Overview: The Molecule That Supports All of Life

- Importance of water
  - Water is the biological medium on Earth
  - All living organisms require water more than any other substance
  - Most cells are surrounded by water, and cells themselves are about 70–95% water
- Makes Earth habitable
  - Only substance to exist in three states at once
Emergent properties of water

- Four properties of water
  - Cohesive behavior
    - As well as adhesive
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

Cohesion

- Water molecules (co)hering to one another through hydrogen bonds
- Helps the transport of water against gravity in plants

Adhesion

- Water molecules (ad)hering to other substances via hydrogen bonds
**Emergent Properties of Water**

- **Surface tension**
  - Measure of how hard it is to break the surface of a liquid
  - Due to cohesion

**Moderation of Temperature**

- Water is a powerful temperature buffer
  - Absorbs heat from warmer air and releases stored heat to cooler air
    - Because...
  - Water can absorb or release a large amount of heat with only a slight change in its own temperature
    - Due to a high specific heat capacity

**Heat and Temperature**

- **Kinetic energy**
  - Energy of motion, energy doing work
- **Heat**
  - Measure of the total amount of kinetic energy due to molecular motion
- **Temperature**
  - Measures the amount of heat due to the average kinetic energy of molecules
Heat and Temperature

- Celsius scale
  - measure of temperature using Celsius degrees (°C)
  - Fahrenheit not used in sciences
- calorie (cal)
  - amount of heat required to raise the temperature of 1 g of water by 1°C
  - The "calories" on food packages are actually kilocalories (kcal), where 1 kcal = 1,000 cal
- joule (J)
  - another unit of energy where
    1 J = 0.239 cal, or 1 cal = 4.184 J

Water's High Specific Heat

- specific heat
  - amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1°C
- specific heat of water
  - 1 cal/g/°C
  - or 4.184 joules/g/°C

Therefore - Water resists changing its temperature because of its high specific heat

Water's high specific heat can be traced to hydrogen bonding

- Heat is absorbed when hydrogen bonds break
  - Heat is put in and much is used to break H-bonds before the molecules can move faster
  - Heat is released when hydrogen bonds form
  - When H-bonds form molecules slow down

- The high specific heat of water minimizes temperature fluctuations to within limits that permit life
Evaporative Cooling

- Evaporation
  - transformation of a substance from liquid to gas
- Heat of vaporization
  - heat a liquid must absorb for 1 g to be converted to gas
- Evaporative cooling
  - as a liquid evaporates, its remaining surface cools
    - highest kinetic energy molecules escape
    - stabilize temperatures in organisms and bodies of water

Insulation of Bodies of Water by Floating Ice

- Ice is less dense than liquid water
  - hydrogen bonds in ice are more ordered
    - results in lower molecular density
- Water reaches its greatest density at 4°C
  - Lower molecular kinetic energy
    - Molecules can pack tighter together
      - higher density
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth
The Solvent of Life

- Solution
  - liquid that is a homogeneous mixture of substances
- Solvent
  - dissolving agent of a solution
- Solute
  - substance that is dissolved
- aqueous solution
  - water is the solvent

Polarity of water

- Form hydrogen bonds easily
  - versatile solvent
- Ionic compounds dissolve in water
  - each ion surrounded by a sphere of water molecules
    - hydration shell
The Solvent of Life

- Nonionic polar molecules
  - also dissolved by water
- Even large polar molecules such as proteins can dissolve in water
  - if they have ionic and polar regions
  - They are water-soluble
Hydrophilic and Hydrophobic Substances

- hydrophilic
  - affinity for water
  - polar or ionic
  - readily dissolve

- hydrophobic
  - no affinity for water
  - difficult or impossible to dissolve
  - oil molecules
  - nonpolar bonds

Solute Concentration in Aqueous Solutions

- most biochemical reactions occur in water
  - aqueous environments to aqueous cytosol

- chemical reactions
  - due to collisions of molecules
    - therefore depend on the concentration of solutes in an aqueous solution

Solute Concentration in Aqueous Solutions

- molecular mass
  - sum of all masses of all atoms in a molecule

- mole
  - typical unit of measure for number of molecules
    - counting molecules impractical
  - 1 mole (mol) = 6.02 x 10^23 molecules
    - avogadro’s number
    - A’s n and the unit dalton were defined such that 6.02 x 10^23 daltons = 1 g

- molarity (M)
  - number of moles of solute per liter of solution
Acidic and basic conditions affect living organisms

- A hydrogen atom in a hydrogen bond between two water molecules can shift from one to the other:
  - hydrogen ion (H⁺)
    - hydrogen atom leaves electron behind
    - transferred as a proton
  - hydronium ion (H₃O⁺)
    - The molecule with the extra proton
    - represented as H⁺
  - hydroxide ion (OH⁻)
    - molecule that lost the proton

Water is in a state of dynamic equilibrium

- in which water molecules dissociate at the same rate at which they are being reformed

Hydronium ion (H₃O⁺)  
Hydroxide ion (OH⁻)

Concentrations of H⁺ and OH⁻ are equal in pure water

- Dynamic equilibrium
- Acids and bases are solutes
- alter concentrations of H⁺ and OH⁻
- pH scale
  - describe whether a solution is acidic or basic
  - Direct measure of H⁺ ion concentration
**Acids and Bases**

- **Acid**
  - substance that increases $H^+$ concentration of a solution
  - $HCl \rightarrow H^+ + Cl^-$
  - $H_2CO_3 \leftrightarrow HCO_3^- + H^+$

- **Base**
  - substance that reduces the $H^+$ concentration of a solution
  - $NaOH \rightarrow Na^+ + OH^-$
  - $NH_3 + H^+ \rightarrow NH_4^+$

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**The pH Scale**

- In any aqueous solution at 25°C the product of $H^+$ and $OH^-$ is constant and can be written as
  - $[H^+][OH^-] = 10^{-14}$

- The **pH** of a solution is defined by the negative logarithm of $H^+$ concentration, written as
  - $pH = -\log [H^+]$

- For a neutral aqueous solution
  - $[H^+]$ is $10^{-7} = -(-7) = 7$

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**Acidic**

- pH below 7

**Basic**

- pH above 7

- Most biological fluids have pH values in the range of 6 to 8
Buffers

- The internal pH of most living cells must remain close to pH 7
- Buffers
  - minimize $H^+$ and $OH^-$ concentration changes
  - consist of an acid-base pair that reversibly combines with $H^+$
  - Bicarbonate buffer system
    - $H_2CO_3 \leftrightarrow HCO_3^- + H^+$

Threats to Water Quality on Earth

- Acid precipitation
  - rain, snow, or fog with a pH lower than 5.6
  - caused mainly by the mixing of different pollutants with water in the air
    - $SO_2(g) + 1/2 O_2(g) \rightarrow SO_3(g)$
    - $H_2O(l) + SO_3(g) \rightarrow H_2SO_4(aq)$
  - can fall at some distance from the source of pollutants
  - Acid precipitation can damage life in lakes and streams
  - Effects of acid precipitation on soil chemistry are contributing to the decline of some forests
Threats to Water Quality on Earth

- Human activities such as burning fossil fuels threaten water quality
- CO₂ is released by fossil fuel combustion and contributes to:
  - A warming of earth called the “greenhouse” effect
  - Acidification of the oceans
    - leads to a decrease in the ability of corals to form calcified reefs
    - \( \text{H}_2\text{O}(l) + \text{CO}_2(g) \leftrightarrow \text{H}_2\text{CO}_3(aq) \)
    - \( \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{CO}_3^{2-} + \text{H}^+ \)
      - Shifts toward HCO_3-
      - Not enough CO_3^{2-}

You should now be able to:

1. List and explain the four properties of water that emerge as a result of its ability to form hydrogen bonds
2. Distinguish between the following sets of terms: hydrophobic and hydrophilic substances; a solute, a solvent, and a solution
3. Define acid, base, and pH
4. Explain how buffers work