Water and its Properties
• Why should we study water in Biology?
• Living things are made of 70-90% water.
• Water is essential for all organisms.
• Most abundant substance
• Essential for all forms of life
• H and O linked by covalent bonds \( \text{H}_2\text{O} \)
• Each water molecule is linked to others
• All the major components in cells (proteins, DNA, RNA and polysaccharides) can dissolve in water
• It solubilizes and modifies the properties of biomolecules
• Water molecule is not linear and the oxygen atom has a higher electronegativity than hydrogen atoms, it carries a slight negative charge, while the hydrogen atoms are slightly positive.
• As a result, water is a polar molecule with an electrical dipole moment.
Bent structure

The water molecule has tetrahedral
Structure of Ice.
Hydrogen bonds (shown as dashed lines) are formed between water molecules.
States of water: Due to the formation of hydrogen bonds

- Water exists in all three states of matter:
  - Solid——ice
  - Liquid
  - Gas——water vapours
Two very important properties of water

1. Water is a polar molecule. *The water molecule is bent, not linear, and so the distribution of charge is asymmetric.*
   - *The* oxygen nucleus draws electrons away from the hydrogen nuclei, which leaves the region around the hydrogen nuclei with a net positive charge.
   - The water molecule is thus an electrically polar structure.

2. Water is highly cohesive. *Water molecules interact strongly with one another through hydrogen bonds.*
   - *These* interactions are apparent in the structure of ice.
   - Networks of hydrogen bonds hold the structure together;
   - similar interactions link molecules in liquid water and account for the cohesion of liquid water, although, in the liquid state, some of the hydrogen bonds are broken.
   - The highly cohesive nature of water dramatically affects the interactions between molecules in aqueous solution.
The polarity and hydrogen-bonding capability of water make it a highly interacting molecule.

Water is an excellent solvent for polar molecules.

The reason is that water greatly weakens electrostatic forces and hydrogen bonding between polar molecules by competing for their attractions.

For example, consider the effect of water on hydrogen bonding between a carbonyl group and the NH group of an amide.
- A hydrogen atom of water can replace the amide hydrogen atom as a hydrogen-bond donor, whereas the oxygen atom of water can replace the carbonyl oxygen atom as a hydrogen-bond acceptor.
- A strong hydrogen bond between a CO group and an NH group forms only if water is excluded.

- The existence of life on Earth depends critically on the capacity of water to dissolve a remarkable array of polar molecules that serve as fuels, building blocks, catalysts, and information carriers.
- High concentrations of these polar molecules can coexist in water, where they are free to diffuse and interact with one another.
HYDROGEN BONDS in water

• Hold water molecules together
• Each water molecule can form a maximum of 4 hydrogen bonds
• The hydrogen bonds joining water molecules are weak, about 1/20th as strong as covalent bonds.
• They form, break, and reform with great frequency

• Extraordinary Properties that are a result of hydrogen bonds.
  – Cohesive behavior
  – Resists changes in temperature
  – High heat of vaporization
  – High boiling point
  – Expands when it freezes
  – solvent property
  – High surface tension
• Many properties of water are emergent properties due to hydrogen bonding.

• The cohesion of water molecules to each other is exploited by plants and animals.

• Water resists temperature changes by absorbing lots of heat.

• Lower density of ice causes it to float & insulate the water below.

• The polarity of water allows it to dissolve other polar molecules.

• Non-polar compounds are hydrophobic and not easily dissolved in water.
Chemistry of WATER

1. **High heat capacity**: Water heats up & cools down slower than most liquids. Holds heat longer than most. This buffers the amount of evaporating and freezing that go on in the environment.

2. **High heat of vaporization**: Evaporation requires a lot of energy. Sweating helps to reduce body heat. Body heat is used as energy to evaporate water. Body loses heat, water gains it and evaporates.

3. **Solvent properties**: Molecules dissolve in water, which allows them to move around more and interact. Water facilitates all chemical reactions in the body.
Chemistry of WATER

4. **Cohesive & adhesive nature**: Water molecules move freely, but stick together (hydrogen bonds). Great for transporting nutrients in plants, and circulation in animals.

5. **High surface tension**: This is another effect of hydrogen bonds.

6. **Solid is less dense than liquid**: Ice floats! Bodies of water freeze from the top down.
Forms of Attraction

- FORMS OF ATTRACTION

- **Cohesion**
  - Attraction between molecules of the same substance

- **Adhesion**
  - Attraction between molecules of different substances
Cohesion

- Attraction between particles of the same substance results in Surface tension (a measure of the strength of water’s surface)
- Produces a surface film on water that allows insects to walk on the surface of water
Properties of Liquids

*Surface tension* is the amount of energy required to stretch or increase the surface of a liquid by a unit area.

![Diagram of liquid molecules showing strong intermolecular forces and high surface tension.](image)

- **Strong intermolecular forces**
- **High surface tension**
Surface tension
Surface tension, a measure of the force necessary to stretch or break the surface of a liquid, is related to cohesion.

- Water has a greater surface tension than most other liquids because hydrogen bonds among surface water molecules resist stretching or breaking the surface.

- Water behaves as if covered by an invisible film.

- Some animals can stand, walk, or run on water without breaking the surface.
Adhesion

- Attraction between two different substances.
- Water will make hydrogen bonds with other surfaces such as glass, soil, plant tissues, and cotton.
- Capillary action—water molecules will “tow” each other along in a thin glass tube.
- Example: transpiration process which plants and trees remove water from the soil, and paper towels soak up water.
Adhesion Causes Capillary Action

Which gives water the ability to “climb” structures
Capillary action of water compared to mercury
Organisms Depend on Cohesion

Hydrogen bonds hold the substance together, a phenomenon called cohesion

• Cohesion is responsible for the transport of the water column in plants
• Cohesion among water molecules plays a key role in the transport of water against gravity in plants
• Adhesion, clinging of one substance to another, contributes too, as water adheres to the wall of the vessels.
Properties of Water

Because water has both adhesive and cohesive properties, capillary action is present.

Capillary action is one of the major reasons that trees and other plants can grow very tall.
Water has a high heat capacity

- In order to raise the temperature of water, the average molecular speed has to increase.
- It takes much more energy to raise the temperature of water compared to other solvents because hydrogen bonds hold the water molecules together!
High Specific Heat

- Amount of heat needed to raise or lower 1g of a substance 1° C.

- Water resists temperature change, both for heating and cooling.

- Water can absorb or release large amounts of heat energy with little change in actual temperature.
Three-fourths of the earth is covered by water. The water serves as a large heat sink responsible for:

1. Prevention of temperature fluctuations that are outside the range suitable for life.
2. Coastal areas having a mild climate
3. A stable marine environment

Specific Heat is the amount of heat that must be absorbed or lost for one gram of a substance to change its temperature by 1°C.
Moderates Temperatures on Earth

Water stabilizes air temperatures by absorbing heat from warmer air and releasing heat to cooler air. Water can absorb or release relatively large amounts of heat with only a slight change in its own temperature.

<table>
<thead>
<tr>
<th>Celsius Scale at Sea Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°C</td>
</tr>
<tr>
<td>37°C</td>
</tr>
<tr>
<td>23°C</td>
</tr>
<tr>
<td>0°C</td>
</tr>
</tbody>
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High Heat of Vaporization

- Amount of energy to convert 1g or a substance from a liquid to a gas

- In order for water to evaporate, hydrogen bonds must be broken.

- As water evaporates, it removes a lot of heat with it.
High Heat of Vaporization

• Water's heat of vaporization is 540 cal/g.
• In order for water to evaporate, each gram must GAIN 540 calories (temperature doesn’t change --- 100°C).
• As water evaporates, it removes a lot of heat with it (cooling effect).
Evaporative Cooling

- The cooling of a surface occurs when the liquid evaporates

- This is responsible for:
  - Moderating earth’s climate
  - Stabilizes temperature in aquatic ecosystems
  - Preventing organisms from overheating
Water vapor forms a kind of global “blanket” which helps to keep the Earth warm.

Heat radiated from the sun warmed surface of the earth is absorbed and held by the vapor.
Density of Water

• Most dense at 4°C
• Contracts until 4°C
• Expands from 4°C to 0°C

The density of water:

1. Prevents water from freezing from the bottom up.

2. Ice forms on the surface first—the freezing of the water releases heat to the water below creating insulation.

3. Makes transition between season less abrupt.
Water is Less Dense as a Solid

• Ice is less dense as a solid than as a liquid (ice floats)
• Liquid water has hydrogen bonds that are constantly being broken and reformed.
• Frozen water forms a crystal-like lattice whereby molecules are set at fixed distances.
When water reaches 0°C, water becomes locked into a crystalline lattice with each molecule bonded to the maximum of four partners.

As ice starts to melt, some of the hydrogen bonds break and some water molecules can slip closer together than they can while in the ice state.

Ice is about 10% less dense than water at 4°C.
3-D Structure of Ice

Water is a Unique Substance

Maximum Density 4°C

Density of Water

Ice is less dense than water

Density (g/mL) vs. Temperature (°C)
Water is Less Dense as a Solid

Water

Ice
Ice floats on water as it is lighter (less dense)
Water as a solvent

- Water is a good solvent and is often referred to as *the universal solvent*.
- Substances that dissolve in water, e.g., salts, sugars, acids, alkalis, and some gases – especially oxygen, carbon dioxide (carbonation) are known as *hydrophilic* (water-loving) substances,
- Substances that do not mix well with water (e.g., fats and oils), are known as *hydrophobic* (water-fearing) substances.
Polarity of Water

• In a water molecule two hydrogen atoms form single polar covalent bonds with an oxygen atom. Gives water more structure than other liquids
  – Because oxygen is more electronegative, the region around oxygen has a partial negative charge.
  – The region near the two hydrogen atoms has a partial positive charge.

• A water molecule is a polar molecule with opposite ends of the molecule with opposite charges.
Chemical Principles

Properties of Water

Water

Water is the solvent of Life!

**Solute** – substance dissolved in a solvent to form a solution

**Solvent** – fluid that dissolves solutes
Solvent for Life

• Solution
  – Solute
  – solvent

• Aqueous solution

• Hydrophilic
  – Ionic compounds dissolve in water
  – Polar molecules (generally) are water soluble

• Hydrophobic
  – Nonpolar compounds
Solution
Weak interactions are the key means by which molecules interact with one another e.g. enzymes with their substrates, hormones with their receptors, antibodies with their antigens.

- The strength and specificity of weak interactions are highly dependent on the medium in which they take place, and the majority of biological interactions take place in water.
Importance of hydrogen Bonds in water

- **Hydrogen bonds** between water molecules contributes to water's **high boiling point**.
- Water molecules actually repel each other at freezing; this means that **frozen water is less dense than liquid water**.
- The hydrogen bonds can absorb and hold on to energy; this makes water a good temperature buffer (i.e.: water changes temperature slowly).
- The polar nature of water molecules contributes to water's **excellent solvent properties**
- Water can ionize to form hydrogen (+) ions and hydroxyl (-) ions. The concentration of these ions determines the pH of water or other solutions

\[
\text{H}_2\text{O} \quad \longleftrightarrow \quad \text{H}^+ + \text{OH}^-
\]
Homeostasis

• Ability to maintain a steady state despite changing conditions

• Water is important to this process because:
  a. Makes a good insulator
  b. Resists temperature change
  c. Universal solvent
  d. Coolant
  e. Ice protects against temperature extremes (insulates frozen