

### **Next Step MCAT 2015 Transition Guide**

With so much of the MCAT<sup>1</sup> changing, it can feel like you've got to start from scratch when thinking about the new test. Not so! The overwhelming majority of material from the old MCAT will still be on the new test.

In the following guide, we go through the old AAMC MCAT outline point by point and show you where that topic is on the new MCAT. We list the topics that are off the test in ***bold, italic text***.

Next to each topic you'll see a code, such as 1D or 5C. The new MCAT has concepts that are categorized as follows:

#### MCAT 2015 Hard Sciences

##### **Biological Biochemical Foundations of Living Systems (the Biological Sciences Section)**

1A: Amino Acids, Proteins, Enzymes

1B: DNA, Replication and Repair, Transcription, Translation, Gene Expression, DNA Biotech

1C: Classical Genetics, Meiosis, Mutation, Evolution

1D: Bioenergetics, Carbs, Cell Respiration, Gluconeogenesis, Metabolism

2A: Membranes, Organelles, Cytoskeleton, Epithelial, Connective Tissue

2B: Prokaryotes, Viruses

2C: Mitosis, Reproduction, Development

3A: Nerve Cells, Nervous System, Lipids, Endocrine System

3B: Physiology

##### **Chemical and Physical Foundations of Biological Systems (the Physical Sciences Section)**

4A: Translation, Force, Work, Energy, Periodic Motion

4B: Fluids, Circulatory, Gas

4C: Electrostatics, Magnetism, Circuits, Electrochem, Nerve Cells

4D: Sound, Light, Spectrometry, Optics

4E: Nuclear Chem, Electronic Structure, Periodic Table, Stoichiometry

5A: Acid/Base, Solutions

5B: Covalent Bonding, Intermolecular Forces

5C: Separations and Purifications

5D: Nucleotides, Amino Acids, Proteins, Lipids, Carbs, Carbonyls, Alcohols, Acids, Phenols

5E: Enzymes, Bioenergetics, Thermochemistry, Thermodynamics, Kinetics, Equilibrium

Finally, note that the new MCAT is a work in progress and is likely to evolve rapidly over the first few years of its use.

Thus, this guide should not be taken as an absolute – it is simply our best estimate based on what the AAMC has released so far.

---

<sup>1</sup> MCAT is a registered trademark of the AAMC. The AAMC has not reviewed this document and does not endorse any test prep company.

**"OLD MCAT" Science Topic Outline**

**BIOLOGY MOLECULAR BIOLOGY: ENZYMES AND METABOLISM**

A. Enzyme Structure and Function 1A, 5E

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

B. Control of Enzyme Activity 1A

1. Feedback inhibition 1A
2. Competitive inhibition 1A
3. Noncompetitive inhibition 1A

C. Basic Metabolism 1D

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

**MOLECULAR BIOLOGY: DNA AND PROTEIN SYNTHESIS**

**DNA Structure and Function**

A. DNA Structure and Function 1B

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

B. DNA Replication 1B

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

C. Repair of DNA 1B

1. Repair during replication 1B
2. Repair of mutations 1B

D. Recombinant DNA Techniques

1. Restriction enzymes 1B
2. Hybridization 1B
3. Gene cloning 1B
4. PCR 1B

**Protein Synthesis**

A. Genetic Code

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

B. Transcription 1B

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

C. Translation 1B

1. Roles of mRNA, tRNA, and rRNA; RNA base-pairing specificity 1B
2. Role and structure of ribosomes 1B

**MOLECULAR BIOLOGY: EUKARYOTES**

A. Eukaryotic Chromosome Organization 1B

1. Chromosomal proteins 1B
2. Telomeres, centromeres 1B

B. Control of Gene Expression in Eukaryotes 1B

1. Transcription regulation 1B
2. DNA binding proteins, transcription factors 1B
3. Cancer as a failure of normal cellular controls, oncogenes, tumor suppressor genes 1B
4. Posttranscriptional control, basic concept of splicing (introns, exons) 1B

**MICROBIOLOGY**

***A. Fungi OFF THE TEST***

1. ***General characteristics OFF THE TEST***
2. ***General aspects of life cycle OFF THE TEST***

**B. Virus Structure 2B**

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

**C. Viral Life Cycle 2B**

1. Self-replicating biological units that must reproduce within specific host cell 2B
2. Generalized phage and animal virus life cycles 2B
3. Attachment to host cell, penetration of cell membrane or cell wall, entry of viral material 2B
4. Use of host synthetic mechanisms to replicate viral components 2B
5. Self-assembly and release of new viral particles 2B
6. Retrovirus life cycle, integration into host DNA, reverse transcriptase 2B
7. Transduction, transfer of genetic material by viruses 2B

**D. Prokaryotic Cell: Bacteria Structure 2B**

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

**E. Prokaryotic Cell: Growth and Physiology 2B**

1. Reproduction by fission 2B
2. High degree of genetic adaptability, acquisition of antibiotic resistance 2B
3. Exponential growth 2B
4. Existence of anaerobic and aerobic variants 2B

**F. Prokaryotic Cell: Genetics**

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

**GENERALIZED EUKARYOTIC CELL**

**A. Nucleus and Other Defining Characteristics 2A**

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

**B. Membrane-bound Organelles 2A**

1. Mitochondria 2A
2. Site of ATP production 2A
3. Self-replication; have own DNA and ribosomes 2A
4. Inner and outer membrane 2A
5. Lysosomes (vesicles containing hydrolytic enzymes) 2A
6. Endoplasmic reticulum 2A
7. Rough (RER) and smooth (SER) 2A
8. RER (site of ribosomes) 2A
9. Role in membrane biosynthesis: SER (lipids), RER (transmembrane proteins) 2A
10. RER (role in biosynthesis of transmembrane and secreted proteins that cotranslationally targeted to RER by signal sequence) 2A
11. Golgi apparatus (general structure; role in packaging, secretion, and modification of glycoprotein carbohydrates) 2A

**C. Plasma Membrane 2A**

1. General function in cell containment 2A
2. Protein and lipid components, fluid mosaic model 2A
3. Osmosis 2A
4. Passive and active transport 2A
5. Membrane channels 2A
6. Sodium–potassium pump 2A
7. Membrane receptors, cell signaling pathways, second messengers 2A
8. Membrane potential 2A
9. Exocytosis and endocytosis 2A
10. Cell–cell communication (general concepts of cellular adhesion) 2A
11. Gap junctions 2A
12. Tight junctions 2A
13. Desmosomes 2A

**D. Cytoskeleton 2A**

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

**E. Cell Cycle and Mitosis 2C**

1. Interphase and mitosis (prophase, metaphase, anaphase, telophase) 2C
2. Mitotic structures and processes a. centrioles, asters, spindles b. chromatids, centromeres, kinetochores c. nuclear membrane breakdown and reorganization d. mechanisms of chromosome movement 2C
3. Phases of cell cycle (G<sub>0</sub>, G<sub>1</sub>, S, G<sub>2</sub>,M) 2C

4. Growth arrest 2C

F. Apoptosis (Programmed Cell Death) 2C

**SPECIALIZED EUKARYOTIC CELLS AND TISSUES**

A. Nerve Cell/Neural 3A

1. Cell body (site of nucleus and organelles) 3A
2. Axon (structure, function) 3A
3. Dendrites (structure, function) 3A
4. Myelin sheath, Schwann cells, oligodendrocytes, insulation of axon 4C
5. Nodes of Ranvier (role in propagation of nerve impulse along axon) 4C
6. Synapse (site of impulse propagation between cells) 4C
7. Synaptic activity 3A
8. Transmitter molecules 3A
9. Synaptic knobs 3A
10. Fatigue 3A
11. Propagation between cells without resistance loss 3A
12. Resting potential (electrochemical gradient) 4C
13. Action potential 4C
14. Threshold, all-or-none 4C
15. Sodium–potassium pump 4C
16. Excitatory and inhibitory nerve fibers (summation, frequency of firing) 3A

B. Muscle Cell/Contractile 3B

1. Abundant mitochondria in red muscle cells (ATP source) 3B
2. Organization of contractile elements (actin and myosin filaments, cross bridges, sliding filament model) 3B
3. Calcium regulation of contraction, sarcoplasmic reticulum 3B
4. Sarcomeres (“I” and “A” bands, “M” and “Z” lines, “H” zone—general structure only) 3B
5. Presence of troponin and tropomyosin 3B

C. Other Specialized Cell Types 2A

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

**NERVOUS AND ENDOCRINE SYSTEMS**

A. Endocrine System: Hormones 3A

1. Function of endocrine system (specific chemical control at cell, tissue, and organ levels) 3A
2. Definitions of endocrine gland, hormone 3A
3. Major endocrine glands (names, locations, products) 3A
4. Major types of hormones 3A

**B. Endocrine System: Mechanisms of Hormone Action 3A**

1. Cellular mechanisms of hormone action 3A
2. Transport of hormones (bloodstream) 3A
3. Specificity of hormones (target tissue) 3A

**C. Nervous System: Structure and Function 3A**

1. Major functions 3A
2. High-level control and integration of body systems 3A
3. Response to external influences 3A
4. Sensory input 3A
5. Integrative and cognitive abilities 3A
6. Organization of vertebrate nervous system 3A
7. Sensor and effector neurons 3A
8. Sympathetic and parasympathetic nervous systems (functions, antagonistic control) 3A
9. Reflexes 3A
10. Feedback loop, reflex arc, effects on flexor and extensor muscles 3A
11. Roles of spinal cord, brain 3A
12. Efferent control 3A

**D. Nervous System: Sensory Reception and Processing 6A**

1. Skin, proprioceptive and somatic sensors 6A
2. Olfaction, taste 6A
3. Hearing 6A
4. Ear structure 6A
5. Mechanism of hearing 6A
6. Vision 6A
7. Light receptors 6A
8. Eye structure 6A
9. Visual image processing 6A

**CIRCULATORY, LYMPHATIC, AND IMMUNE SYSTEMS – All 3B**

**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)
7. Structural and functional differences
8. Pressure and flow characteristics
9. Capillary Beds:

- i. Mechanisms of gas and solute exchange
- ii. Mechanism of heat exchange

10. Composition of blood

- i. Plasma, chemicals, blood cells
- ii. Erythrocyte production and destruction (spleen, bone marrow)
- iii. Regulation of plasma volume

11. Coagulation, clotting mechanisms, role of liver in production of clotting factors 9. Oxygen and carbon dioxide transport by blood

12. Hemoglobin, hematocrit

13. Oxygen content

14. Oxygen affinity

15. Details of oxygen transport: biochemical characteristics of hemoglobin a. modification of oxygen affinity

B. Lymphatic System

1. Major functions

- i. equalization of fluid distribution
- ii. transport of proteins and large glycerides
- iii. 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

2. Macrophages, neutrophils, mast cells, natural killer cells, dendritic cells

3. T lymphocytes

4. B lymphocytes, plasma cells

5. Tissues

- i. Bone marrow
- ii. Spleen
- iii. Thymus
- iv. Lymph nodes

6. Basic aspects of innate immunity and inflammatory response

7. Concepts of antigen and antibody

8. Structure of antibody molecule

9. Mechanism of stimulation by antigen; antigen presentation

**DIGESTIVE AND EXCRETORY SYSTEMS – All 3B**

A. Digestive System

1. Ingestion

- i. Saliva as lubrication and source of enzymes
- ii. Epiglottal action
- iii. Pharynx (function in swallowing)
- iv. Esophagus (transport function)

2. Stomach

- i. Storage and churning of food
- ii. Low pH, gastric juice, protection by mucus against self-destruction
- iii. Production of digestive enzymes, site of digestion
- iv. Structure (gross)

3. Liver

- i. Production of bile
- ii. Roles in nutrient metabolism, vitamin storage
- iii. Roles in blood glucose regulation, detoxification
- iv. Structure (gross)

4. Bile

- i. Storage in gallbladder
- ii. Function

5. Pancreas

- i. Production of enzymes, bicarbonate
- ii. Transport of enzymes to small intestine
- iii. Structure (gross)

6. Small Intestine

- i. Absorption of food molecules and water
- ii. Function and structure of villi
- iii. Production of enzymes, site of digestion
- iv. Neutralization of stomach acid
- v. Structure (anatomic subdivisions)

7. Large Intestine

- i. Absorption of water
- ii. Bacterial flora
- iii. Structure (gross)

8. Rectum (storage and elimination of waste, feces)

9. Muscular control

- i. Sphincter muscle b. peristalsis

B. Excretory System

1. Roles in homeostasis

- i. Blood pressure

- ii. Osmoregulation
  - iii. Acid–base balance
  - iv. Removal of soluble nitrogenous waste
2. Kidney structure
- i. Cortex
  - ii. Medulla
3. Nephron structure
- i. Glomerulus
  - ii. Bowman’s capsule
  - iii. Proximal tubule
  - iv. Loop of Henle
  - v. Distal tubule
  - vi. Collecting duct
4. Formation of urine
- i. Glomerular filtration
  - ii. Secretion and reabsorption of solutes
  - iii. Concentration of urine
  - iv. Countercurrent multiplier mechanism (basic function)
5. Storage and elimination (ureter, bladder, urethra)

**MUSCLE AND SKELETAL SYSTEMS – AII 3B**

**A. Muscle System**

- 1. Functions
  - i. Support, mobility
  - ii. Peripheral circulatory assistance
  - iii. Thermoregulation (shivering reflex)
- 2. Structural characteristics of skeletal, smooth, and cardiac muscle; striated versus nonstriated
- 3. Nervous control
  - i. Motor neurons
  - ii. Neuromuscular junctions, motor end plates
  - iii. Voluntary and involuntary muscles
  - iv. Sympathetic and parasympathetic innervation

**B. Skeletal System**

- 1. Functions
  - i. Structural rigidity and support
  - ii. Calcium storage
  - iii. Physical protection

2. Skeletal structure
  - i. Specialization of bone types; structures
  - ii. Joint structures
  - iii. Endoskeleton versus exoskeleton
3. Cartilage (structure, function)
4. Ligaments, tendons
5. Bone structure
  - i. Calcium–protein matrix
  - ii. Bone growth (osteoblasts, osteoclasts)

**RESPIRATORY SYSTEM – All 3B**

A. Respiratory System

1. General structure and function
  - i. Gas exchange, thermoregulation
  - ii. Protection against disease, particulate matter
2. Breathing mechanisms
  - i. Diaphragm, rib cage, differential pressure
  - ii. Resiliency and surface tension effects

**SKIN SYSTEM – All 3B**

A. Skin System

1. Functions in homeostasis and osmoregulation
2. Functions in thermoregulation
  - i. Hair, erectile musculature
  - ii. Fat layer for insulation
  - iii. Sweat glands, location in dermis
  - iv. Vasoconstriction and vasodilation in surface capillaries
3. Physical protection
  - i. Nails, calluses, hair
  - ii. Protection against abrasion, disease organisms
4. Structure
  - i. Layer differentiation, cell types, tissue types (epithelial, connective)
  - ii. Relative impermeability to water

**REPRODUCTIVE SYSTEM AND DEVELOPMENT**

**A. Reproductive System 3B**

1. Male and female reproductive structures and their functions 3B
2. Gonads 3B
3. Genitalia 3B
4. Differences between male and female structures 3B
5. Gametogenesis by meiosis 2C
6. Ovum and sperm 2C
  - i. Differences in formation 2C
  - ii. Differences in morphology 2C
  - iii. Relative contribution to next generation 2C
  
7. Reproductive sequence (fertilization, implantation, development, birth) 2C

**B. Embryogenesis 2C**

1. Stages of early development (order and general features of each) 2C
  - i. Fertilization 2C
  - ii. Cleavage 2C
  - iii. Blastula formation 2C
  - iv. Gastrulation 2C
  - v. First cell movements 2C
  - vi. Formation of primary germ layers (endoderm, mesoderm, ectoderm) 2C
  - vii. Neurulation 2C
  
2. Major structures arising out of primary germ layers 2C

**C. Developmental Mechanisms 2C**

1. Cell specialization 2C
  - i. Determination 2C
  - ii. Differentiation 2C
  - iii. Tissue types 2C
  
2. Cell communication in development 2C
3. Gene regulation in development 2C
4. Programmed cell death 2C

**GENETICS**

A. Mendelian Concepts 1C

1. Phenotype and genotype (definitions, probability calculations, pedigree analysis) 1C
2. Gene 1C
3. Locus 1C
4. Allele (single, multiple) 1C
5. Homozygosity and heterozygosity 1C
6. Wild type 1C
7. Recessiveness 1C
8. Complete dominance 1C
9. Codominance 1C
10. Incomplete dominance, leakage, penetrance, expressivity 1C
11. Gene pool 1C

B. Meiosis and Genetic Variability 1C

1. Significance of meiosis 1C
2. Important differences between meiosis and mitosis 1C
3. Segregation of genes 1C
  - i. Independent assortment 1C
  - ii. Linkage 1C
  - iii. Recombination 1C
  - iv. Single crossovers 1C
  - v. Double crossovers 1C
4. Sex-linked characteristics 1C
  - i. Very few genes on Y chromosome 1C
  - ii. Sex determination 1C
  - iii. Cytoplasmic inheritance, mitochondrial inheritance 1C
5. Mutation 1C
  - i. General concept of mutation 1C
  - ii. Types of mutations (random, translation error, transcription error, base substitution, insertion, deletion, frameshift) 1C
  - iii. Chromosomal rearrangements (inversion, translocation) 1C
  - iv. Advantageous versus deleterious mutation 1C
  - v. Inborn errors of metabolism 1C
  - vi. Relationship of mutagens to carcinogens 1C

C. Analytic Methods 1C

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

## **EVOLUTION**

### A. Evolution 1C

1. Natural selection 1C
2. Fitness concept 1C
3. Selection by differential reproduction 1C
4. Concepts of natural and group selection 1C
5. Evolutionary success as increase in percent representation in the gene pool of the next generation 1C
6. Speciation 1C
  - i. Definition of species 1C
  - ii. Polymorphism 1C
  - iii. Adaptation and specialization 1C
  - iv. Concepts of ecological niche, competition 1C
  - v. Concept of population growth through competition 1C
  - vi. Inbreeding 1C
  - vii. Outbreeding 1C
  - viii. Bottlenecks, genetic drift 1C
  - ix. Divergent, parallel, and convergent evolution 1C
  - x. Symbiotic relationships i. Parasitism ii. Commensalism iii. Mutualism 1C
7. Relationship between ontogeny and phylogeny 1V
8. Evolutionary time as measured by gradual random changes in genome 1V
9. ***Origin of life OFF THE TEST***
10. ***Comparative Anatomy OFF THE TEST***

### ***B. Chordate features OFF THE TEST***

1. ***Notochord OFF THE TEST***
2. ***Pharangeal pouches, brachial arches OFF THE TEST***
3. ***Dorsal nerve cord OFF THE TEST***
4. ***Vertebrate phylogeny (vertebrate classes and relations to each other) OFF THE TEST***

## **ORGANIC CHEMISTRY**

### **THE COVALENT BOND**

#### A. Sigma and Pi Bonds 5B

1. Hybrid orbitals ( $sp^3$ ,  $sp^2$ ,  $sp$ , and their respective geometries) 5B
2. Valence shell electron-pair repulsion (VSEPR) theory, predictions of shapes of molecules (e.g.,  $NH_3$ ,  $H_2O$ ,  $CO_2$ ) 5B
3. Structural formulas 5B
4. Delocalized electrons and resonance in ions and molecules 5B

B. Multiple Bonding 5B

1. Its effect on bond length and bond energies 5B
2. Rigidity in molecular structure 5B

C. Stereochemistry of Covalently Bonded Molecules 5B

1. Isomers 5B
  - i. Constitutional isomers 5B
  - ii. Stereoisomers (e.g., diastereomers, enantiomers, cis and trans isomers) 5B
  - iii. Conformational isomers 5B
2. Polarization of light, specific rotation 5B
3. Absolute and relative configuration 5B
  - i. Conventions for writing R and S forms 5B
  - ii. Conventions for writing E and Z forms 5B
4. Racemic mixtures, separation of enantiomers 5C

**MOLECULAR STRUCTURE AND SPECTRA**

A. Absorption Spectroscopy 4D

1. Infrared region 4D
  - i. Intramolecular vibrations and rotations 4D
  - ii. Recognizing common characteristic group absorptions, fingerprint region 4D
2. Visible region 4D
  - i. Absorption in visible region yielding complementary color 4D
  - ii. Effect of structural changes on absorption 4D
3. Ultraviolet region 4D
  - i. Electron and nonbonding electron transitions 4D
  - ii. Conjugated systems 4D

B. Mass Spectrometry 4E

1. Mass-to-charge ratio ( $m/z$ ) 4E
2. Molecular ion peak 4E

C.  $^1\text{H}$  NMR Spectroscopy 4D

1. Protons in a magnetic field, equivalent protons 4D
2. Spin-spin splitting 4D

**SEPARATIONS AND PURIFICATIONS AII 5C**

- 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 OFF THE TEST**

- 1. **Description OFF THE TEST**
  - i. **Nomenclature OFF THE TEST**
  - ii. **Physical properties OFF THE TEST**
- 2. **Important reactions OFF THE TEST**
  - i. **Combustion OFF THE TEST**
  - ii. **Substitution reactions with halogens, etc. OFF THE TEST**
- 3. **General principles OFF THE TEST**
  - i. **Stability of free radicals, chain reaction mechanism, inhibition OFF THE TEST**
  - ii. **Ring strain in cyclic compounds OFF THE TEST**
  - iii. **Bicyclic molecules OFF THE TEST**

**OXYGEN-CONTAINING COMPOUNDS**

**A. Alcohols 5D**

- 1. Description 5D
  - i. Nomenclature 5D
  - ii. Physical properties 5D
- 2. Important reactions 5D
- 3. Substitution reactions ( $S_N1$  or  $S_N2$ , depending on alcohol and derived alkyl halide) 5D
- 4. Oxidation 5D
- 5. **Pinacol rearrangement in polyhydroxyalcohols, synthetic uses OFF THE TEST**
- 6. Protection of alcohols 5D
- 7. **Reactions with  $SOCl_2$  and  $PBr_3$  OFF THE TEST**
- 8. Preparation of mesylates and tosylates 5D
- 9. Esterification 5D
- 10. Inorganic esters 5D

11. General principles 5D
  - i. Hydrogen bonding 5D
  - ii. Acidity of alcohols compared to other classes of oxygen-containing compounds 5D
  - iii. Effect of chain branching on physical properties 5D

**B. Aldehydes and Ketones 5D**

1. Description 5D
2. Nomenclature 5D
3. Physical properties 5D
4. Important reactions 5D
  - i. Nucleophilic addition reactions at C=O bond 5D
    1. Acetal, hemiacetal 5D
    2. Imine, enamine 5D
  - ii. Reactions at adjacent positions 5D
    1. Haloform reactions 5D
    2. Aldol condensation 5D
    3. Oxidation 5D
5. 1,3-dicarbonyl compounds, internal hydrogen bonding 5D
6. Keto–enol tautomerism 5D
7. Organometallic reagents 5D
8. **Wolff–Kishner reaction OFF THE TEST**
9. **Grignard reagents OFF THE TEST**
10. General principles 5D
  - i. Effect of substituents on reactivity of C=O; steric hindrance 5D
  - ii. Acidity of  $\alpha$  hydrogens; carbanions 5D
  - iii. Unsaturated carbonyl compounds, their resonance structures 5D

**C. Carboxylic Acids 5D**

1. Description 5D
  - i. Nomenclature 5D
  - ii. Physical properties and solubility 5D
2. Important reactions 5D
  - i. Carboxyl group reactions 5D
    1. Nucleophilic attack 5D
    2. Reduction 5D
    3. Decarboxylation 5D
    4. Esterification 5D
3. reactions at  $\alpha$  position 5D
  - i. Halogenation 5D
  - ii. Substitution reactions 5D

4. General principles 5D
  - i. Hydrogen bonding 5D
  - ii. Dimerization 5D
  - iii. Acidity of the carboxyl group 5D
  - iv. Inductive effect of substituents 5D
  - v. Resonance stability of carboxylate anion 5D

D. Acid Derivatives (Acid Chlorides, Anhydrides, Amides, Esters) 5D

1. Description
  - i. Nomenclature 5D
  - ii. Physical properties 5D
2. Important reactions 5D
  - i. Preparation of acid derivatives 5D
  - ii. Nucleophilic substitution 5D
  - iii. **Hofmann rearrangement OFF THE TEST**
  - iv. Transesterification 5D
  - v. Hydrolysis of fats and glycerides (saponification) 5D
  - vi. Hydrolysis of amides 5D
3. General principles 5D
  - i. Relative reactivity of acid derivatives 5D
  - ii. Steric effects 5D
  - iii. Electronic effects 5D
  - iv. Strain (e.g.,  $\beta$ -lactams) 5D

E. Keto Acids and Esters 5D

1. Description
  - i. Nomenclature 5D
2. Important reactions 5D
  - i. Decarboxylation 5D
  - ii. Acetoacetic ester synthesis 5D
3. General principles 5D
  - i. Acidity of  $\alpha$  hydrogens in keto esters 5D
  - ii. Keto-enol tautomerism 5D

**AMINES**

A. Description 5D

1. Nomenclature 5D

2. Stereochemistry, physical properties 5D
3. Important reactions 5D
4. Amide formation 5D
5. **Reaction with nitrous acid OFF THE TEST**
6. **Alkylation OFF THE TEST**
7. **Hofmann elimination OFF THE TEST**
8. General principles
  - i. Basicity 5D
  - ii. Stabilization of adjacent carbocations 5D
  - iii. Effect of substituents on basicity of aromatic amines 5D

### **BIOLOGICAL MOLECULES**

#### **A. Carbohydrates 1D**

1. Description 1D
  - i. Nomenclature, classification, common names 1D
  - ii. Absolute configurations 1D
  - iii. Cyclic structure and conformations of hexoses 1D
  - iv. Epimers and anomers 1D
2. Hydrolysis of the glycoside linkage 1D
3. Reactions of monosaccharides 1D

#### **B. Amino Acids and Proteins 5D**

1. Description 5D
  - i. Absolute configuration(s) 5D
  - ii. Amino acids classified as dipolar ions 5D
  - iii. Classification 5D
    1. Acidic or basic 5D
    2. Hydrophobic or hydrophilic 5D
2. Important reactions 5D
  - i. Peptide linkage 5D
  - ii. Hydrolysis 5D
3. General principles 5D
  - i. 1o structure of proteins 5D
  - ii. 2o structure of proteins 5D
4. Lipids 5D
5. Description, structure 5D
  - i. Steroids 5D
  - ii. Terpenes 5D
  - iii. Triacyl glycerols 5D

iv. Free fatty acids 5D

**C. Phosphorus Compounds OFF THE TEST**

1. **Description OFF THE TEST**
2. **Structure of phosphoric acids (anhydrides, esters) OFF THE TEST**
3. **Important reactions OFF THE TEST**
  - i. **Wittig reaction OFF THE TEST**

**GENERAL CHEMISTRY**

**ELECTRONIC STRUCTURE AND PERIODIC TABLE – All 4E**

**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 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; Physical and Chemical Properties of Elements**

1. Alkali metals
2. Alkaline earth metals
3. Halogens
4. Noble gases
5. Transition metals
6. Representative elements
7. Metals and nonmetals
8. Oxygen group

**C. The Periodic Table: Variations of Chemical Properties with Group and Row**

**D. Electronic structure**

1. Representative elements
2. Noble gases
3. Transition metals

**E. Valence electrons**

**F. First and second ionization energies**

1. Definition

2. Prediction from electronic structure for elements in different groups or rows
  3. Definition
  4. Variations with group and row
  5. Definition
  6. Comparative values for some representative elements and important groups
4. Electron affinity
5. Electronegativity
6. Electron shells and the sizes of atoms

**BONDING – All 5B**

A. The Ionic Bond (Electrostatic Forces Between Ions)

1. Electrostatic energy  $q_1q_2/r$
2. Electrostatic energy lattice energy
3. Electrostatic force  $q_1q_2/r^2$

B. The Covalent Bond

C. Sigma and pi bonds

1. Hybrid orbitals ( $sp^3$ ,  $sp^2$ ,  $sp$ , and respective geometries)
2. Valence shell electron-pair repulsion (VSEPR) theory, predictions of shapes of molecules (e.g.,  $NH_3$ ,  $H_2O$ ,  $CO_2$ )

D. Lewis electron dot formulas

1. Resonance structures
2. Formal charge
3. Lewis acids and bases

E. Partial ionic character

1. Role of electronegativity in determining charge distribution
2. Dipole moment

**PHASES AND PHASE EQUILIBRIA**

A. Gas Phase – All 4B

1. Absolute temperature, K
2. Pressure, simple mercury barometer
3. Molar volume at  $0^\circ C$  and 1 atm = 22.4 L/mol
4. Ideal gas
  - a. Definition
  - b. Ideal gas law ( $PV = nRT$ )
  - c. Boyle's law
  - d. Charles's law
    - i. Avogadro's law

- B. Kinetic theory of gases
- C. Deviation of real-gas behavior from ideal gas law
  - 1. Qualitative
  - 2. Quantitative (van der Waals equation)
    - i. Partial pressure, mole fraction
    - ii. Dalton's law relating partial pressure to composition
- D. Intermolecular Forces 5C
  - 1. Hydrogen bonding 5C
  - 2. Dipole interactions 5C
  - 3. London dispersion forces 5C
- E. Phase Equilibria 5E
  - 1. Phase changes, phase diagrams 5E
  - 2. Freezing point, melting point, boiling point, condensation point 5A
- F. Molality 5A
- G. Colligative properties 2A
- H. **Vapor pressure lowering (Raoult's law) OFF THE TEST**
- I. **Boiling point elevation ( $\Delta T_b = K_b m$ ) OFF THE TEST**
- J. **Freezing point depression ( $\Delta T_f = K_f m$ ) OFF THE TEST**
- K. Osmotic pressure 2A
- L. **Colloids OFF THE TEST**
- M. Henry's law 3B

**STOICHIOMETRY – All 4E**

- A. Molecular weight
- B. Empirical formula versus molecular formula
- C. Metric units commonly used in the context of chemistry
- D. Description of composition by percent mass
- E. Mole concept, Avogadro's number
- F. Definition of density
- G. Oxidation number
  - 1. Common oxidizing and reducing agents
  - 2. Disproportionation reactions
  - 3. Redox titration
- H. Description of reactions by chemical equations
  - 1. Conventions for writing chemical equations
  - 2. Balancing equations including redox equations
  - 3. Limiting reactants
  - 4. Theoretical yields

**THERMODYNAMICS AND THERMOCHEMISTRY – AII 5E**

A. Energy Changes in Chemical Reactions: Thermochemistry

1. Thermodynamic system, state function
2. Endothermic and exothermic reactions
  - i. Enthalpy H, standard heats of reaction and formation
  - ii. Hess's law of heat summation
3. Bond dissociation energy as related to heats of formation
4. Measurement of heat changes (calorimetry), heat capacity, specific heat capacity (specific heat capacity of water = 4.184 J/g·K)
5. Entropy as a measure of "disorder," relative entropy for gas, liquid, and crystal states
6. Free energy G
7. Spontaneous reactions and  $\Delta G_o$

B. Thermodynamics

1. Zeroth law (concept of temperature)
2. First law ( $\Delta E = q + w$ , conservation of energy)
3. Equivalence of mechanical, chemical, electrical, and thermal energy units
4. Second law (concept of entropy)
5. Temperature scales, conversions
6. Heat transfer (conduction, convection, radiation)
7. Heat of fusion, heat of vaporization
8. PV diagram (work done = area under or enclosed by curve)

**RATE PROCESSES IN CHEMICAL REACTIONS: KINETICS AND EQUILIBRIUM – AII 5E**

A. Reaction rates

B. Rate law, dependence of reaction rate on concentrations of reactants

1. Rate constant
2. Reaction order

C. Rate-determining step

D. Dependence of reaction rate on temperature

1. Activation energy
2. Activated complex or transition state
3. Interpretation of energy profiles showing energies of reactants and products, activation energy,  $\Delta H$  for the reaction
4. Arrhenius equation

E. Kinetic control versus thermodynamic control of a reaction

F. Catalysts, enzyme catalysis

- G. Equilibrium in reversible chemical reactions
  1. Law of mass action
  2. The equilibrium constant
  3. Application of Le Châtelier's principle
- H. Relationship of the equilibrium constant and  $\Delta G_o$

**SOLUTION CHEMISTRY – All 5A**

- A. Ions in Solution
  1. Anion, cation (common names, formulas, and charges for familiar ions; e.g.,  $\text{NH}_4^+$ , ammonium;  $\text{PO}_4^{3-}$ , phosphate;  $\text{SO}_4^{2-}$ , sulfate)
  2. Hydration, the hydronium ion
- B. Solubility
- C. Units of concentration (e.g., molarity)
- D. Solubility product constant, the equilibrium expression
- E. Common-ion effect, its use in laboratory separations
- F. Complex ion formation
- G. Complex ions and solubility
- H. Solubility and pH

**ACIDS AND BASES – All 5A**

- A. Acid–Base Equilibria
  1. Bronsted–Lowry definition of acids and bases
  2. Ionization of water
  3.  $K_w$ , its approximate value ( $K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 10^{-14}$  at 25°C)
  4. pH definition
  5. pH of pure water
- B. Conjugate acids and bases
- C. Strong acids and bases (common examples; e.g., nitric, sulfuric)
- D. Weak acids and bases (common examples; e.g., acetic, benzoic)
  1. Dissociation of weak acids and bases with or without added salt
  2. Hydrolysis of salts of weak acids or bases
  3. Calculation of pH of solutions of weak acids or bases
- E. Equilibrium constants  $K_a$  and  $K_b$  ( $\text{p}K_a$  and  $\text{p}K_b$ )
- F. Buffers
  1. Definition, concepts (common buffer systems)

2. Influence on titration curves

G. Titration

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

**ELECTROCHEMISTRY – All 4C**

A. Electrolytic cell

1. Electrolysis
2. Anode, cathode
3. Electrolytes
4. Faraday's law relating amount of elements deposited (or gas liberated) at an electrode to current

B. Electron flow, oxidation and reduction at the electrodes

C. Galvanic (voltaic) cell

1. Half-reactions
2. Reduction potentials, cell potential
3. Direction of electron flow

**PHYSICS**

**TRANSLATIONAL MOTION – All 4A**

- A. Dimensions (length or distance, time)
- B. Vectors, components
- C. Vector addition
- D. Speed, velocity (average and instantaneous)
- E. Acceleration
- F. Freely falling bodies

**FORCE AND MOTION, GRAVITATION – All 4A**

- A. Center of mass
- B. Newton's first law (inertia)
- C. Newton's second law ( $F = ma$ )
- D. Newton's third law (forces equal and opposite)
- E. Concept of a field
- F. Law of gravitation ( $F = -Gm_1m_2/r^2$ )
- G. Uniform circular motion

- H. Centripetal force ( $F = -mv^2/r$ )
- I. Weight
- J. Friction (static and kinetic)
- K. Motion on an inclined plane
- L. Analysis of pulley systems
- M. Force

**EQUILIBRIUM AND MOMENTUM – All 4A**

A. Equilibrium

- 1. Concept of force, units
- 2. Translational equilibrium ( $\sum F_i = 0$ )
- 3. Rotational equilibrium ( $\sum \tau_i = 0$ )
- 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 – All 4A**

A. Work

- 1. Derived units, sign conventions
- 2. Path independence of work done in gravitational field
- 3. Mechanical advantage
- 4. Work–energy theorem
- 5. Power

B. Energy

- 1. Kinetic energy ( $KE = mv^2/2$ , units)
- 2. Potential energy
  - i. Gravitational, local ( $PE = mgh$ )
  - ii. Spring ( $PE = kx^2/2$ )
  - iii. Gravitational, general ( $PE = -GmM/r$ )
- 3. Conservation of energy

4. Conservative forces
5. Power, units

**WAVES AND PERIODIC MOTION – All 4A**

A. Periodic Motion

1. Amplitude, period, frequency
2. Phase
3. Hooke's law ( $F = -kx$ )
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, wave speed
3. Amplitude and intensity
4. Superposition of waves, interference, wave addition
5. Resonance
6. Standing waves (nodes, antinodes)
7. Beat frequencies
8. Refraction and general nature of diffraction

**SOUND – All 4D**

A. Production of sound

- B. Relative speed of sound in solids, liquids, and gases  
C. Intensity of sound (decibel units, log scale)  
D. Attenuation

1. Doppler effect (moving sound source or observer, reflection of sound from a moving object)
2. Pitch
3. Resonance in pipes and strings
4. Harmonics
5. Ultrasound

**FLUIDS AND SOLIDS**

A. Fluids – All 4B

1. Density, specific gravity
2. Archimedes' principle (buoyancy)
3. Hydrostatic pressure
  - i. Pascal's law
  - ii. Pressure versus depth ( $P = \rho gh$ )

- Poiseuille flow (viscosity)
- Continuity equation ( $A_v = \text{constant}$ )
- Concept of turbulence at high velocities
- Surface tension
- Bernoulli's equation

B. Solids

- Density**
- Elastic properties (elementary properties)**
- Elastic limit**
- Thermal expansion coefficient  $\alpha$
- Shear**
- Compression**

**ELECTROSTATICS AND ELECTROMAGNETISM – All 4C**

A. Electrostatics

- Charges, conductors, charge conservation
- Insulators
- Coulomb's law ( $F = kq_1q_2/r^2$ , sign conventions)
- Electric field
  - Field lines
  - Field due to charge distribution

A. Potential difference, absolute potential at point in space

B. Equipotential lines

C. Electric dipole

- Definition of dipole
- Behavior in electric field
- Potential due to dipole

D. Electrostatic induction

E. Gauss's law

F. Magnetism

- Definition of the magnetic field  $B$
- Existence and direction of force on charge moving in magnetic field

G. Electromagnetic Radiation (Light)

- Properties of electromagnetic radiation (general properties only)
- Radiation velocity equals constant  $c$  in vacuum
- Radiation consists of oscillating electric and magnetic fields that are mutually perpendicular to each other and to the propagation direction
- Classification of electromagnetic spectrum (radio, infrared, UV, X-rays, etc.)

**ELECTRONIC CIRCUIT ELEMENTS – AII 4C**

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
  - i. Ohm's law ( $I = V/R$ )
  - ii. Resistors in series
  - iii. Resistors in parallel
  - iv. Resistivity ( $\rho = RA/L$ )
5. Capacitance
  - i. Concept of parallel-plate capacitor
  - ii. Energy of charged capacitor
  - iii. Capacitors in series
  - iv. Capacitors in parallel
  - v. Dielectrics
6. Discharge of a capacitor through a resistor
7. Conductivity theory

B. Circuits

1. Power in circuits ( $P = VI$ ,  $P = I^2 R$ )

C. Alternating Currents and Reactive Circuits

1. Root-mean-square current
2. Root-mean-square voltage

**LIGHT AND GEOMETRICAL OPTICS – AII 4D**

A. Light (Electromagnetic Radiation)

1. Concept of interference, Young's double-slit experiment

B. Thin films, diffraction grating, single-slit diffraction

C. Other diffraction phenomena, X-ray diffraction

D. Polarization of light

E. Doppler effect (moving light source or observer)

F. Visual spectrum, color a. energy b. lasers.

G. Geometrical Optics

H. Reflection from plane surface (angle of incidence equals angle of reflection)

I. Refraction, refractive index  $n$ , Snell's law ( $n_1 \sin \theta_1 = n_2 \sin \theta_2$ )

J. Dispersion (change of index of refraction with wavelength)

- K. Conditions for total internal reflection
- L. Spherical mirrors
  - 1. Mirror curvature, radius, focal length
  - 2. Use of formula  $(1/p) + (1/q) = 1/f$  with sign conventions
  - 3. Real and virtual images

- M. Thin lenses
  - 1. Converging and diverging lenses, focal length
  - 2. Use of formula  $(1/p) + (1/q) = 1/f$  with sign conventions
  - 3. Real and virtual images
  - 4. Lens strength, diopters
  - 5. Lens aberration

- N. Combination of lenses
- O. Ray tracing
- P. Optical instruments

**ATOMIC AND NUCLEAR STRUCTURE – All 4E**

- A. Atomic Structure and Spectra
  - 1. Emission spectrum of hydrogen (Bohr model)
  - 2. Atomic energy levels
    - i. Quantized energy levels for electrons
    - ii. Calculation of energy emitted or absorbed when an electron changes energy levels
- B. Atomic Nucleus
- C. Atomic number, atomic weight
- D. Neutrons, protons, isotopes
- E. Nuclear forces
- F. Radioactive decay ( $\alpha$ ,  $\beta$ ,  $\gamma$ , half-life, stability, exponential decay, semilog plots)
- G. General nature of fission
- H. General nature of fusion
- I. Mass deficit, energy liberated, binding energy