

**MCAT Physical Sciences Topics*****CHEMISTRY***

In this portion of the test you will be asked to apply basic theories of general chemistry to given problems. You should be familiar enough with such topics as solution chemistry, thermodynamics, kinetics, and electrochemistry and with the fundamentals of stoichiometry, electronic structure, bonding, phase equilibria, and acids and bases to solve basic chemistry problems and evaluate research in general chemistry. These concepts constitute the background knowledge you will need in order to answer questions, even though the questions may deal with situations or problems you have not previously encountered.

Major topics are indicated with Roman numerals (I, II, III, etc.). These topics are discussed in brief introductory paragraphs. The paragraphs are followed by alphabetical topic subdivisions (A, B, C, etc.) which specify the content in more detail.

**I. STOICHIOMETRY**

An important skill in chemistry is the ability to understand and balance chemical equations. Inherent in this skill is the understanding of mole concepts, chemical formulas, and oxidation numbers. You should be able to apply the concepts below to experimental situations and be able to reason about the relationships between elements and compounds in chemical reactions.

- A. Molecular weight
- B. Empirical formula versus molecular formula
- C. Metric units
- 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. Redox titration
- H. Description of reactions by chemical equations
  - 1. Conventions for writing chemical equations
  - 2. Balancing equations, including oxidation-reduction equations

**II. ELECTRONIC STRUCTURE AND THE PERIODIC TABLE**

Electronic structure is the key link between quantum theories and the chemical and physical properties of elements and compounds. This link is also critical to understanding the dynamics and complexities of chemical reactions. In addition, the order and location of elements in the periodic table are directly related to electronic structure. You will need to understand these relationships and apply them to the general periodic trends.

- A. Electronic structure
  - 1. Orbital structure of hydrogen atom, principal quantum number ( $n$ ), number of electrons per orbital
  - 2. Ground state, excited state
  - 3. Conventional notation for electronic structure

- B. Classification of elements and chemical properties of groups and rows
  - 1. Valence electrons of the common groups
  - 2. First and second ionization energies and trends
  - 3. Electron affinity
    - a. Variation of properties within groups and rows
  - 4. Electronegativity

### III. BONDING

Most physical and chemical properties of substances can be related to bond formation and characteristics. Covalent and ionic bonds are an extension of the electronic structures of the elements involved. Questions may range from the clarification or explanation of a molecule's structure and reactivity to the hypothetical evaluation of compounds and their relative polarity or ionic character.

- A. The ionic bond (electrostatic forces between ions)
- B. The covalent bond
  - 1. Lewis electron dot formulas
    - a. Resonance structures
    - b. Formal charge
    - c. Lewis acid, Lewis base
    - d. Valence shell electron pair repulsion and the prediction of shapes of molecules
  - 2. Partial ionic character
    - a. Role of electronegativity in determining charge distribution
    - b. Dipole moment

### IV. PHASES AND PHASE EQUILIBRIA

In addition to undergoing reactions, chemicals and elements are dynamic in phase, changing with conditions into gas, liquid, or solid form. The gas phase was well studied by a number of early scientists, who identified several relations that can be expressed as the ideal gas law. Later, the kinetic molecular theory of gases provided a firmer theoretical basis for the properties of gases. Intermolecular forces are a major factor in determining the individual phase characteristics of elements and compounds. The equilibrium or relationship between phases is often represented in a phase diagram. You will need to understand these concepts in order to answer questions in this section.

- A. Gas phase
  - 1. Standard temperature and pressure, standard molar volume
  - 2. Ideal gas
    - a. Ideal gas law ( $PV = nRT$ )
    - b. Boyle's law
    - c. Charles' law
  - 3. Kinetic molecular theory of gases
  - 4. Qualitative aspects of deviation of real gas behavior from ideal gas law

5. Partial pressure, mole fraction
6. Dalton's law relating partial pressure to composition
- B. Liquid phase (inter- and intramolecular forces)
  1. Hydrogen bonding
  2. Dipole interactions
  3. Van der Waals' forces
- C. Phase equilibria (solids, liquids, and gases)
  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

## V. SOLUTION CHEMISTRY

Most chemical reactions necessary for life occur in aqueous solutions. You should be familiar with ions in solution, solubility, and precipitation reactions.

- A. Ions in solution
  1. Anion
  2. Cation
  3. Common names, formulas, and charges for familiar ions
- B. Solubility
  1. Units of concentration (e.g., molarity)
  2. Solubility product constant, the equilibrium expression
  3. Common-ion effect

## VI. ACIDS AND BASES

Acids and bases, both weak and strong, are major factors in many reactions. The concepts below are important for understanding many of the complex processes and equilibria needed to sustain life.

- A. Acid/base equilibria
  1. Brønsted definition of acid and base
  2. Ionization of water
    - a.  $K_w$ , its approximate value ( $K_w = [\text{H}^+][\text{OH}^-] = 10^{-14}$  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 and titration curves
- B. Acid/base titrations
  1. Indicators
  2. Neutralization
  3. Interpretation of titration curves

## VII. THERMODYNAMICS AND THERMOCHEMISTRY

Thermodynamics and thermochemistry are the links between chemical bonding and energy. Although they can be explained in terms of bond energies, the thermodynamics of a reaction are most evident in the heat evolved or absorbed during a reaction. In addition, the concept of thermodynamics is useful in explaining why a reaction does or does not occur under specific conditions. Questions will require you to understand and apply these concepts.

- A. Thermochemistry
  1. Thermodynamic system, state function
  2. Conservation of energy
  3. Endothermic/exothermic reactions
    - a. Enthalpy  $\Delta H$  and standard heats of reaction
    - b. Hess' law of heat summation
  4. Bond dissociation energy as related to heats of formation
  5. Measurement of heat changes (calorimetry)
    - a. Heat capacity
    - b. 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  $\Delta G^\circ$
- B. Thermodynamics
  1. First law:  $\Delta E = Q - W$
  2. Equivalence of mechanical, chemical, and thermal energy units
  3. Temperature scales
  4. Heat transfer
    - a. Conduction
    - b. Convection
    - c. Radiation
  5. Coefficient of expansion
  6. Heats of fusion, vaporization

## VIII. RATE PROCESSES IN CHEMICAL REACTIONS: KINETICS AND EQUILIBRIUM

Reactions occur at a wide variety of rates and to various degrees of completion. Reaction equilibrium and rate concepts help us understand how to optimize conditions for the reactions we may want and how to limit those we do not want. In addition, there may be situations in which a reaction is either kinetically or thermodynamically controlled, requiring a full understanding of both concepts. In a biological setting, enzymes are the catalysts that maintain control of the chemical pathways needed for life. You should be able to apply your understanding of these topics to the topics presented in this section.

- A. Reaction rate
- B. Dependence of reaction rate upon concentration of reactants
  - 1. Rate law
  - 2. Rate constant
  - 3. Reaction order
- C. Rate-determining step
- D. Dependence of reaction rate upon temperature; activation energy
  - 1. Activated complex or transition state
  - 2. The interpretation of energy profiles showing energies of reactants and products, activation energy, and  $\Delta H$  for the reaction
- E. Kinetic control versus thermodynamic control of a reaction
- F. Catalysts; the special case of enzyme catalysis
- G. Equilibrium in reversible chemical reactions
  - 1. Law of mass action
  - 2. The equilibrium constant
  - 3. Application of LeChatelier's principle
- H. Relationship of the equilibrium constant and  $\Delta G^\circ$

## IX. ELECTROCHEMISTRY

Electrochemistry combines aspects of ionic solution chemistry, thermodynamics, and phase equilibria in order to explain how electric current is produced or used in a galvanic or electrolytic cell. You should be prepared to employ the following concepts in the analysis of galvanic, electrolytic, or concentration cells.

- A. Electrolytic cell
  - 1. Electrolysis
  - 2. Anode, cathode
  - 3. Electrolyte
  - 4. Faraday's law relating amount of elements deposited (or gas liberated) at an electrode to current
  - 5. Electron flow, oxidation and reduction at the electrodes
- B. Galvanic cell
  - 1. Half-cell reactions
  - 2. Reduction potentials, cell potential
  - 3. Direction of electron flow
- C. Concentration cell, direction of electron flow

**PHYSICS**

In this portion of the test you will be asked to apply basic theories of noncalculus physics to given problems. Topics include mechanics, wave motion, electricity and magnetism, light and optics, and modern physics. You should be prepared to apply your knowledge of these concepts to experimental situations. You will also need to be familiar with the conventions of problem solving in physics. Major physics topics are indicated by Roman numerals; alphabetic topic subdivisions describe the section content in more detail.

**X. TRANSLATIONAL MOTION**

The concepts of distance, speed, velocity, and acceleration describe the location and motion of an object at a point in time. Questions in this section require you to interpret relationships among these variables and apply these relationships to problems in physics.

- A. Units and dimensions
- B. Vectors
- C. Speed, velocity, and acceleration
- D. Uniformly accelerated motion
- E. Freely falling bodies
- F. Projectiles

**XI. FORCE AND MOTION, GRAVITATION**

Different forces act on objects to cause motion. Newton's second and third laws and the law of gravitation describe the movement of objects under the influence of force. The motions that occur can be circular or linear and with or without acceleration. Questions require you to interpret the ways objects move when acted upon by forces.

- A. Mass, center of mass, weight
- B. Newton's second law
- C. Newton's third law
- D. Law of gravitation
- E. Uniform circular motion, centripetal force
- F. Friction
- G. Inclined planes
- H. Pulley systems

**XII. EQUILIBRIUM AND MOMENTUM**

Equilibrium occurs when a body is at rest or moves with a constant velocity. Forces, torques, Newton's first law, and inertia describe translational and rotational equilibria. Questions about equilibrium call upon your understanding of the way forces act upon an object.

Momentum is a vector property that describes the motion of a system. The momentum of a system of particles can be used to describe the motion of the system by itself or when it is involved in elastic or inelastic collisions with other systems. Questions about momentum require you to interpret the motions of interacting bodies.

- A. Equilibrium
  1. Translational equilibrium
  2. Rotational equilibrium, torques, lever arms
  3. Newton's first law, inertia
- B. Momentum
  1. Impulse
  2. Conservation of linear momentum
  3. Elastic and inelastic collisions

### XIII. WORK AND ENERGY

Work and energy describe how objects interact with their environment and with other objects. The concepts of conservation of energy, work, and power describe the forms of energy and the transformations that occur between these forms. Questions in this section require you to apply your knowledge of these concepts to experimental situations.

- A. Work
- B. Kinetic energy
- C. Potential energy
- D. Conservation of energy
- E. Conservative forces
- F. Power

### XIV. WAVE CHARACTERISTICS AND PERIODIC MOTION

Wave characteristics and periodic motion describe the motion of systems that vibrate. Concepts used to describe this motion include transverse and longitudinal waves, superposition of waves, resonance, Hooke's law, and simple harmonic motion. Questions involve the interpretation of wave characteristics and the analysis of systems exhibiting periodic motion.

- A. Wave characteristics
  1. Transverse and longitudinal motion
  2. Wavelength, frequency, velocity, amplitude, intensity
  3. Superposition of waves, phase, interference, addition
  4. Resonance
  5. Standing waves, nodes
  6. Beats
- B. Periodic motion
  1. Hooke's law
  2. Simple harmonic motion
  3. Pendulum motion

### XV. SOUND

Sound waves are longitudinal waves that can travel only in a material medium. The concepts of speed, resonance, and the Doppler effect describe the behavior of sound waves in different media. You should understand wave behavior as it specifically applies to sound waves in order to answer questions in this section.

- A. Production of sound
- B. Relative speed of sound in solids, liquids, and gases
- C. Intensity, pitch
- D. Doppler effect
- E. Resonance in pipes and strings
- F. Harmonics

## XVI. FLUIDS AND SOLIDS

This section deals with the physical properties of fluids at rest and the way in which fluids move. Archimedes' principle and Bernoulli's equation describe fluid statics and dynamics. Analysis of instrumentation and experiments involving fluids are important applications of these concepts. Questions in this section require you to understand and apply these concepts.

Solids that are subjected to forces can undergo stress and/or strain. Questions in this section require you to analyze the elastic properties of solids in order to interpret the reactions of solids to stress and strain.

- A. Fluids
  - 1. Density, specific gravity
  - 2. Buoyancy, Archimedes' principle
  - 3. Hydrostatic pressure
  - 4. Viscosity
  - 5. Continuity equation
  - 6. Bernoulli's equation
  - 7. Turbulence
  - 8. Surface tension
- B. Solids
  - 1. Density
  - 2. Elementary topics in elastic properties

## XVII. ELECTROSTATICS AND ELECTROMAGNETISM

When electrically charged objects interact, their behavior can be described in terms of charge, electric force, electric field, and potential difference. Questions on electrostatics require you to interpret the electrostatic properties of a particular situation.

The motions of charged particles are affected by magnetic fields. The characteristics of the magnetic field determine the specifics of this movement. Electromagnetic waves are generated by accelerating electric charges and do not need a medium for propagation. The spectrum of electromagnetic waves includes a wide range of waves, including light and X rays. Questions on electromagnetism require you to interpret the ways magnetic fields act upon charged particles.

- A. Electrostatics
  - 1. Charge, charge conservation, conductors, insulators
  - 2. Coulomb's law, electric force
  - 3. Electric field
    - a. Field lines
    - b. Field due to charge distribution

4. Potential difference, absolute potential, equipotential lines
  5. Electric dipole
- B. Electromagnetism
1. Magnetic fields
  2. Electromagnetic spectrum, X rays

### XVIII. ELECTRIC CIRCUITS

In order to understand the workings of electric circuits, you must analyze the current through and the voltage across electric circuit elements wired in a variety of configurations. When batteries or other power supplies are wired to resistors and capacitors in parallel or series, application of Ohm's law interprets how the current and voltage vary. Questions require you to understand the motion of current through various circuits.

- A. Current
- B. Batteries, electromotive force, voltage, terminal potential, internal resistance
- C. Resistance, Ohm's law, series and parallel circuits, resistivity
- D. Capacitor, dielectrics
- E. Electric power
- F. Root-mean-square current and voltage

### XIX. LIGHT AND GEOMETRICAL OPTICS

Optical devices can be used to modify the appearance of light. The concepts of reflection and refraction describe the behavior of light as it encounters these devices. The nature of light and the way it behaves when traveling through different media are also important in understanding the behavior of light. You will need to understand the interaction of light with mirrors and lenses in various media to answer questions in this section.

- A. Visual spectrum, color
- B. Polarization
- C. Reflection, mirrors, total internal reflection
- D. Refraction, refractive index, Snell's law
- E. Dispersion
- F. Thin lenses, combination of lenses, diopters, lens aberrations

### XX. ATOMIC AND NUCLEAR STRUCTURE

The internal structure of the atom can be described as a nucleus orbited by electrons in different energy levels. The components of the nucleus and the transitions of electrons between energy levels are important aspects of the physical description of the atom. Questions in this section require you to understand the characteristics of these atomic components.

- A. Atomic number, atomic weight
- B. Neutrons, protons, isotopes
- C. Radioactive decay, half-life
- D. Quantized energy levels for electrons
- E. Fluorescence