Chemistry Comes Alive: Part B

Classes of Compounds

• Inorganic compounds
  • Water, salts, and many acids and bases
  • Do not contain carbon
• Organic compounds
  • Carbohydrates, fats, proteins, and nucleic acids
  • Contain carbon, usually large, and are covalently bonded

Water

• 60%–80% of the volume of living cells
• Most important inorganic compound in living organisms because of its properties

Properties of Water

• High heat capacity
  • Absorbs and releases heat with little temperature change
  • Prevents sudden changes in temperature
• High heat of vaporization
  • Evaporation requires large amounts of heat
  • Useful cooling mechanism

Properties of Water

• Polar solvent properties
  • Dissolves and dissociates ionic substances
  • Forms hydration layers around large charged molecules, e.g., proteins (colloid formation)
  • Body’s major transport medium

Properties of Water

• Reactivity
  • A necessary part of hydrolysis and dehydration synthesis reactions
• Cushioning
  • Protects certain organs from physical trauma, e.g., cerebrospinal
Salts
• Ionic compounds that dissociate in water
• Contain cations other than H\(^+\) and anions other than OH\(^-\)
• Ions (electrolytes) conduct electrical currents in solution
• Ions play specialized roles in body functions (e.g., sodium, potassium, calcium, and iron)

Acids and Bases
• Both are electrolytes
  • Acids are proton (hydrogen ion) donors (release H\(^+\) in solution)
    • HCl → H\(^+\) + Cl\(^-\)

Acids and Bases
• Bases are proton acceptors (take up H\(^+\) from solution)
  • NaOH → Na\(^+\) + OH\(^-\)
    • OH\(^-\) accepts an available proton (H\(^+\))
    • OH\(^-\) + H\(^+\) → H\(_2\)O
  • Bicarbonate ion (HCO\(_3\)\(^-\)) and ammonia (NH\(_3\)) are important bases in the body

Acid-Base Concentration
• Acid solutions contain [H\(^+\)]
  • As [H\(^+\)] increases, acidity increases
• Alkaline solutions contain bases (e.g., OH\(^-\))
  • As [H\(^+\)] decreases (or as [OH\(^-\)] increases), alkalinity increases

pH: Acid-Base Concentration
• pH = the negative logarithm of [H\(^+\)] in moles per liter
• Neutral solutions:
  • Pure water is pH neutral (contains equal numbers of H\(^+\) and OH\(^-\))
  • pH of pure water = pH 7: [H\(^+\)] = 10 \(^{-7}\) M
  • All neutral solutions are pH 7

pH: Acid-Base Concentration
• Acidic solutions
  • ↑ [H\(^+\)], ↓ pH
  • Acidic pH: 0–6.99
  • pH scale is logarithmic: a pH 5 solution has 10 times more H\(^+\)
than a pH 6 solution
• Alkaline solutions
  • ↓ [H⁺], ↑ pH
  • Alkaline (basic) pH: 7.01–14

**Acid-Base Homeostasis**
• pH change interferes with cell function and may damage living tissue
• Slight change in pH can be fatal
• pH is regulated by kidneys, lungs, and buffers

**Buffers**
• Mixture of compounds that resist pH changes
• Convert strong (completely dissociated) acids or bases into weak (slightly dissociated) ones
  • Carbonic acid-bicarbonate system

**Organic Compounds**
• Contain carbon (except CO₂ and CO, which are inorganic)
• Unique to living systems
• Include carbohydrates, lipids, proteins, and nucleic acids

**Organic Compounds**
• Many are polymers—chains of similar units (monomers or building blocks)
  • Synthesized by dehydration synthesis
  • Broken down by hydrolysis reactions

**Carbohydrates**
• Sugars and starches
• Contain C, H, and O [(CH₂O)ₙ]
• Three classes
  • Monosaccharides
  • Disaccharides
  • Polysaccharides

**Carbohydrates**
• Functions
  • Major source of cellular fuel (e.g., glucose)
  • Structural molecules (e.g., ribose sugar in RNA)
Monosaccharides
- Simple sugars containing three to seven C atoms
- \((\text{CH}_2\text{O})_n\)

Disaccharides
- Double sugars
- Too large to pass through cell membranes

Polysaccharides
- Polymers of simple sugars, e.g., starch and glycogen
- Not very soluble

Lipids
- Contain C, H, O (less than in carbohydrates), and sometimes P
- Insoluble in water
- Main types:
  - Neutral fats or triglycerides
  - Phospholipids
  - Steroids
  - Eicosanoids

Triglycerides
- Neutral fats—solid fats and liquid oils
- Composed of three fatty acids bonded to a glycerol molecule
- Main functions
  - Energy storage
  - Insulation
  - Protection

Saturation of Fatty Acids
- Saturated fatty acids
  - Single bonds between C atoms; maximum number of H
  - Solid animal fats, e.g., butter
- Unsaturated fatty acids
  - One or more double bonds between C atoms
  - Reduced number of H atoms
  - Plant oils, e.g., olive oil

Phospholipids
- Modified triglycerides:
- Glycerol + two fatty acids and a phosphorus (P)-containing group
- “Head” and “tail” regions have different properties
- Important in cell membrane structure

**Steroids**
- Steroids—interlocking four-ring structure
- Cholesterol, vitamin D, steroid hormones, and bile salts

**Eicosanoids**
- Many different ones
- Derived from a fatty acid (arachidonic acid) in cell membranes
- Prostaglandins

**Other Lipids in the Body**
- Other fat-soluble vitamins
  - Vitamins A, E, and K
- Lipoproteins
  - Transport fats in the blood

**Proteins**
- Polymers of amino acids (20 types)
  - Joined by peptide bonds
- Contain C, H, O, N, and sometimes S and P

**Structural Levels of Proteins**

**Fibrous and Globular Proteins**
- Fibrous (structural) proteins
  - Strandlike, water insoluble, and stable
  - Examples: keratin, elastin, collagen, and certain contractile fibers

**Fibrous and Globular Proteins**
- Globular (functional) proteins
  - Compact, spherical, water-soluble and sensitive to environmental changes
  - Specific functional regions (active sites)
  - Examples: antibodies, hormones, molecular chaperones, and enzymes

**Protein Denaturation**
• Shape change and disruption of active sites due to environmental changes (e.g., decreased pH or increased temperature)
• Reversible in most cases, if normal conditions are restored
• Irreversible if extreme changes damage the structure beyond repair (e.g., cooking an egg)

**Molecular Chaperones (Chaperonins)**
• Ensure quick and accurate folding and association of proteins
• Assist translocation of proteins and ions across membranes
• Promote breakdown of damaged or denatured proteins
• Help trigger the immune response
• Produced in response to stressful stimuli, e.g., O₂ deprivation

**Enzymes**
• Biological catalysts
  • Lower the activation energy, increase the speed of a reaction (millions of reactions per minute!)

**Characteristics of Enzymes**
• Often named for the reaction they catalyze; usually end in -ase (e.g., hydrolases, oxidases)
• Some functional enzymes (holoenzymes) consist of:
  • Apoenzyme (protein)
  • Cofactor (metal ion) or coenzyme (a vitamin)

**Summary of Enzyme Action**

**Nucleic Acids**
• DNA and RNA
  • Largest molecules in the body
  • Contain C, O, H, N, and P
  • Building block = nucleotide, composed of N-containing base, a pentose sugar, and a phosphate group

**Deoxyribonucleic Acid (DNA)**
• Four bases:
  • adenine (A), guanine (G), cytosine (C), and thymine (T)
• Double-stranded helical molecule in the cell nucleus
- Provides instructions for protein synthesis
- Replicates before cell division, ensuring genetic continuity

**Ribonucleic Acid (RNA)**
- Four bases:
  - adenine (A), guanine (G), cytosine (C), and uracil (U)
- Single-stranded molecule mostly active outside the nucleus
- Three varieties of RNA carry out the DNA orders for protein synthesis
  - messenger RNA, transfer RNA, and ribosomal RNA

**Adenosine Triphosphate (ATP)**
- Adenine-containing RNA nucleotide with two additional phosphate groups

**Function of ATP**
- Phosphorylation:
  - Terminal phosphates are enzymatically transferred to and energize other molecules
  - Such “primed” molecules perform cellular work (life processes) using the phosphate bond energy