge = 0). • Unequal sharing of electrons results in **polar covalent bonds**. This occurs when an atom in a covalent bond pulls electrons more strongly towards it than the other atom, resulting in a **partial negative charge** ($\delta -$) for the atom with higher electron density and a **partial positive charge** ($\delta +$) for the atom with lower electron density. • Polar covalent bonds within a molecule result in different charges at various locations within the molecule, which affects its physical and chemical properties. When polar molecules interact, their opposite charges **ephemerally attract**. Even though all **intermolecular interactions** are much weaker than covalent bonds, they become significant when millions of them are occurring at the same time. • **Hydrogen bonds** are a specific type of intermolecular attractions that occur when hydrogen is covalently bonded to an oxygen or nitrogen atom. The atoms within this polar covalent bond become partially charged, which attracts oppositely charged atoms in other molecules, forming hydrogen bonds. Hydrogen bonding is the strongest intermolecular force. 

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 type attract each other by intermolecular forces. Cohesion of water molecules due to hydrogen bonding has important 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 form hydrogen bonds with each other, and since they have fewer neighboring water molecules to bond with (because they are exposed to air on one side), they will form stronger bonds with neighboring water molecules. The resultant surface tension allows it to support the movement of some organisms on its surface like basilisk lizards and water striders.
- The area in which water evaporates from leaves (during transpiration) creates a low-pressure point that draws water up **xylem vessels** from higher-pressure points. The water stream moving upwards is **c**ontinuous within the xylem due to **c**ohesion between water molecules.

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 type attract each other by intermolecular forces. Adhesion of water molecules due to hydrogen bonding has important consequences for organisms:

- Water molecules are attracted to the polar molecules that make up the inner walls of xylem vessels. During transpiration, adhesive forces help prevent the water column that is being pulled upwards from breaking under tension by 'sticking' to the xylem walls.
- Soil is porous, which enables water to move against gravity (upwards) by adhering to charged soil particles. This helps plants access water in the soil through their roots.

Both cohesion and adhesion forces work together to move water up xylem and soil under the **cohesion-tension theory**.

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** (polar) molecules are polar and dissolve in water because they can form **polar associations** (intermolecular attractions) with it.
- **Hydrophobic** (non-polar) molecules are non-polar and do not dissolve in water because they cannot form intermolecular attractions with it. However, they can dissolve in other hydrophobic substances.

The hydrophilicity of most compounds (enzymes, sugars, nucleic acids) makes water an excellent medium for metabolic reactions that occur in the cytoplasm and internal compartments of membrane-bound organelles. Water's polarity also allows it to transport hydrophilic compounds in plants (xylem) and animals (blood).

The hydrophobicity of some compounds enables them to also carry out important life functions. In humans, steroid hormones and non-polar proteins are able to pass through the hydrophobic cell membrane in order to execute their roles. In plants, the **cuticle** (waxy non-polar layer on leaf surface) reduces transpiration to prevent dehydration.

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.

Hydrogen bonding has significant consequences for the physical properties of water.

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 through 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.

- **Black throated loon**:
  - The bird relies on water buoyancy to stay afloat at the surface
  - The bird's webbed feet and efficient streamlined body helps it overcome water's viscosity
  - The bird produces oil from a gland that reduces 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 respire air
  - The seal's paddle-like feet and streamlined body help it swim through the viscosity of water
  - 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.
Hydrogen is an atom with 1 proton and 1 electron. **Deuterium** (a hydrogen **isotope**) is an atom with 1 proton, **1 neutron**, and 1 electron. H_2O may contain any of these two isotopes. Scientists measured the ratio of the two isotopes in oceanic water and compared it to that in asteroids. This led to the **asteroid theory** for the existence of water on Earth, which posits that asteroids containing hydrated material hit earth millions of years ago, which introduced water to Earth. Water was retained due to: • The **strong gravitational field** of Earth, which prevents most of the water from escaping into space. • **Low temperatures** that allow water to be condensed to a liquid, which due to hydrogen bonding is much easier to retain than water vapor inside the Earth's atmosphere. Other non-mutually exclusive theories for the origins of water on Earth 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 (like the sun) where a planet's surface temperature could allow for liquid water to exist on its surface. Since water is the universal medium for life, it is intuitive to search for extraterrestrial life in such zones 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?

Review questions

SL and HL

- Define polarity. [1]
- Describe the nature of hydrogen bonding. [2]
- Distinguish between covalent and hydrogen bonding. [2]
- Explain the consequences of cohesion on living organisms. [4]
- Draw **two** water molecules experiencing hydrogen bonding. [4]
- Explain the consequences of adhesion on living organisms. [4]
- Compare the physical properties of water and air. [4]
- Explain the adaptations **two** organisms have to the physical properties of water. [8]
- Describe the chemical and physical properties of water that arise due to hydrogen bonding. [8]
- Discuss the challenges and opportunities of water as a habitat. [8]

Additional Higher Level

- Define the Goldilocks zone. [1]
- Outline why water was retained on Earth. [2]
- Explain why the search for extraterrestrial life is linked to the presence of water. [2]
- Outline the extraplanetary origin of water on Earth. [3]

References

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