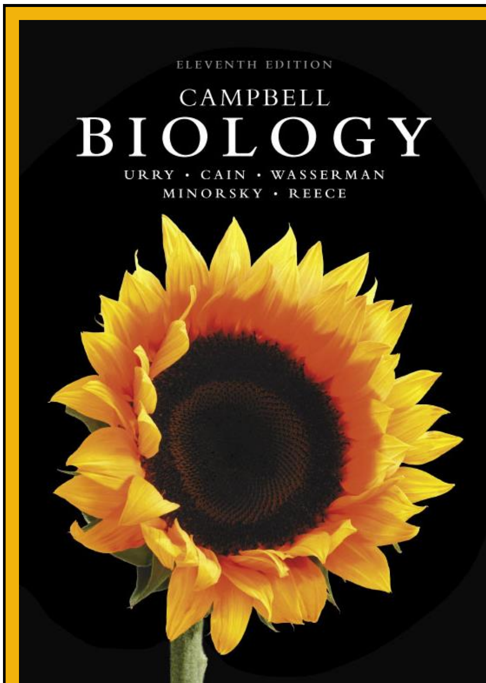


Chapter 3

Water and Life

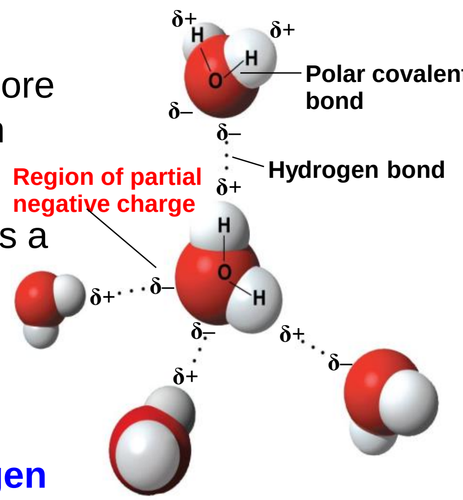
Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

The Molecule That Supports All of Life

- Water makes life possible on Earth
- Water is the only common substance to exist in the natural environment in **all three physical states** of matter
- Water's unique emergent properties help make Earth *suitable* for life
- The structure of the water molecule allows it to interact with other molecules

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

- In the water molecule, the electrons of the **polar covalent bonds** spend more time near the oxygen than the hydrogen
- The water molecule is thus a **polar molecule**: *The overall charge is unevenly distributed*
- Polarity allows water molecules to form **hydrogen bonds** with each other



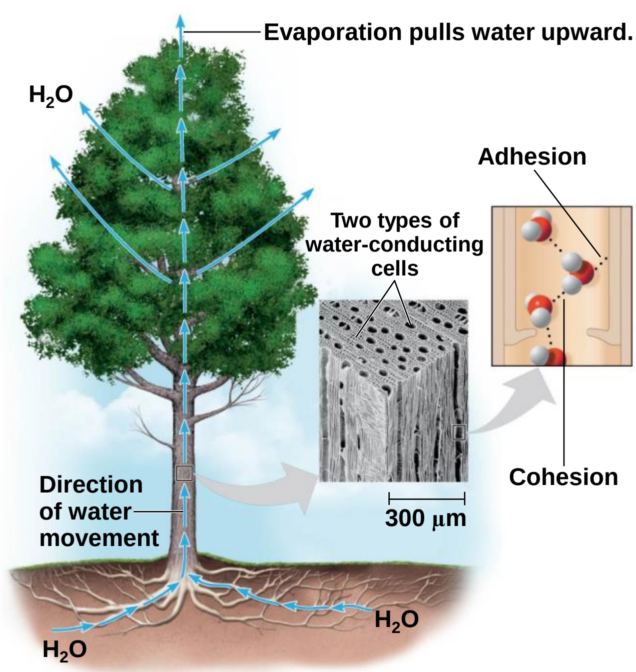
Concept 3.2: Four emergent properties of water contribute to Earth's suitability for life

- 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

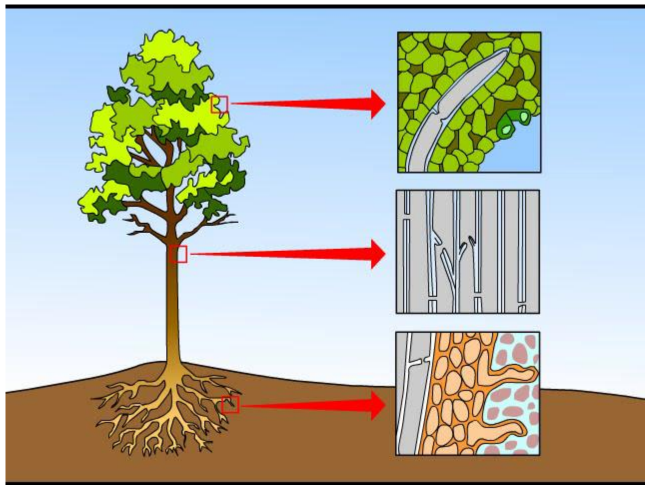
Cohesion of Water Molecules

- 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

Figure 3.3



Animation: Water Transport in Plants



- **Surface tension** is a measure of how difficult it is to break the surface of a liquid
- Water has an unusually **high** surface tension due to hydrogen bonding between the molecules at the air-water interface and to the water below

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

Temperature and Heat

- **Kinetic energy** is the energy of motion
- The kinetic energy associated with *random motion of atoms or molecules* is called **thermal energy**
- **Temperature** represents the average kinetic energy of the molecules in a body of matter
- Thermal energy in transfer from one body of matter to another is defined as **heat**

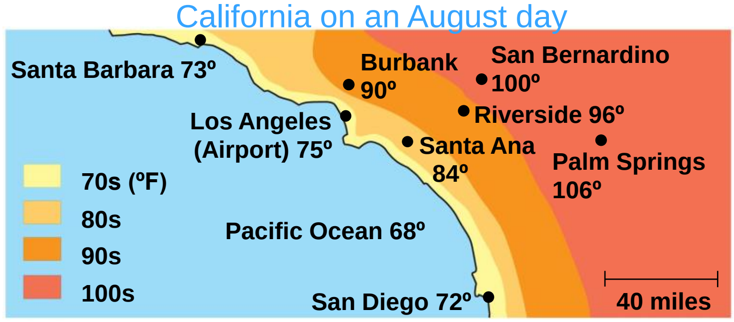
- A **calorie** (**cal**) is the amount of heat required to raise the temperature of 1 g of water by 1ºC
- It is also the amount of heat released when 1 g of water cools by 1ºC
- The “Calories” on food packages are actually **kilocalories** (**kcal**); 1 kcal = 1,000 cal
- The **joule** (**J**) is another unit of energy; 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

Temperatures for the Pacific Ocean and Southern California on an August day

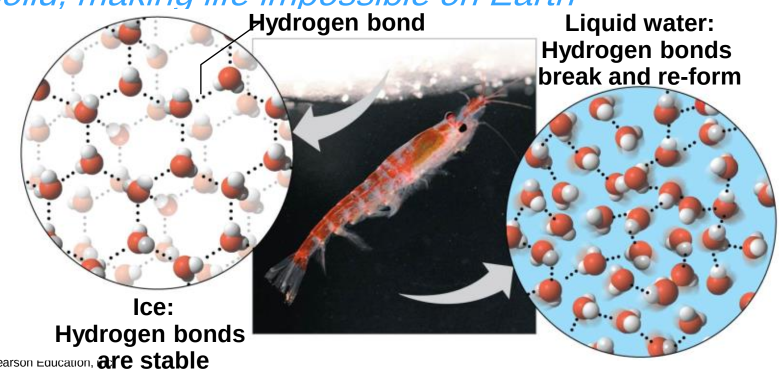


Evaporative Cooling

- Evaporation (or vaporization) 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

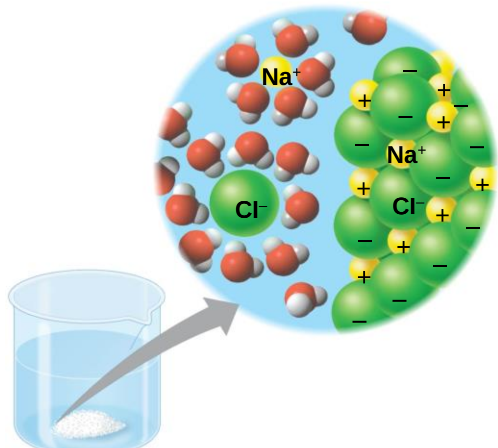
- Ice floats in liquid water because hydrogen bonds in ice are more “ordered,” making ice less dense than water
- Water reaches its greatest density at 4ºC
- *If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth*



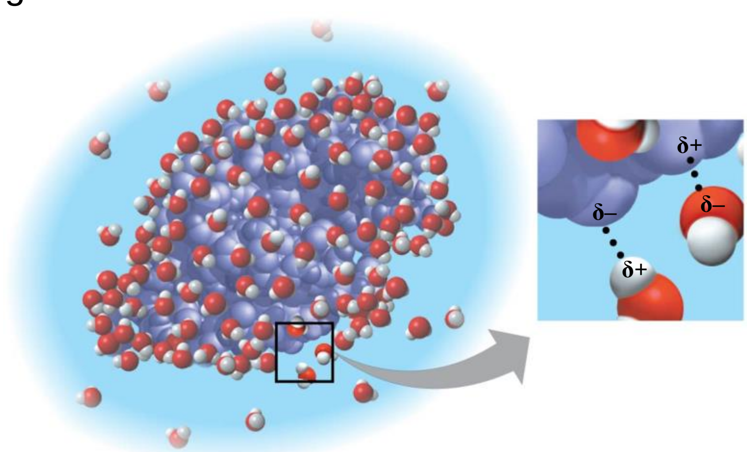
Water: The Solvent of Life

- A **solution** is a liquid that is a completely homogeneous mixture of substances
- The **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**
- 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**
- Hydrophobic molecules related to oils are the major ingredients of ***cell membranes***

Solute Concentration in Aqueous Solutions

- Most chemical reactions in organisms involve solutes dissolved in water
- When carrying out experiments, we use mass to calculate the number of solute molecules 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

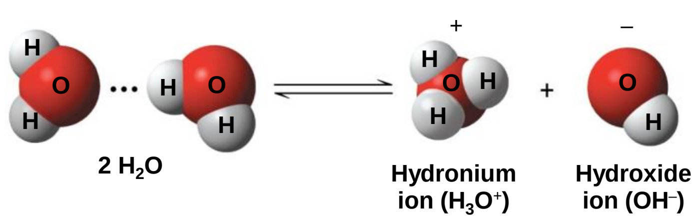
Possible Evolution of Life on Other Planets

- Biologists seeking life on other planets have concentrated their search on planets that might have water
- More than 800 planets have been found outside our solar system; *there is evidence that a few of them have water vapor*
- In our solar system, Mars has been found to have water (ice)

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

- 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 the **pH scale** to describe whether a solution is acidic or basic (alkaline)

Acids and Bases

- An **acid** is a substance that *increases* the H^+ concentration of a solution
- A **base** is a substance that *reduces* the H^+ concentration of a solution
- Strong acids and bases **dissociate** completely in water
- Weak acids and bases *reversibly* release and accept back hydrogen ions, but can still shift the balance of H^+ and OH^- away from neutrality

The pH Scale

- In any aqueous solution at 25ºC, the product of H^+ and OH^- concentrations is constant and can be written as

$$[H^+][OH^-] = 10^{-14}$$

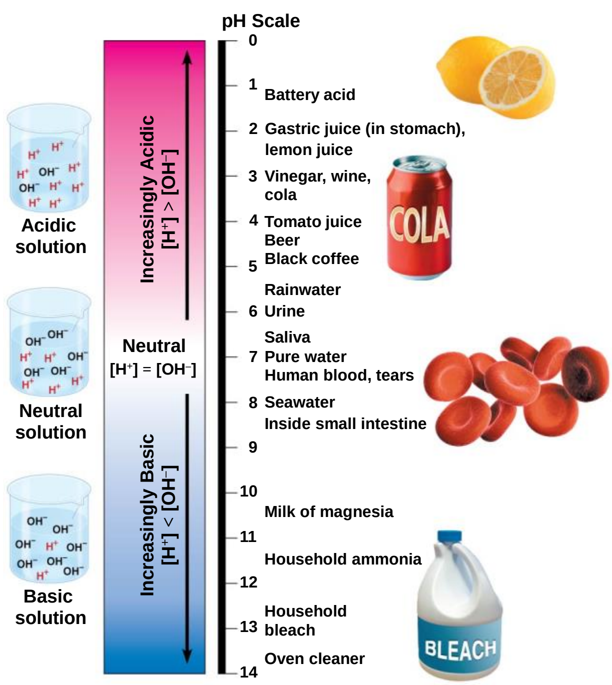
- The **pH** of a solution is defined by the negative logarithm of H^+ concentration, written as

$$pH = -\log [H^+]$$

- For a neutral aqueous solution, $[H^+] = [OH^-]$ is 10^{-7}, so

$$pH = -(-7) = 7$$

- 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



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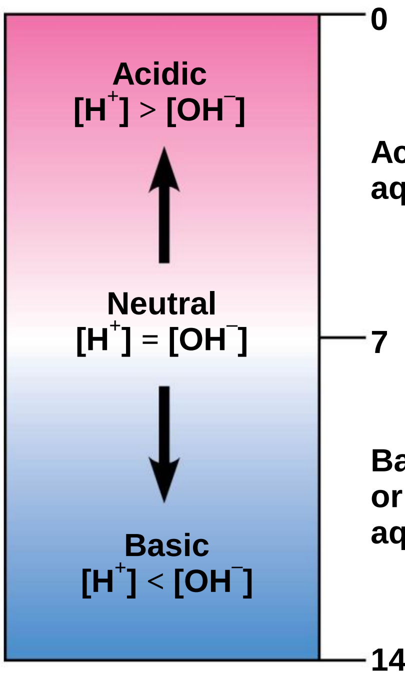

Buffers

- The internal pH of most living cells is close to 7
- **Buffers** are substances that *minimize* changes in concentrations of H^+ and OH^- in a solution
- Most buffer solutions contain a weak acid and its corresponding base, which combine reversibly with H^+ ions

End of chapter 2

Class activity

- What would be the effect on the properties of the water molecule if oxygen and hydrogen had equal electronegativity?
- If water cannot form hydrogen bonds, what will happen to the shrimp's habitat shown in the previous slide?

Class activity

- If water is a universal solvent. What are the consequences for life?

Class activity

- Compared with a basic solution at pH 9, the same volume of acidic solution at pH 4 has ………………… times as many H+ ions.
- HCl is a strong acid that dissociates in water. HCl → H^+ + Cl^-. What is the pH of 0.01 M HCl?