MCAT
MEDICAL COLLEGE ADMISSION TEST

Topics for Biological and Physical Sciences Sections of the MCAT – Effective April 2003

Biology

Molecular Biology: Enzymes and Metabolism

A. ENZYME STRUCTURE AND FUNCTION
   1. Function of enzymes in catalyzing biological reactions
   2. Reduction of activation energy
   3. Substrates and enzyme specificity

B. CONTROL OF ENZYME ACTIVITY
   1. Feedback inhibition
   2. Competitive inhibition
   3. Non-competitive inhibition

C. BASIC METABOLISM
   1. Glycolysis, anaerobic and aerobic, substrates and products
   2. Krebs cycle, substrates and products, general features of the pathway
   3. Electron transport chain and oxidative phosphorylation, substrates and products, general features of the pathway
   4. Metabolism of fats and proteins

Molecular Biology: DNA and Protein Synthesis

I. DNA STRUCTURE AND FUNCTION
   A. DNA STRUCTURE AND FUNCTION
      1. Watson-Crick model of DNA; double helix
      2. DNA composition: purine and pyrimidine bases, sugars, phosphate
      3. Base pairing specificity: A with T, G with C
      4. Function in transmission of genetic information

   B. DNA REPLICATION
      1. Mechanism of replication: separation of strands, specific coupling of free nucleic acids
      2. Semi-conservative nature of replication

   C. REPAIR OF DNA
      1. Repair during replication
      2. Repair of mutations

   D. RECOMBINANT DNA
      1. Restriction enzymes
      2. Hybridization
      3. Gene cloning

II. PROTEIN SYNTHESIS
   A. GENETIC CODE
      1. Central Dogma: DNA $\rightarrow$ RNA $\rightarrow$ protein
      2. Codon-anticodon relationship
      3. Missense, nonsense codons
      4. Initiation, termination codons

B. TRANSCRIPTION
   1. Messenger RNA
   2. tRNA, rRNA
   3. Mechanism of transcription

C. TRANSLATION
   1. Roles of mRNA, tRNA, rRNA
   2. Role and structure of ribosomes

Molecular Biology: Eukaryotes

A. EUKARYOTIC CHROMOSOME ORGANIZATION
   1. Chromosomal proteins
   2. Telomeres, centromeres

B. CONTROL OF GENE EXPRESSION IN EUKARYOTES
   1. Transcription regulation
   2. DNA binding proteins, transcription factors
   3. Cancer as a failure of normal cellular controls, oncogenes
   4. Post-transcriptional control [GEC]

Genetics

A. MENDELIAN CONCEPTS
   1. Phenotype and genotype
   2. Gene
   3. Locus
   4. Allele: single and multiple
   5. Homo- and heterozygosity
   6. Wild type
   7. Recessiveness
   8. Complete dominance
   9. Co-dominance
   10. Incomplete dominance, leakage, penetrance, expressivity
   11. Gene pool

B. MEIOSIS AND GENETIC VARIABILITY
   1. Significance of meiosis
   2. Important differences between meiosis and mitosis
   3. Segregation of genes
      a. Independent assortment
      b. linkage
      c. recombination
      d. single crossovers
      e. double crossovers
   4. Sex-linked characteristics
      a. very few genes on Y chromosome
      b. sex determination
      c. cytoplasmic inheritance

5. Mutation
    a. general concept of mutation-error in DNA sequence
    b. types of mutations: random, translation error, transcription error, base substitution, inversion, addition, deletion, translocation, mispairing
    c. advantageous vs. deleterious mutation
    d. inborn errors of metabolism
    e. relationship of mutagens to carcinogens]

C. ANALYTIC METHODS
1. Hardy-Weinberg Principle
2. Test cross: back cross, concepts of parental, F1 and F2 generations

Microbiology

A. FUNGI
1. General characteristics
2. General aspects of life cycle

B. VIRUS STRUCTURE
1. General structural characteristics, nucleic acid and protein
2. Lack organelles, nucleus
3. Structural aspects of typical bacteriophage
4. Genomic content RNA or DNA
5. Size relative to bacteria and eukaryotic cells

C. VIRAL LIFE CYCLE
1. Self-replicating biological units that must reproduce within specific host cell
2. Generalized phage and animal virus life cycles:
    a. attachment to host, penetration of cell membrane or cell wall, and entry of viral genetic material
    b. use of host synthetic mechanism to replicate viral components
    c. self-assembly and release of new viral particles
3. Retrovirus life cycle: integration into host DNA
4. Transduction: transfer of genetic material by viruses [MIC]

C. PROKARYOTIC CELL: STRUCTURE, BACTERIA
1. Lack of nuclear membrane, mitotic apparatus
2. Lack of typical eukaryotic organelles
3. Major classifications of bacteria by shape: bacilli (rod-shaped); spirilli (spiral shaped); cocci (spherical); eubacteria; archaea
4. Presence of cell wall in bacteria
5. Flagellar propulsion, mechanism

D. PROKARYOTIC CELL: GROWTH AND PHYSIOLOGY
1. Reproduction by fission
2. High degree of genetic adaptability, acquisition of antibiotic resistance
3. Exponential growth
4. Existence of anaerobic and aerobic variants
5. Parasitic and symbiotic

E. PROKARYOTIC CELL: GENETICS
1. Existence of plasmids, extragenomic DNA
2. Transformation: incorporation into bacterial genome of DNA fragments from external medium

Generalized Eukaryotic Cell

A. NUCLEUS
1. Defining characteristics: membrane bound nucleus, presence of organelles, meiotic division
2. Nucleus: compartmentalization, storage of genetic information
3. Nucleolus: location and function
4. Nuclear envelope, nuclear pores

B. MEMBRANE-BOUND ORGANELLES
1. Mitochondria
    a. site of ATP production
    b. self-replication
    c. inner and outer membrane
2. Lysosomes: membrane vesicle containing hydrolytic enzymes
3. Endoplasmic reticulum:
    a. rough and smooth components
    b. rough endoplasmic reticulum site of ribosomes
    c. double membrane structure, role in membrane biosynthesis
    d. role in biosynthesis of secreted proteins
4. Golgi apparatus: general structure and role in packaging and secretion

C. PLASMA MEMBRANE
1. General function in cell containment
2. Protein and lipid components, fluid mosaic model
3. Osmosis
4. Passive and active transport
5. Membrane channels
6. Sodium/potassium pump
7. Membrane receptors
8. Membrane potential
9. Exocytosis and endocytosis
10. Cell-cell communication (General concepts of cellular adhesion)
    a. gap junctions
    b. tight junctions
    c. desmosomes

D. CYTOSKELETON
1. General function in cell support and movement
2. Microfilaments: composition and role in cleavage and contractility
3. Microtubules: composition and role in support and transport
4. Intermediate filaments, role in support
5. Composition and function of eukaryotic cilia and flagella
6. Centrioles, microtubule organizing centers

E. MITOSIS
1. Mitotic process: prophase, metaphase, anaphase, telophase, interphase
2. Mitotic structures:
    a. centrioles, asters, spindles
    b. chromatids, centromeres, kinetochores
    c. nuclear membrane breakdown and reorganization
    d. mechanisms of chromosome movement
3. Phases of cell cycle: G_0, G_1, S, G_2, M
4. Growth arrest

Specialized Eukaryotic Cells and Tissues

A. NERVE CELL/NEURAL
1. Cell body: site of nucleus, organelles
2. Axon: structure and function
3. Dendrites: branched extensions of cell body
4. Myelin sheath, Schwann cells, insulation of axon
5. Nodes of Ranvier: propagation of nerve impulse along axon
6. Synapse: site of impulse propagation between cells
7. Synaptic activity
    a. transmitter molecules
    b. synaptic knobs
    c. fatigue
    d. propagation between cells without resistance loss
8. Resting potential: electrochemical gradient
9. Action potential
    a. threshold, all-or-none
    b. sodium/potassium pump
10. Excitatory and inhibitory nerve fibers: summation, frequency of firing

B. MUSCLE CELL/CONTRACTILE
1. Structural characteristics of striated, smooth, and cardiac muscle
2. Abundant mitochondria in red muscle cells-ATP source
3. Organization of contractile elements: actin and myosin filaments, crossbridges, sliding filament model
4. Calcium regulation of contraction
5. Sacromeres: “I” and “A” bands, “M” and “Z” lines, “H” zone (General structure only)
6. Presence of troponin and tropomyosin
7. Calcium regulation of contraction

C. OTHER SPECIALIZED CELL TYPES
1. Epithelial cells (cell types, simple epithelium, stratified epithelium)
2. Endothelial cells
3. Connective tissue cells (major cell types, fiber types, loose vs. dense, cartilage, extracellular matrix)

Nervous and Endocrine Systems

A. ENDOCRINE SYSTEM: HORMONES
   1. Function of endocrine system: specific chemical control at cell, tissue, and organ level
   2. Definition of endocrine gland, hormone
   3. Major endocrine glands: names, locations, products
   4. Major types of hormones

B. ENDOCRINE SYSTEM: MECHANISMS OF HORMONE ACTION
   1. Cellular mechanisms of hormone action
   2. Transport of hormones: blood supply
   3. Specificity of hormones: target tissue
   4. Integration with nervous system: feedback control

C. NERVOUS SYSTEM: STRUCTURE AND FUNCTION
   1. Major functions
      a. high level control and integration of body systems
      b. adaptive capability to external influences
      c. sensory input
      d. integrative and cognitive ability
   2. Organization of vertebrate nervous system
   3. Sensor and effector neurons
   4. Sympathetic and parasympathetic nervous systems: antagonistic control
   5. Reflexes
      a. feedback loop, reflex arc
      b. role of spinal cord, brain
      c. efferent control

D. NERVOUS SYSTEM: SENSORY RECEPTION AND PROCESSING
   1. Skin, proprioceptive, and somatic sensors
   2. Olfaction, taste
   3. Hearing
      a. ear structure
      b. mechanism of hearing
   4. Vision
      a. light receptors
      b. eye structure
      c. visual image processing

Circulatory, Lymphatic, and Immune Systems

A. CIRCULATORY SYSTEM
   1. Functions: circulation of oxygen, nutrients, hormones, ions and fluids, removal of metabolic waste
   2. Role in thermoregulation
   3. Four-chambered heart: structure and function
   4. Systolic and diastolic pressure
   5. Pulmonary and systemic circulation
   6. Arterial and venous systems
      a. structural and functional differences
      b. pressure and flow characteristics

7. Capillary beds
    a. mechanisms of gas and solute exchange
    b. mechanism of heat exchange
    c. source of peripheral resistance
8. Composition of blood
    a. plasma, chemicals, blood cells
    b. erythrocyte production and destruction; spleen, bone marrow
    c. regulation of plasma volume
    d. coagulation, clotting mechanisms
9. Oxygen transport by blood
    a. hemoglobin, hematocrit
    b. oxygen content
    c. oxygen affinity
10. Details of oxygen transport (biochemical characteristics of hemoglobin) modification of oxygen affinity

B. LYMPHATIC SYSTEM

Major functions

a. equalization of fluid distribution
b. transport of proteins and large glycerides
c. production of lymphocytes involved in immune reactions
d. return of materials to the blood
e. Composition of lymph: similarity to blood plasma; substances transported
f. Source of lymph: diffusion from capillaries by differential pressure
g. Lymph nodes: activation of lymphocytes

C. IMMUNE SYSTEM

1. Cells
    a. T-lymphocytes
    b. B-lymphocytes
2. Tissues
    a. bone marrow
    b. spleen
    c. thymus
    d. lymph nodes
3. Concept of antigen and antibody
4. Structure of antibody molecule
5. Mechanism of stimulation by antigen

Respiration System

A. RESPIRATORY SYSTEM

1. General function
    a. gas exchange, thermoregulation
    b. protection against disease, particulate matter
2. Breathing mechanisms
    a. diaphragm, rib cage, differential pressure
    b. resiliency and surface tension effects

Skin System

A. SKIN SYSTEM
- 1. Functions in homeostasis and osmoregulation
- *2.* Functions in thermoregulation
  - a. hair, erectile musculature
  - b. fat layer for insulation
  - c. sweat glands, location in dermis
  - *d.* vasoconstriction and vasodilation in surface capillaries
- 3. Physical protection
  - a. nails, calluses, hair
  - b. protection against abrasion, disease organisms
- 4. Structure (detail structure)
  - a. layer differentiation
  - b. relative impermeability to water

Digestive and Excretory Systems

A. DIGESTIVE SYSTEM
- 1. Ingestion
  - a. saliva as lubrication and source of enzymes
  - b. epiglottal action
  - c. pharynx function in swallowing
  - d. esophagus, transport function
- 2. Stomach
  - a. storage and churning of food
  - b. low pH, gastric juice, mucal protection against self-destruction
  - c. production of digestive enzymes, site of digestion
  - d. structure
- 3. Liver
  - a. production of bile
  - b. role in nutrient metabolism, vitamin storage
  - c. role in blood glucose regulation, detoxification
  - d. gross structure
- 4. Bile
  - a. storage in gall bladder
  - b. function
- 5. Pancreas
  - a. production of enzymes
  - b. transport of enzymes to small intestine
  - c. structure (gross)
- 6. Small Intestine
  - a. absorption of food molecules
  - b. function and structure of villi
  - c. production of enzymes, site of digestion
  - d. neutralization of stomach acid
  - e. structure (gross)
- 7. Large Intestine
  - a. anatomic subdivisions
  - b. absorption of water
  - c. bacterial flora
  - d. structure (gross)

8. Rectum: storage and elimination of waste, feces
9. Muscular control
    a. sphincter muscle
    b. peristalsis

B. EXCRETORY SYSTEM
1. Roles in homeostasis
    a. blood pressure
    b. osmoregulation
    c. acid-base balance
    d. removal of soluble nitrogenous waste
2. Kidney structure
    a. cortex
    b. medulla
3. Nephron structure
    a. glomerulus
    b. Bowman's capsule
    c. proximal tubule
    d. loop of Henle
    e. distal tubule
    f. collecting duct
4. Formation of urine
    a. glomerular filtration
    b. secretion and reabsorption of solutes
    c. concentration of urine
    d. counter-current multiplier mechanism
5. Storage and elimination: ureter, bladder, urethra

Muscle and Skeletal Systems

A. MUSCLE SYSTEM
1. Important functions
    a. support, mobility
    b. peripheral circulatory assistance
    c. thermoregulation (shivering reflex)
2. Structure of three basic muscle types: striated, smooth, cardiac
3. Nervous control
    a. motor neurons
    b. neuromuscular junctions, motor end plates
    c. voluntary and involuntary muscles
    d. sympathetic and parasympathetic innervation

B. SKELETAL SYSTEM
1. Functions
    a. structural rigidity and support
    b. calcium storage
    c. physical protection
2. Skeletal structure
    a. specialization of bone types, structures
    b. joint structures
    c. endo- vs. exoskeleton
3. Cartilage: structure and function

4. Ligaments, tendons
5. Bone structure
    a. calcium/protein matrix
    b. bone growth

Reproductive System and Development

A. REPRODUCTIVE SYSTEM
1. Male and female reproductive structures and their functions
    a. gonads
    b. genitalia
    c. differences between male and female structures
2. Gametogenesis by meiosis
3. Ovum and sperm
    a. differences in formation
    b. differences in morphology
    c. relative contribution to next generation
4. Reproductive sequence: fertilization; implantation; development; birth

B. EMBRYOGENESIS
1. Stages of early development: order and general features of each
    a. fertilization
    b. cleavage
    c. blastula formation
    d. gastrulation
        i. first cell movements
        ii. formation of primary germlayers: endoderm, mesoderm, ectoderm
    e. neurulation
2. Major structures arising out of primary germ layers

C. DEVELOPMENTAL MECHANISMS
1. Cell specialization
    a. determination
    b. differentiation
    c. tissue types
2. Cell communication in development
3. Gene regulation in development
4. Programmed cell death

Evolution

A. EVOLUTION
1. Natural selection
    a. fitness concept
    b. selection by differential reproduction
    c. concepts of natural and group selection
    d. evolutionary success as increase in percent representation in the gene pool of the next generation

2. Speciation
    a. definition of species
    b. polymorphism
    c. adaptation and specialization
    d. concepts of ecological niche, competition
    e. concept of population growth through competition
    f. inbreeding
    g. outbreeding
    h. bottlenecks
    i. divergent, parallel, and convergent evolution
    j. Symbiotic relationships
        a. Parasitism
        b. Commensalism
3. Ontogeny recapitulates phylogeny
4. Evolutionary time as measured by gradual random changes in genome
5. Origin of life

B. COMPARATIVE ANATOMY
1. Chordate features
    a. notochord
    b. pharangeal pouches, brachial arches
    c. dorsal nerve cord
2. Vertebrate phylogeny: vertebrate classes and relations to each other

Organic Chemistry
The Covalent Bond
1. *σ and π bonds (No Alkenes)*
    a. hybrid orbitals: sp^3, sp^2, sp and respective geometries
    b. valence shell electron pair repulsion and the prediction of shapes of molecules (e.g., NH_3, H_2O, CO_2)
    c. structural formulas for molecules involving H, C, N, O, F, S, P, Si, Cl
    d. delocalized electrons and resonance in ions and molecules
2. Multiple bonding *(No Alkenes)*
    a. its effect on bond length and bond energies
    b. rigidity in molecular structure
3. Stereochemistry of covalently bonded molecules
    a. isomers
        i. structural isomers
        ii. stereoisomers (e.g. diastereomers, enantiomers, cis/trans isomers)
        iii. conformational isomers
    b. polarization of light, specific rotation
    c. absolute and relative configuration
        i. conventions for writing R and S forms
        ii. conventions for writing E and Z forms
    d. racemic mixtures, separation of enantiomers by biological means

Molecular Strucure and Spectra
1. Absorption spectroscopy
    a. infrared region

i. intramolecular vibrations and rotations
ii. recognizing common characteristic group absorptions, fingerprint region

b. visible region
i. absorption in visible region gives complementary color (e.g., carotene)
ii. effect of structural changes on absorption (e.g., indicators)

c. ultraviolet region *(No Alkenes)*
i. π-electron and non-bonding electron transition
ii. conjugated systems

2. Mass spectroscopy: m/e ratio, parent peak
3. NMR spectroscopy
a. protons in a magnetic field; equivalent protons
b. spin-spin splitting

Separations and Purifications

1. Extraction: distribution of solute between two immiscible solvents
2. Distillation
3. Chromatography-basic principles involved in separation process
a. column chromatography
i. gas-liquid chromatography
b. paper chromatography [1, u]
c. thin-layer chromotography
4. Recrystalization; solvent choice from solubility data

Hydrocarbons

A. ALIPHATIC - ALKANES
1. Description
a. nomenclature
b. physical properties
2. Important reactions
a. combustion
b. substitution reactions with halogens, etc.
3. General principles
a. stability of free radicals; chain reaction mechanism; inhibition
b. ring strain in cyclic compounds
c. bicyclic molecules

Oxygen Containing Compounds

A. ALCOHOLS
1. Description
a. nomenclature
b. physical properties
c. infrared absorption of OH group

2. Important reactions
    a. substitution reactions: S_N1 or S_N2, depending on alcohol and derived alkyl halide
    b. oxidation
    c. pinacol rearrangement in polyhydroxyalcohols; synthetic uses
    d. protection of alcohols
    e. reactions with $SOCl_2$ and PBr_3
    f. preparation of mesylates and tosylates
    g. esterification
    h. inorganic esters
3. General principles
    a. hydrogen bonding
    b. acidity of alcohols compared to other classes of oxygen-containing compounds
    c. effect of chain branching on physical properties

B. ALDEHYDES AND KETONES
1. Description
    a. nomenclature
    b. physical properties
    c. infrared absorption of C=O bond
2. Important reactions
    a. nucleophilic addition reactions at C=O bond
        i. acetal, hemiacetal
        ii. imine, enamine
    b. reactions at adjacent positions
        i. haloform reactions
        ii. aldol condensation
        iii. oxidation
    c. 1,3-dicarbonyls: internal H-bonding
    d. keto-enol tautomerism
    e. organometallic reagents
    f. acetoacetic ester syntheses
    g. Wolff-Kishner reaction
    h. Grignard reagents
3. General principles
    a. effect of substituents on reactivity of C=O; steric hindrance
    b. acidity of αH; carbanions
    c. α, β-unsaturated carbonyls—resonance structures

C. CARBOXYLIC ACIDS
1. Description
    a. nomenclature
    b. physical properties and solubility
    c. infrared absorption

2. Important reactions
    a. carboxyl group reactions
        i. nucleophilic attack
        ii. reduction
        iii. decarboxylation
        iv. esterification
    b. reactions at 2 position
        i. halogenation
        ii. substitution reactions
3. General principles
    a. H bonding
    b. dimerization
    c. acidity of the carboxyl group
    d. inductive effect of substituents
    e. resonance stability of carboxylate anion

D. ACID DERIVATIVES (ACID CHLORIDES, ANHYDRIDES, AMIDES, ESTERS)
1. Description
    a. nomenclature
    b. physical properties
    c. infrared absorption
2. Important reactions
    a. preparation of acid derivatives
    b. nucleophilic substitution
    c. Hoffman degradation of amides; migration of aryl group
    d. transesterification
    e. hydrolysis of fats and glycerides (saponification)
    f. hydrolysis of amides
3. General principles
    a. relative reactivity of acid derivatives
    b. steric effects
    c. electronic effects
    d. strain (e.g., β-lactams)

E. KETO ACIDS AND ESTERS
1. Description; nomenclature
2. Important reactions
    a. decarboxylation
    b. acetoacetic ester synthesis
3. General principles
    a. acidity of α hydrogen and β-keto ester
    b. keto-enol tautomerism

Amines
1. Description
    a. nomenclature
    b. stereochemistry and physical properties
    c. infrared absorption

2. Major reactions
    a. amide formation
    b. reactions with nitrous acid
    c. alkylation
    d. Hoffman elimination
3. General principles
    a. basicity
    b. stabilization of adjacent carbonium ions (carbocations)
    c. effect of substituents on basicity of aromatic amines

Biological Molecules

A. CARBOHYDRATE
1. Description
    a. nomenclature and classification, common names
    b. absolute configuration
    c. cyclic structure and conformations of hexoses
    d. epimers and anomers
2. Hydrolysis of the glycoside linkage

B. AMINO ACIDS AND PROTEINS
1. Description
    a. absolute configuration at the α position
    b. amino acids as dipolar ions classification
    c. classification
        i. acidic or basic
        ii. hydrophobic or hydrophilic
2. Reactions
    a. peptide linkage
    b. hydrolysis
3. General principles
    a. 1° structure of proteins
    b. 2° structure of proteins

C. LIPIDS

Description; structure
    a. steroids
    b. terpenes
    c. triacyl glycerols
    d. free fatty acids

D. PHOSPHORUS COMPOUNDS
1. Description
    a. structure of phosphoric acids (anhydrides and esters)
2. Important reactions
    a. Wittig reaction

General Concepts in Organic Chemistry

A. CLASSIFICATION OF ORGANIC COMPOUNDS ACCORDING TO FUNCTIONAL GROUPS

B. REACTIONS, REACTION MECHANISMS, AND THE PRINCIPLES INVOLVED (metabolic enzyme-controlled reactions and pathways are not included in this topic area)

C. STRUCTURE AND STEREOCHEMISTRY OF ORGANIC COMPOUNDS

D. IUPAC NOMENCLATURE OF ORGANIC COMPOUNDS

E. MULTISTEP SYNTHESIS/RETROSYNTHESIS

General Chemistry

Electronic Structure and Periodic Table

A. ELECTRONIC STRUCTURE
   1. Orbital structure of hydrogen atom, principal quantum number n, number of electrons per orbital
   2. Ground state, excited states
   3. Absorption and emission spectra
   4. Quantum numbers l, m, s, and number of quantum states (electrons) per orbital]
   5. Common names and geometric shapes for orbitals s, p, d
   6. Conventional notation for electronic structure
   7. Bohr atom
   8. Effective nuclear charge

B. THE PERIODIC TABLE: CLASSIFICATION OF ELEMENTS INTO GROUPS BY ELECTRONIC STRUCTURE
   1. Alkali metals; their chemical characteristics
   2. Alkaline earth metals; their chemical characteristics
   3. Halogens; their chemical characteristics
   4. Noble gases; their physical and chemical characteristics
   5. Transition metals
   6. Representative elements
   7. Metals and non-metals
   8. Oxygen group

C. THE PERIODIC TABLE: VARIATIONS OF CHEMICAL PROPERTIES WITH GROUP AND ROW
   1. Electronic structure
      a. the representative elements
      b. the noble gases
      c. transition metals
   2. Valence electrons
   3. First and second ionization energy
      a. definition
      b. prediction from electronic structure for elements in different groups or rows
   4. Electron affinity
      a. definition
      b. variation with group and row

5. Electronegativity
    a. definition
    b. comparative values for some representative elements and important groups
6. Electron shells and the sizes of atoms

Bonding

A. THE IONIC BOND (ELECTROSTATIC FORCES BETWEEN IONS)
1. $E = kQ_1Q_2/d$
2. E = lattice energy
3. Force attraction = $R(n+e)(n-e)/d^2$

B. THE COVALENT BOND
1. σ and π bonds
    a. hybrid orbitals: sp^3, sp^2, sp and respective geometries
    b. valence shell electron pair repulsion and the prediction of shapes of molecules (e.g., NH_3, H_2O, CO_2)

2. Lewis electron dot formulas
    a. resonance structures
    b. formal change
    c. Lewis acids and bases
3. Partial ionic character
    a. role of electronegativity in determining charge distribution
    b. dipole moment

Phases and Phase Equilibria

A. GAS PHASE
1. Absolute temperature, K scale
2. Pressure, simple mercury barometer
3. Molar volume at 0°C and 1 atm = 22.4 mol/L
4. Ideal gas
    a. definition
    b. ideal gas law PV=nRT
        i. Boyle's law
        ii. Charles' law
        iii. Avogadro's number
5. Kinetic molecular theory of gases
6. Deviation of real-gas behavior from ideal gas law
    a. qualitative
    b. quantitative (Van der Waals' equation)
7. Partial pressure, mole fraction
8. Dalton's law relating partial pressure to composition

B. LIQUID PHASE: INTERMOLECULAR FORCES
1. Hydrogen bonding
2. Dipole interactions
3. Van der Waals' forces (London dispersion forces)

C. PHASE EQUILIBRIA
1. Phase changes and phase diagrams
2. Freezing point, melting point, boiling point

3. Molality
4. Colligative properties
    a. vapor pressure lowering (Raoult's law)
    b. boiling point elevation (($\Delta T_b = k_b m$)
    c. freezing point depression (($\Delta T_f = -k_f m$)
    d. osmotic pressure
5. Colloids
6. Henry's Law

Stoichiometry

1. Molecular weight
2. Empirical formula versus molecular formula
3. Metric units commonly used in the context of chemistry
4. Description of composition by % mass
5. Mole concept; Avagadro's number
6. Definition of density
7. Oxidation number
    a. common oxidizing and reducing agents
    b. disproportionation reactions
    c. redox titration
8. Description of reactions by chemical equations
    a. conventions for writing chemical equations
    b. balancing equations, including oxidation-reduction equations
    c. limiting reactants
    d. theoretical yields

Thermodynamics and Thermochemistry

A. ENERGY CHANGES IN CHEMICAL REACTIONS-THERMOCHEMISTRY

1. Thermodynamic system, state function
2. Conservation of energy
3. Endothermic/exothermic reactions
    a. enthalpy H and standard heats of reaction and formation
    b. Hess' law of heat summation
4. Bond dissociation energy as related to heats of formation
5. Measurement of heat changes (calorimetry); heat capacity; specific heat (specific heat of water = 1 cal/°C)
6. Entropy as a measure of "disorder"; relative entropy for gas, liquid, and crystal states
7. Free energy G
8. Spontaneous reactions and ΔG°

B. THERMODYNAMICS

1. Zeroth law: concept of temperature
2. First law: (ΔE = Q – W (conservation of energy)
3. Equivalence of mechanical, chemical, electrical and thermal energy units
4. Second law: concept of entropy
5. Temperature scales, conversion
6. Heat transfer: conduction, convection, radiation
7. Specific heat, specific heat of water (1 cal / °C·g)
8. Heat of fusion, heat of vaporization
9. PV diagram: work done = area under or enclosed by curve

10. Calorimetry

Rate Processes in Chemical Reactions – Kinetics and Equlibrium

1. Reaction rates
2. Dependence of reaction rate upon concentration of reactants; rate law
    a. rate constant
    b. reaction order
3. Rate determining step
5. Kinetic control versus thermodynamic control of a reaction
6. Catalysts; the special case of enzyme catalysis
7. Equilibrium in reversible chemical reactions
    a. Law of Mass Action
    b. the equilibrium constant
    c. application of LeChatelier's principle
8. Relationship of the equilibrium constant and $\Delta G°$

Solution Chemistry

A. IONS IN SOLUTION

1. Anion, cation; common names, formulas and charges for familiar ions (e.g., NH_4^+ ammonium, PO_4^{3-} phosphate, SO_4^{2-} sulfate)
2. Hydration, the hydronium ion

B. SOLUBILITY

1. Units of concentration (e.g., molarity)
2. Solubility product constant; the equilibrium expression
3. Common-ion effect; its use in laboratory separations
    a. complex ion formation]
    b. complex ions and solubility
    c. solubility and pH

Acids/Bases

A. ACID/BASE EQUILIBRIA

1. Brønsted definition of acid, base
2. Ionization of water
    a. K_w, its approximate value ($K_w = [H^+][OH^-] = 10^{-14}$ at STP)
    b. definition of pH; pH of pure water
3. Conjugate acids and bases (e.g., amino acids)
4. Strong acids and bases (common examples, e.g., nitric, sulfuric)
5. Weak acids and bases (common examples, e.g. acetic, benzoic)
    a. dissociation of weak acids and bases with or without added salt
    b. hydrolysis of salts of weak acids or bases
    c. calculation of pH of solutions of salts of weak acids or bases
6. Equilibrium constants K_a and K_b: pK_a, pK_b
7. Buffers
    a. definition and concepts (common buffer systems)
    b. influence on titration curves

B. TITRATION

1. Indicators
2. Neutralization
3. Interpretation of titration curves

4. Redox titration

Electrochemistry

1. Electrolytic cell
   a. electrolysis
   b. anode, cathode
   c. electrolyte
   d. Faraday's law relating amount of elements deposited (or gas liberated) at an electrode to current
   e. electron flow; oxidation, and reduction at the electrodes
2. Galvanic or voltaic cell
   a. half reactions
   b. reduction potentials; cell potential
   c. direction of electron flow

Physics

Translational Motion

1. Units and dimensions
2. Vectors, components
3. Vector addition
4. Speed, velocity (average and instantaneous)
5. Acceleration
6. Freely falling bodies

Force and Motion, Gravitation

1. Center of mass
2. Newton's first law, inertia
3. Newton's second law ($F = ma$)
4. Newton's third law, forces equal and opposite
5. Concept of a field
6. Law of gravitation ($F = K_G m_1 m_2 / r^2$)
7. Uniform circular motion
8. Centripetal acceleration ($F=mv^2/r$)
9. Weight
10. Friction, static and kinetic
11. Motion on an inclined plane
12. Analysis of pulley systems
13. Force

Equilibrium and Momentum

A. EQUILIBRIUM

1. Concept of force, units
2. Translational equilibrium ($\Sigma F_i = 0$)
3. Rotational equilibrium ($\Sigma \tau_I = 0$)
4. Analysis of forces acting on an object
5. Newton's first law, inertia
6. Torques, lever arms
7. Weightlessness

B. MOMENTUM
1. Momentum = mv
2. Impulse = Ft
3. Conservation of linear momentum
4. Elastic collisions
5. Inelastic collisions

Work and Energy

A. WORK
1. Derived units, sign conventions
2. Amount of work done in gravitational field is path-independent
3. Mechanical advantage
4. Work-kinetic energy theorem
5. Power

B. ENERGY
1. Kinetic energy: KE = 1/2 mv^2; units
2. Potential energy
   a. PE = mgh (gravitational, local)
   b. PE = 1/2kx^2 (spring)
   c. PE = –GmM/r (gravitational, general)
3. Conservation of energy
4. Conservative forces
5. Power, units

Waves and Periodic Motion

A. PERIODIC MOTION
1. Amplitude, period, frequency
2. Phase
3. Hooke's law, force F= –kx
4. Simple harmonic motion; displacement as a sinusoidal function of time
5. Motion of a pendulum
6. General periodic motion: velocity, amplitude

B. WAVE CHARACTERISTICS
1. Transverse and longitudinal waves
2. Wavelength, frequency, velocity
3. Amplitude, intensity
4. Supposition of waves, interference, addition
5. Resonance
6. Standing waves, nodes
7. Beat frequencies
8. Refraction and diffraction

Sound
1. Production of sound
2. Relative speed of sound in solids, liquids and gases
3. Intensity of sound, decibel units, log scale
4. Attenuation

5. Doppler effect: moving sound source or observer, reflection of sound from a moving object
6. Pitch
7. Resonance in pipes and strings
8. Harmonics
9. Ultrasound

Fluids and Solids

A. FLUIDS

1. Density, specific gravity
2. Buoyancy, Archimededs' principle
3. Hydrostatic pressure
   a. Pascal's law
   b. $P = \rho gh$ (pressure vs. depth)
4. Viscosity: Poiseuille flow
5. Continuity equation ($A \cdot v$ = constant)
6. Concept of turbulence at high velocities
7. Surface tension
8. Bernoulli's equation

B. SOLIDS

1. Density
2. Elastic properties (elementary properties)
3. Elastic limit
4. Thermal expansion coefficient
5. Shear
6. Compression

Electrostatics and Electromagnetism

A. ELECTROSTATICS

1. Charge, conductors, charge conservation
2. Insulators
3. Coulomb's law: $F = kq_1q_2/r^2$, sign conventions
4. Electric field
   a. field lines
   b. field due to charge distribution
5. Potential difference, absolute potential at point in space
6. Equipotential lines
7. Electric dipole
   a. definition of dipole
   b. behavior in electric field
   c. potential due to dipole
8. Electrostatic induction
9. Gauss' law

B. MAGNETISIM

1. Definition of the magnetic field **B**
2. Existence and direction of force on charge moving in magnetic field

C. LIGHT, ELECTROMAGNETIC RADIATION
   1. Properties of electromagnetic radiation (General properties only)
      a. velocity equals constant c, in vacuo
      b. electromagnetic radiation consists of perpendicularly oscillating electric and magnetic fields; direction of propagation is perpendicular to both
   2. Classification of electromagnetic spectrum (x-rays)

A. MAGNETISIM
   1. Orbits of charged particles moving in magnetic field
   2. General concepts of sources of the magnetic field
   3. Nature of solenoid, toroid
   4. Ampere's law for magnetic field induced by current in straight wire and other simple configurations
   5. Comparison of **E** and **B** relations
      a. force of **B** on a current
      b. energy

Electronic Circuit Elements

A. CIRCUIT ELEMENTS
   1. Current $I = \Delta Q/\Delta t$, sign conventions, units
   2. Battery, electromotive force, voltage
   3. Terminal potential, internal resistance of battery
   4. Resistance
      a. Ohm's law: $I = V/R$
      b. resistors in series
      c. resistors in parallel
      d. resistivity ($r = R\ A/t$)
   5. Capacitance
      a. concept of parallel plate capacitor
      b. energy of charged capacitor
      c. capacitors in series
      d. capacitors in parallel
      e. ddielectric
   6. Discharge of a capacitor through a resistor

B. CIRCUITS
   Power in circuits: $P = VI$, $P = I^2R$

C. ALTERNATING CURRENTS AND REACTIVE CIRCUITS
   1. Root-mean-square current
   2. Root-mean-square voltage

Light and Geometrical Optics

A. LIGHT, ELECTROMAGNETIC RADIATION
   1. Concept of interference; Young double slit experiment
   2. Thin films, diffraction grating, single slit diffraction
   3. Other diffraction phenomena, x-ray diffraction
   4. Polarization of light
   5. Visual spectrum, color
      a. energy
      b. lasers

B. GEOMETRICAL OPTICS
1. Reflection from plane surface: angle of incidence equals angle of reflection
2. Refraction, refractive index n; Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
3. Dispersion, change of index of refraction with wavelength
4. Conditions for total internal reflection
5. Spherical mirrors
   a. center of curvature
   b. focal length
   c. real and virtual images
6. Thin lenses
   a. converging and diverging lenses
   b. use of formula $1/p + 1/q = 1/f$, with sign conventions
   c. lens strength, diopters
7. Combination of lenses
8. Lens aberration
9. Ray tracing
10. Optical instruments]

Atomic and Nuclear Structure

I. PHYSICS

A. Atomic Structure and Spectra
1. Emission spectrum of hydrogen (Bohr model)
2. Atomic energy levels
   a. quantized energy levels for electrons
   b. calculation of energy emitted or absorbed when an electron changes energy levels

B. Atomic Nucleus
1. Atomic number, atomic weight
2. Neutrons, protons, isotopes
3. Nuclear forces
4. Radioactive decay: α, β, γ, half-life, exponential decay, semi-log plots
5. General nature of fission
6. General nature of fusion
7. Mass deficit, energy liberated

II. CHEMISTRY

Atomic and Nuclear Structure
1. Nuclear particles
2. Atomic number, atomic weight
3. Isotopes
4. Binding energy
5. Nuclear decay
   a. α, β and γ decay
   b. stability, half-life

Basic Concepts and General Techniques

A. UNITS AND DIMENSIONS
   1. Metric units:
      a. conversions within metric system
      b. conversion from metric to English units
      c. conversion within English system
   2. Dimensional balance, checking equations for dimensional correctness
   3. Significant figures
   4. Numerical estimation

B. BASIC CONCEPTS
   1. Mass, length, time
   2. Role of experiment and measurement

C. GRAPHING TECHNIQUES
   1. Cartesian co-ordinate system
   2. Use of semi-log graph paper
   3. Use of log-log graph paper

D. ERROR ANALYSIS
   1. Random vs. systematic errors
   2. Propagation of errors
   3. Mean and standard deviation
   4. Chi
   5. Student *t*