Overview: The Molecule That Supports All of Life

- 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
- The abundance of water is the main reason the Earth is habitable

Concept 3.1: Polar covalent bonds in water molecules result in hydrogen bonding

- The water molecule is a **polar molecule**: the opposite ends have opposite charges
- Polarity allows water molecules to form hydrogen bonds with each other

Concept 3.2: Four emergent properties of water contribute to Earth's suitability for life

- Four of water's properties that facilitate an environment for life are
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

Cohesion of Water Molecules

- Collectively, hydrogen bonds hold water molecules together, a phenomenon called **cohesion**
- Cohesion helps the transport of water against gravity in plants
- **Adhesion** is an attraction between different substances, for example, between water and plant cell walls
- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion

Moderation of Temperature by Water

- Water absorbs heat from warmer air and releases stored heat to cooler air
- Water can absorb or release a large amount of heat with only a slight change in its own temperature

Heat and Temperature

- **Kinetic energy** is the energy of motion
- **Heat** is a measure of the total amount of kinetic energy due to molecular motion
- **Temperature** measures the intensity of heat due to the average kinetic energy of molecules
- The **Celsius scale** is a measure of temperature using Celsius degrees (°C)
- A **calorie (cal)** is the 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
- The **joule (J)** is another unit of energy where
  1 J = 0.239 cal, or 1 cal = 4.184 J

Water's High Specific Heat

- The **specific heat** of a substance is the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1ºC
- The specific heat of water is 1 cal/g/ºC
- 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 released when hydrogen bonds form
- The high specific heat of water minimizes temperature fluctuations to within limits that permit life

Evaporative Cooling

- Evaporation is transformation of a substance from liquid to gas

- **Heat of vaporization** is the heat a liquid must absorb for 1 g to be converted to gas
- As a liquid evaporates, its remaining surface cools, a process called **evaporative cooling**
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water

Floating of Ice on Liquid Water

- Ice floats in liquid water because hydrogen bonds in ice are more "ordered," making ice less dense
- Water reaches its greatest density at 4°C
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth

Water: The Solvent of Life

- A **solution** is a liquid that is a homogeneous mixture of substances
- A **solvent** is the dissolving agent of a solution
- The **solute** is the substance that is dissolved
- An **aqueous solution** is one in which water is the solvent
- Water is a versatile solvent due to its polarity, which allows it to form hydrogen bonds easily
- When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**
- Water can also dissolve compounds made of nonionic polar molecules
- Even large polar molecules such as proteins can dissolve in water if they have ionic and polar regions

Hydrophilic and Hydrophobic Substances

- A **hydrophilic** substance is one that has an affinity for water
- A **hydrophobic** substance is one that does not have an affinity for water
- Oil molecules are hydrophobic because they have relatively nonpolar bonds
- A **colloid** is a stable suspension of fine particles in a liquid

Solute Concentration in Aqueous Solutions

- Most biochemical reactions occur in water
- Chemical reactions depend on collisions of molecules and therefore on the concentration of solutes in an aqueous solution

- **Molecular mass** is the sum of all masses of all atoms in a molecule
- Numbers of molecules are usually measured in moles, where 1 **mole (mol)** = 6.02×10^{23} molecules
- Avogadro's number and the unit *dalton* were defined such that 6.02×10^{23} daltons = 1 g
- **Molarity (*M*)** is the number of moles of solute per liter of solution

Possible Evolution of Life on Other Planets with Water

- The remarkable properties of water support life on Earth in many ways
- Astrobiologists seeking life on other planets are concentrating their search on planets with water
- To date, more than 200 planets have been found outside our solar system; one or two of them contain water
- In our solar system, Mars has been found to have water

Concept 3.3: 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
  - The hydrogen atom leaves its electron behind and is transferred as a proton, or **hydrogen ion** (H^+)

- The molecule with the extra proton is now a **hydronium ion** (H_3O^+), though it is often represented as H^+
- The molecule that lost the proton is now a **hydroxide ion** ($OH^–$)

- Water is in a state of dynamic equilibrium in which water molecules dissociate at the same rate at which they are being reformed
- Though statistically rare, the dissociation of water molecules has a great effect on organisms
- Changes in concentrations of H^+ and $OH^–$ can drastically affect the chemistry of a cell
- Concentrations of H^+ and $OH^–$ are equal in pure water
- Adding certain solutes, called acids and bases, modifies the concentrations of H^+ and $OH^–$
- Biologists use something called the pH scale to describe whether a solution is acidic or basic (the opposite of acidic)

Acids and Bases

- An **acid** is any substance that increases the H^+ concentration of a solution
- A **base** is any substance that reduces the H^+ concentration of a solution

The pH Scale

- In any aqueous solution at 25°C the product of H^+ and $OH^–$ is constant and can be written as
- The **pH** of a solution is defined by the negative logarithm of H^+ concentration, written as
- For a neutral aqueous solution, $[H^+]$ is $10^{–7}$, so
- Acidic solutions have pH values less than 7
- Basic solutions have pH values greater than 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** are substances that minimize changes in concentrations of H^+ and $OH^–$ in a solution
- Most buffers consist of an acid-base pair that reversibly combines with H^+

Acidification: A Threat to Water Quality

- Human activities such as burning fossil fuels threaten water quality
- CO_2 is the main product of fossil fuel combustion
- About 25% of human-generated CO_2 is absorbed by the oceans
- CO_2 dissolved in sea water forms carbonic acid; this process is called **ocean acidification**
- As seawater acidifies, H^+ ions combine with carbonate ions to produce bicarbonate
- Carbonate is required for calcification (production of calcium carbonate) by many marine organisms, including reef-building corals
- Calcium carbonate disassociates in acidic seawater, resulting in shell deterioration of such marine organisms, as well as of established reef
- The burning of fossil fuels is also a major source of sulfur oxides and nitrogen oxides
- These compounds react with water in the air to form strong acids that fall in rain or snow
- **Acid precipitation** is rain, fog, or snow with a pH lower than 5.2
- Acid precipitation damages life in lakes and streams and changes soil chemistry on land