Johns Hopkins Engineering

Molecular Biology

The Chemistry of the Cell

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WHITING SCHOOL
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Outline

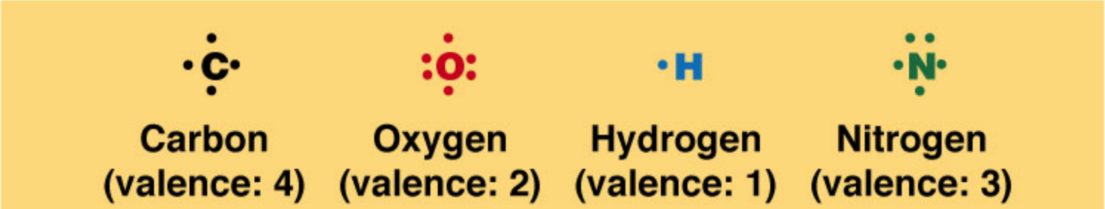
- The Chemistry of the Cell
  - Characteristics of carbon
  - Characteristics of water
  - Selectively permeable membranes

The Importance of Carbon

- Study of all classes of **carbon-containing** compounds is **organic chemistry**
- Biological chemistry (*biochemistry*) is the study of the chemistry of living systems
- The carbon atom (C) is the most important atom in biological molecules
- Specific bonding properties of carbon account for the characteristics of carbon-containing compounds

Bonding Properties of Carbon

- The carbon atom has a *valence* of 4 (outermost electron shell lacks 4 of 8 electrons needed to fill it), so can form 4 chemical bonds with other atoms
- Carbon atoms are most likely to form covalent bonds with one another and with oxygen (O), hydrogen (H), nitrogen (N), and sulfur (S)
- Covalent bonds - the sharing of a pair of electrons between two atoms

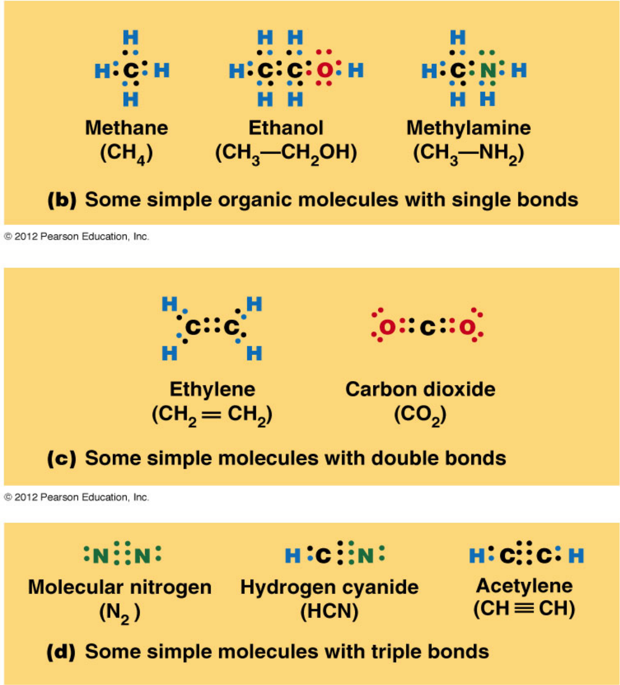


(a) Some biologically important atoms and their valences

Covalent Bonding of Carbon Atoms

- Sharing one pair of electrons between two atoms forms a single bond
- Double and triple bonds involve two atoms sharing two and three pairs of electrons, respectively
- Whether carbon atoms form single, double or triple bonds with other atoms, the total number of covalent bonds per carbon is four

Figure 2-1B-D



One shared electron pair

Two shared electron pairs

Three shared electron pairs

Carbon-containing Molecules are Stable

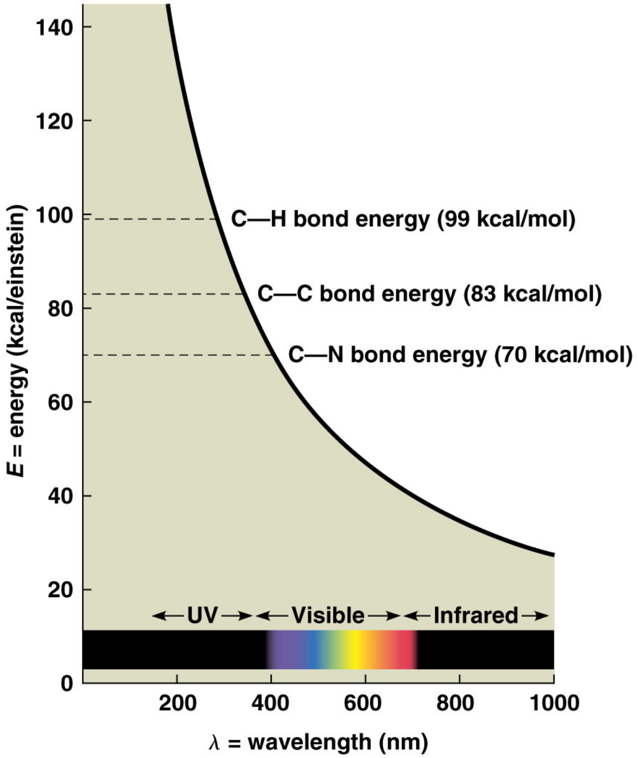
- Stability is expressed as bond energy - the amount of energy required to break 1 *mole* (~6x 10^{23}) of bonds
- Bond energy is expressed as *calories per mole* (*cal/mol*)
- **A calorie is the amount of energy needed to raise the temperature of 1g of water by 1°C**
- A *kcal* (*kilocalorie*) is equal to 1000 calories

Bond Energies of Covalent Bonds

- A lot of energy is needed to break covalent bonds
  - C-C, 83 kcal/mol
  - C-N, 70 kcal/mol
  - C-O, 84 kcal/mol
  - C-H, 99 kcal/mol
- Double and triple bonds are even harder to break
  - C=C, 146 kcal/mol
  - C≡C, 212 kcal/mol

Importance of Strong Bonds

- Solar radiation has an inverse relationship between wavelength and energy content
- The visible portion of sunlight is lower in energy than C-C bonds
- So, visible light cannot break the bonds of organic molecules
- Higher energy, ultraviolet light, is more hazardous

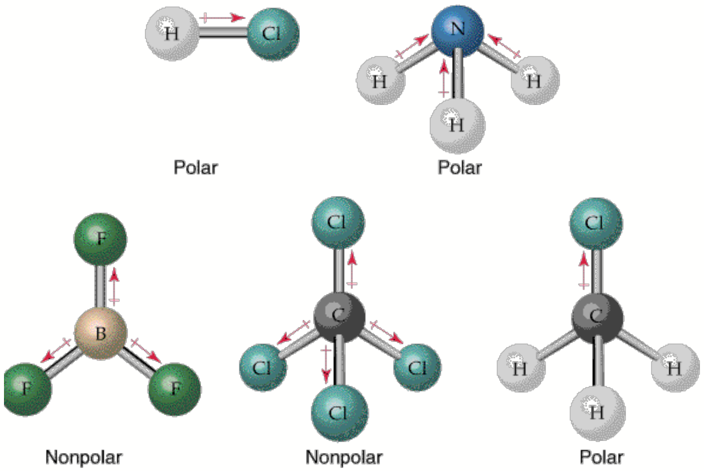


Carbon-containing Molecules are Diverse

- A large variety of compounds can be formed by relatively few kinds of atoms
- Rings or chains of carbon atoms can form
- Chains may branch and may have single or double bonds between the carbons
- Variety of structures possible is due to the **tetravalent** nature of the carbon atom

Bond Polarity

- In *polar* bonds electrons are not shared equally between two atoms
- Polar bonds result from a high *electronegativity* (affinity for electrons) of oxygen and sulfur compared to carbon and hydrogen
- Polar bonds have high water solubility compared to C-C or C-H bonds, in which electrons are shared equally



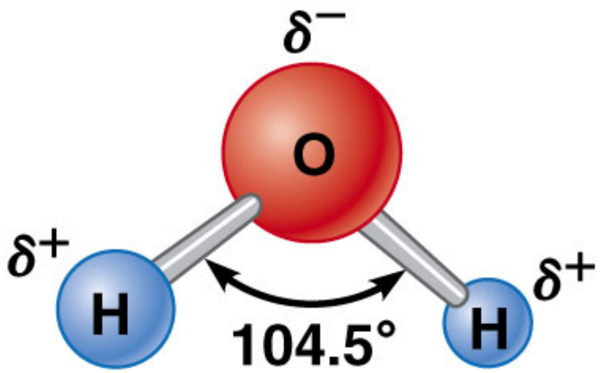
Credit: quora.com

The Importance of Water

- Water has an indispensable role as the universal solvent in biological systems
  - It is the single most abundant component of cells and organisms
  - About 75-85% of a cell by weight is water
  - Its Chemical characteristics make water indispensable for life

Water Molecules are Polar

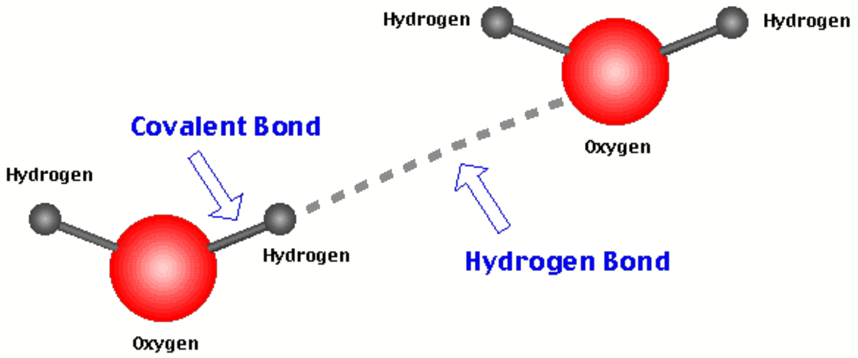
- Unequal distribution of electrons gives water its polarity
- The water molecule is bent rather than linear
- The oxygen atom at one end of the molecule is highly electronegative, drawing the electrons toward it
- This results in a partial negative charge at this end of the molecule, and a partial positive charge around the hydrogen atoms



(a) Polarity of water molecule

Water Molecules are Cohesive

- Because of their polarity, water molecules are attracted to each other and orient so the electronegative oxygen of one molecule is associated with the electropositive hydrogens of nearby molecules



Credit: Socratic.org

- Such associations, called hydrogen bonds, are about 1/10 as strong as covalent bonds

Hydrogen Bonds Aid Cohesiveness

- Water is characterized by an extensive network of hydrogen-bonded molecules, which make it *cohesive*

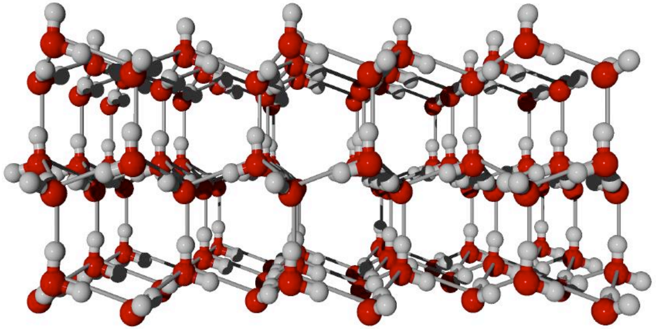
- The combined effect of many hydrogen bonds accounts for water's high
  - *Surface tension*
  - *Boiling point*
  - *Specific heat*
  - *Heat of vaporization*

Surface Tension of Water

- Is the result of the collective strength of vast numbers of hydrogen bonds

- Allows insects to walk along the surface of water without breaking the surface

- Allows water to move upward through conducting tissues of some plants



Credit: nyu.edu

Figure 2-9

Water Has a High Temperature-Stabilizing Capacity

- High specific heat gives water its temperature-stabilizing capacity
- Specific heat - the amount of heat a substance must absorb to raise its temperature 1^{o}C
- The specific heat of water is 1.0 calorie per gram, much higher than most liquids

Temperature-stabilizing Capacity

- Heat that would raise the temperature of other liquids is first used to break numerous hydrogen bonds in water
- Water therefore changes temperature relatively slowly, protecting living systems from extreme temperature changes
- Without this characteristic of water, energy released in cell metabolism would cause overheating and death

Water is an Excellent Solvent

- A solvent is a fluid in which another substance, the solute, can dissolve
- Water is able to dissolve a large variety of substances, due to its polarity
- Most of the molecules in cells are also polar and so can form hydrogen bonds, or ionic bonds with water

Credit: socratic.org

Selectively Permeable Membranes

- Cells need a physical barrier between their contents and the outside environment

- Such a barrier should be
  - impermeable to much of the cell contents
  - not completely impermeable, allowing some materials into and out of the cell
  - insoluble in water to maintain the integrity of the barrier
  - permeable to water to allow flow of water in and out of the cell

Membranes Surround Cells

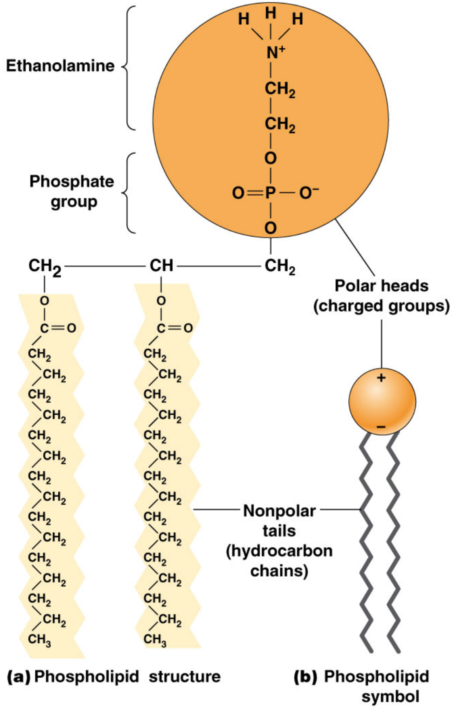
- The cellular membrane is a hydrophobic permeability barrier
- Consists of *phospholipids, glycolipids,* and *membrane proteins*
- Membranes of most organisms also contain *sterols* - *cholesterol* (animals), *ergosterols* (fungi), or *phytosterols* (plants)

Membrane Lipids are Amphipathic

- Membrane lipids are amphipathic; they have both hydrophobic and hydrophilic regions

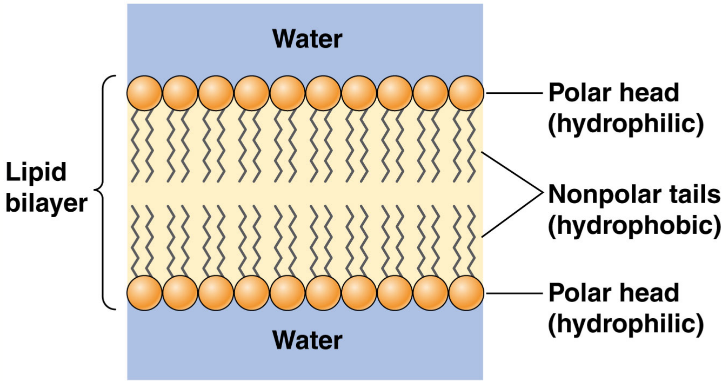
- Amphipathic phospholipids have a polar *head*, due to a negatively charged phosphate group linked to a positively charged group

- They also have two nonpolar hydrocarbon *tails*



A Membrane is a Lipid Bilayer with Proteins Embedded within it

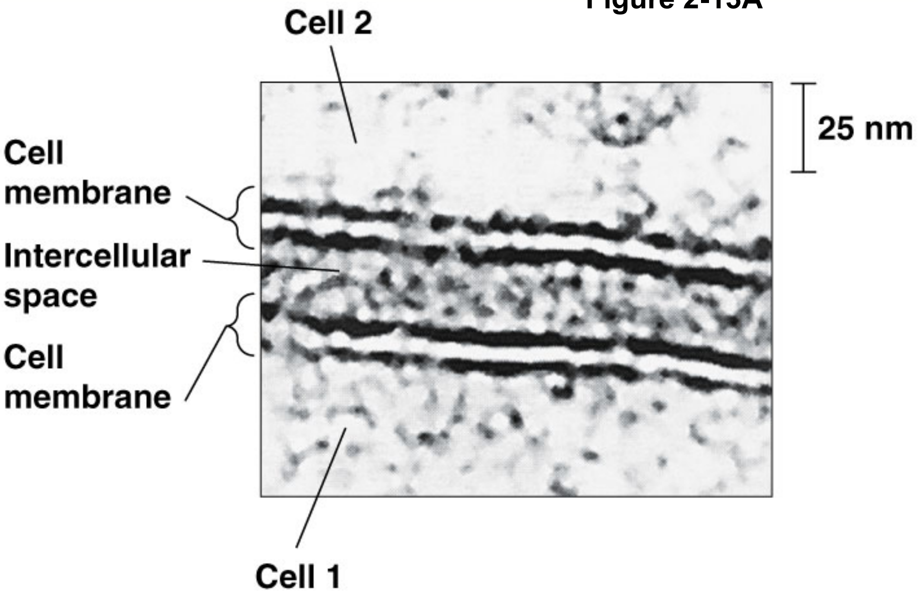
- In water, amphipathic molecules undergo hydrophobic interactions
- The polar heads of membrane phospholipids face outward toward the aqueous environment
- The hydrophobic tails are oriented inward



The resulting structure is the lipid bilayer

Electron Micrograph of Membranes

Figure 2-13A



(a) Electron micrograph of the membranes of two adjacent cells

Membranes are Selectively Permeable

- Because of the hydrophobic interior, membranes are readily permeable to nonpolar molecules
- However, they are quite impermeable to most polar molecules and very impermeable to ions
- Cellular constituents are mostly polar or charged and are prevented from entering or leaving the cell
- However, very small molecules diffuse

The rate at which a molecule diffuses across a synthetic lipid bilayer depends on its size and solubility.

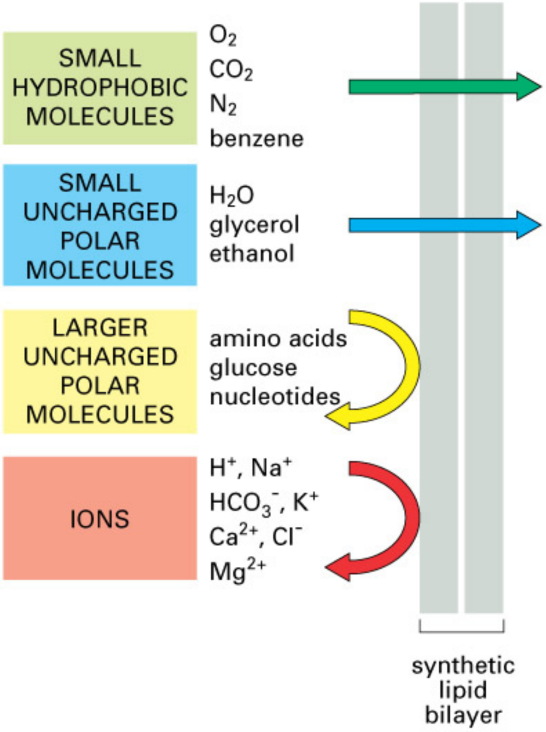


Figure 12-2 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Module 1 Summary

- Modern Cell Biology
  - Cytology
  - Biochemistry
  - Genetics
- The Importance of Water
- Selectively Permeable Membranes
  - Characteristics
  - Functions

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