# Content Outline for Biological Science Section of the MCAT

# 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. Noncompetitive 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

### *DNA Structure and Function*

### A. DNA Structure and Function
1. Double-helix structure
2. DNA composition (purine and pyrimidine bases, deoxyribose, phosphate)
3. Base-pairing specificity, concept of complementarity
4. Function in transmission of genetic information

### B. DNA Replication
1. Mechanism of replication (separation of strands, specific coupling of free nucleic acids, DNA polymerase, primer required)
2. Semiconservative nature of replication

### C. Repair of DNA
1. Repair during replication
2. Repair of mutations

### D. Recombinant DNA Techniques
1. Restriction enzymes
2. Hybridization

3. Gene cloning
4. PCR

***Protein Synthesis***

**A. Genetic Code**
1. Typical information flow (DNA → RNA → protein)
2. Codon–anticodon relationship, degenerate code
3. Missense and nonsense codons
4. Initiation and termination codons (function, codon sequences)

**B. Transcription**
1. mRNA composition and structure (RNA nucleotides, 5′ cap, poly-A tail)
2. tRNA and rRNA composition and structure (e.g., RNA nucleotides)
3. Mechanism of transcription (RNA polymerase, promoters, primer not required)

**C. Translation**
1. Roles of mRNA, tRNA, and rRNA; RNA base-pairing specificity
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, tumor suppressor genes
4. Posttranscriptional control, basic concept of splicing (introns, exons)

**MICROBIOLOGY**

**A. Fungi**
1. General characteristics
2. General aspects of life cycle

**B. Virus Structure**
1. General structural characteristics (nucleic acid and protein, enveloped and nonenveloped)
2. Lack of organelles and 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 cell, penetration of cell membrane or cell wall, entry of viral material
    b. use of host synthetic mechanisms to replicate viral components
    c. self-assembly and release of new viral particles
3. Retrovirus life cycle, integration into host DNA, reverse transcriptase
4. Transduction, transfer of genetic material by viruses

**D. Prokaryotic Cell: Bacteria Structure**
1. Lack of nuclear membrane and mitotic apparatus
2. Lack of typical eukaryotic organelles
3. Major classifications: bacilli (rod-shaped), spirilli (spiral-shaped), cocci (spherical); eubacteria, archaebacteria
4. Presence of cell wall
5. Flagellar propulsion

**E. 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

**F. Prokaryotic Cell: Genetics**
1. Existence of plasmids, extragenomic DNA, transfer by conjugation
2. Transformation (incorporation into bacterial genome of DNA fragments from external medium)
3. Regulation of gene expression, coupling of transcription and translation

## GENERALIZED EUKARYOTIC CELL

**A. Nucleus and Other Defining Characteristics**
1. Defining characteristics (membrane-bound nucleus, presence of organelles, mitotic division)
2. Nucleus (compartmentalization, storage of genetic information)
3. Nucleolus (location, function)
4. Nuclear envelope, nuclear pores

**B. Membrane-bound Organelles**
1. Mitochondria
    a. site of ATP production
    b. self-replication; have own DNA and ribosomes
    c. inner and outer membrane
2. Lysosomes (vesicles containing hydrolytic enzymes)
3. Endoplasmic reticulum
    a. rough (RER) and smooth (SER)
    b. RER (site of ribosomes)
    c. role in membrane biosynthesis: SER (lipids), RER (transmembrane proteins)

    d. RER (role in biosynthesis of transmembrane and secreted proteins that cotranslationally targeted to RER by signal sequence)
4. Golgi apparatus (general structure; role in packaging, secretion, and modification of glycoprotein carbohydrates)

**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, cell signaling pathways, second messengers
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; role in cleavage and contractility)
3. Microtubules (composition; 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. Cell Cycle and Mitosis**

1. Interphase and mitosis (prophase, metaphase, anaphase, telophase)
2. Mitotic structures and processes
    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

**F. Apoptosis (Programmed Cell Death)**

## SPECIALIZED EUKARYOTIC CELLS AND TISSUES

### A. Nerve Cell/Neural

1. Cell body (site of nucleus and organelles)
2. Axon (structure, function)
3. Dendrites (structure, function)
4. Myelin sheath, Schwann cells, oligodendrocytes, insulation of axon
5. Nodes of Ranvier (role in 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. Abundant mitochondria in red muscle cells (ATP source)
2. Organization of contractile elements (actin and myosin filaments, cross bridges, sliding filament model)
3. Calcium regulation of contraction, sarcoplasmic reticulum
4. Sarcomeres ("I" and "A" bands, "M" and "Z" lines, "H" zone—general structure only)
5. Presence of troponin and tropomyosin

### C. Other Specialized Cell Types

1. Epithelial cells (cell types, simple epithelium, stratified epithelium)
2. Endothelial cells
3. Connective tissue cells (major tissues and cell types, fiber types, loose versus dense, extracellular matrix)

## NERVOUS AND ENDOCRINE SYSTEMS

### A. Endocrine System: Hormones

1. Function of endocrine system (specific chemical control at cell, tissue, and organ levels)
2. Definitions 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 (bloodstream)
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. response to external influences
    c. sensory input
    d. integrative and cognitive abilities
2. Organization of vertebrate nervous system
3. Sensor and effector neurons
4. Sympathetic and parasympathetic nervous systems (functions, antagonistic control)
5. Reflexes
    a. feedback loop, reflex arc, effects on flexor and extensor muscles
    b. roles 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, function)
4. Systolic and diastolic pressure
5. Pulmonary and systemic circulation
6. Arterial and venous systems (arteries, arterioles, venules, veins)
    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
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, role of liver in production of clotting factors
9. Oxygen and carbon dioxide transport by blood
   a. hemoglobin, hematocrit
   b. oxygen content
   c. oxygen affinity
10. Details of oxygen transport: biochemical characteristics of hemoglobin
   a. modification of oxygen affinity

**B. Lymphatic System**

1. Major functions
   a. equalization of fluid distribution
   b. transport of proteins and large glycerides
   c. return of materials to the blood
2. Composition of lymph (similarity to blood plasma; substances transported)
3. Source of lymph (diffusion from capillaries by differential pressure)
4. Lymph nodes (activation of lymphocytes)

**C. Immune System: Innate and Adaptive Systems**

1. Cells and their basic functions
   a. macrophages, neutrophils, mast cells, natural killer cells, dendritic cells
   b. T lymphocytes
   c. B lymphocytes, plasma cells
2. Tissues
   a. bone marrow
   b. spleen
   c. thymus
   d. lymph nodes
3. Basic aspects of innate immunity and inflammatory response
4. Concepts of antigen and antibody
5. Structure of antibody molecule
6. Mechanism of stimulation by antigen; antigen presentation

## 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, protection by mucus against self-destruction
   c. production of digestive enzymes, site of digestion
   d. structure (gross)

3. Liver
    a. production of bile
    b. roles in nutrient metabolism, vitamin storage
    c. roles in blood glucose regulation, detoxification
    d. structure (gross)
4. Bile
    a. storage in gallbladder
    b. function
5. Pancreas
    a. production of enzymes, bicarbonate
    b. transport of enzymes to small intestine
    c. structure (gross)
6. Small intestine
    a. absorption of food molecules and water
    b. function and structure of villi
    c. production of enzymes, site of digestion
    d. neutralization of stomach acid
    e. structure (anatomic subdivisions)
7. Large intestine
    a. absorption of water
    b. bacterial flora
    c. 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. countercurrent multiplier mechanism (basic function)

5. Storage and elimination (ureter, bladder, urethra)

## MUSCLE AND SKELETAL SYSTEMS

### A. Muscle System

1. Functions
    a. support, mobility
    b. peripheral circulatory assistance
    c. thermoregulation (shivering reflex)
2. Structural characteristics of skeletal, smooth, and cardiac muscle; striated versus nonstriated
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. endoskeleton versus exoskeleton
3. Cartilage (structure, function)
4. Ligaments, tendons
5. Bone structure
    a. calcium–protein matrix
    b. bone growth (osteoblasts, osteoclasts)

## RESPIRATORY SYSTEM

### A. Respiratory System

1. General structure and 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
    a. layer differentiation, cell types, tissue types (epithelial, connective)
    b. relative impermeability to water

## 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 germ layers (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

## GENETICS

### A. Mendelian Concepts

1. Phenotype and genotype (definitions, probability calculations, pedigree analysis)
2. Gene
3. Locus
4. Allele (single, multiple)
5. Homozygosity and heterozygosity
6. Wild type
7. Recessiveness
8. Complete dominance
9. Codominance
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, mitochondrial inheritance
5. Mutation
    a. general concept of mutation
    b. types of mutations (random, translation error, transcription error, base substitution, insertion, deletion, frameshift)
    c. chromosomal rearrangements (inversion, translocation)
    d. advantageous versus deleterious mutation
    e. inborn errors of metabolism
    f. relationship of mutagens to carcinogens

### C. Analytic Methods

1. Hardy–Weinberg principle
2. Testcross (backcross; concepts of parental, F1, and F2 generations)

## 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, genetic drift
    i. divergent, parallel, and convergent evolution
    j. symbiotic relationships
        i. parasitism
        ii. commensalism
        iii. mutualism
3. Relationship between ontogeny and 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

### A. Sigma and Pi Bonds

1. Hybrid orbitals ($sp^3$, $sp^2$, $sp$, and their respective geometries)
2. Valence shell electron-pair repulsion (VSEPR) theory, predictions of shapes of molecules (e.g., $NH_3$, $H_2O$, $CO_2$)
3. Structural formulas
4. Delocalized electrons and resonance in ions and molecules

### B. Multiple Bonding

1. Its effect on bond length and bond energies
2. Rigidity in molecular structure

### C. Stereochemistry of Covalently Bonded Molecules

1. Isomers
    a. constitutional isomers
    b. stereoisomers (e.g., diastereomers, enantiomers, cis and trans isomers)
    c. conformational isomers
2. Polarization of light, specific rotation
3. Absolute and relative configuration
    a. conventions for writing R and S forms
    b. conventions for writing E and Z forms
4. Racemic mixtures, separation of enantiomers

## MOLECULAR STRUCTURE AND SPECTRA

### A. Absorption Spectroscopy

1. Infrared region
    a. intramolecular vibrations and rotations
    b. recognizing common characteristic group absorptions, fingerprint region
2. Visible region
    a. absorption in visible region yielding complementary color
    b. effect of structural changes on absorption
3. Ultraviolet region
    a. $\pi$-electron and nonbonding electron transitions
    b. conjugated systems

### B. Mass Spectrometry

1. Mass-to-charge ratio ($m/z$)
2. Molecular ion peak

### C. $^1$H NMR Spectroscopy

1. Protons in a magnetic field, equivalent protons
2. Spin–spin splitting

## SEPARATIONS AND PURIFICATIONS

### A. Extraction (Distribution of Solute Between Two Immiscible Solvents)

### B. Distillation

### C. Chromatography (Basic Principles Involved in Separation Process)

1. Gas–liquid chromatography
2. Paper chromatography
3. Thin-layer chromatography

### D. Recrystallization (Solvent Choice from Solubility Data)

## HYDROCARBONS

### A. 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
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
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-dicarbonyl compounds, internal hydrogen bonding
    d. keto–enol tautomerism
    e. organometallic reagents
    f. Wolff–Kishner reaction
    g. Grignard reagents
3. General principles
    a. effect of substituents on reactivity of C=O; steric hindrance
    b. acidity of **α** hydrogens; carbanions
    c. α, β −unsaturated carbonyl compounds, their resonance structures

## C. Carboxylic Acids

1. Description
    a. nomenclature
    b. physical properties and solubility
2. Important reactions
    a. carboxyl group reactions
        i. nucleophilic attack
        ii. reduction
        iii. decarboxylation
        iv. esterification
    b. reactions at α position
        i. halogenation
        ii. substitution reactions
3. General principles
    a. hydrogen 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
2. Important reactions
    a. preparation of acid derivatives
    b. nucleophilic substitution
    c. Hofmann rearrangement
    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., $\beta$-lactams)

**E. Keto Acids and Esters**

1. Description
    a. nomenclature
2. Important reactions
    a. decarboxylation
    b. acetoacetic ester synthesis
3. General principles
    a. acidity of α hydrogens in $\beta$−keto esters
    b. keto–enol tautomerism

**AMINES**

1. Description
    a. nomenclature
    b. stereochemistry, physical properties
2. Important reactions
    a. amide formation
    b. reaction with nitrous acid
    c. alkylation
    d. Hofmann elimination
3. General principles
    a. basicity
    b. stabilization of adjacent carbocations
    c. effect of substituents on basicity of aromatic amines

## BIOLOGICAL MOLECULES

### A. Carbohydrates

1. Description
    a. nomenclature, classification, common names
    b. absolute configurations
    c. cyclic structure and conformations of hexoses
    d. epimers and anomers
2. Hydrolysis of the glycoside linkage
3. Reactions of monosaccharides

### B. Amino Acids and Proteins

1. Description
    a. a absolute configuration(s)
    b. amino acids classified as dipolar ions
    c. classification
        i. acidic or basic
        ii. hydrophobic or hydrophilic
2. Important reactions
    a. peptide linkage
    b. hydrolysis
3. General principles
    a. 1º structure of protein
    b. 2º structure of proteins

### C. Lipids

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

### D. Phosphorus Compounds

1. Description
    a. structure of phosphoric acids (anhydrides, esters)
2. Important reactions
    a. Wittig reaction