# AAMC'S COMPLETE LIST OF CHEMICAL AND PHYSICAL FOUNDATIONS OF BIOLOGICAL SYSTEMS

## CHEMICAL AND PHYSICAL FOUNDATIONS OF BIOLOGICAL SYSTEMS

**4A. Translational motion, forces, work, energy, and equilibrium in living systems**
**4B. Importance of fluids for the circulation of blood, gas movement, and gas exchange**
**4C. Electrochemistry and electrical circuits and their elements**
**4D. How light and sound interact with matter**
**4E. Atoms, nuclear decay, electron structure, and atomic chemical behavior**
**5A Unique nature of water and its solutions**
**5B. Nature of molecules and intermolecular interactions**
**5C. Separation and purification methods**
**5D. Structure, function, and reactivity of biologically-relevant molecules**
**5E. Principles of chemical thermodynamics and kinetics**

(DETAILED INFORMATION FOUND ON SUBSEQUENT PAGES)

## 4A. TRANSLATIONAL MOTION, FORCES, WORK, ENERGY, AND EQUILIBRIUM IN LIVING SYSTEMS

Physics units and dimensions
Vectors, components
Vector addition
Speed, velocity (average and instantaneous)
Acceleration
Newton's First Law, Inertia
Newton's Second Law *(F=ma)*
Newton's Third Law, forces equal and opposite
Friction, static and kinetic
Center of mass
Equilibrium, overview
Vector analysis of forces acting on a point object
Torques, lever arms
Work done by a constant force
Mechanical advantage
Work kinetic Energy Theorem
Conservation forces
Kinetic Energy
Potential Energy (gravitational, local, spring)
Conservation of energy
Power, units (of energy point systems)
Amplitude, frequency, phase
Transverse and longitudinal waves: wavelength and propagation speed

## 4B. IMPORTANCE OF FLUIDS FOR THE CIRCULATION OF BLOOD, GAS MOVEMENT, AND GAS ENERGY

Density, specific gravity
Buoyancy, Archimedes' Principle
Hydrostatic pressure (Pascal's Law, formula for hydrostatic pressure)
Viscosity: Poiseuille Flow
Continuity equation
Concept of turbulence at high velocities
Surface tension
Bernoulli's equation
Venturi effect, pitot tube
Arterial and venous systems; pressure and flow
Absolute temperature, (K) Kelvin Scale
Pressure, simple mercury barometer
Molar volume at at 0°C and 1 atm = 22.4 L/mol
Ideal gas (definition, ideal gas law, Boyle's Law, Avogadro's Law
Kinetic molecular theory of gases
Heat capacity at constant volume and at constant pressure
Boltzmann's Constant
Deviation of real gas behavior from Ideal Gas Law (Qualitative, Quantitative, Van der Waals' Equation
Partial pressure, mole fraction
Dalton's Law relation partial pressure to composition

## 4C. ELECTROCHEMISTRY AND ELECTRICAL CIRCUITS AND THEIR ELEMENTS

Electrostatics
Charge, conductors, charge conservation, insulators
Coulomb's Law
Electric fields, field lines, field and charge distribution
Electrostatic energy, electric potential
Current $I = \Delta Q/\Delta t$, sign conventions, units
Electromotive force, voltage
Resistance: Ohm's Law $I = V/R$, resistors, resistivity $\rho = R\ A / L$
Capacitance: parallel plates, charged capacitors, dielectrics
Conductivity: metallic, electrolytic
ElectroMeters
Definition of magnetic field, motion of charged particles in magnetic fields; Lorentz force
Electrolytic cell, electrolysis, anode, cathode
Electrolyte, Faraday's Law
Electron flow, oxidation, reduction at the electrodes
Galvanic or Voltaic cells, half-reactions
Reduction potentials, cell potential, direction of electron flow
Concentration cell
Batteries
Electromotive force, Voltage
Lead-storage batteries, nickel-cadmium batteries
Myelin sheath, Schwann cells, insulation of axon
Nodes of Ranvier: propagation of nerve impulse along axon

## 4D. HOW LIGHT AND SOUND INTERACT WITH MATTER

Production of sound
Relative speed of sound in solids, liquids, and gases
Intensity of sound, decibel units, log scale
Attenuation (Damping)
Doppler Effect
Pitch, resonance in pipes and strings
Ultrasound, shock waves
Concept of Interference; Young Double-slit Experiment
Thin films, diffraction grating, single-slit diffraction
Other diffraction phenomena, X-ray diffraction
Polarization of light: linear and circular
Properties of electromagnetic radiation
Velocity equals constant *c, in vacuo*
Electromagnetic radiation consists of perpendicularly oscillating electric and magnetic fields; direction of propagation is perpendicular to both
Classification of electromagnetic spectrum, photon energy $E = hf$
Visual spectrum, color
Infrared region (intramolecular vibrations and rotations)
Recognizing common characteristic group absorptions, fingerprint region
Visible region (absorption, complementary colors, carotene)
Effect of structural changes on absorption (e.g., indicators)
Ultraviolet region (π-Electron and non-bonding electron transitions, conjugated systems)
NMR spectroscopy (protons in a magnetic field; equivalent protons, spin-spin splitting)
Optics: Reflection from plane surface: angle of incidence equals angle of reflection
Refraction, refractive index $n$; Snell's law: $n1 \sin \theta 1 = n2 \sin \theta 2$
Dispersion, change of index of refraction with wavelength
Conditions for total internal reflection
Spherical mirrors (center of curvature, focal length, real and virtual images)
Thin lenses: converging and diverging, lens strength, diopters
Use of formula $1/p + 1/q = 1/f$, with sign conventions
Lens aberration
Optical instruments, the human eye

## 4E. ATOMS, NUCLEAR DECAY, ELECTRONIC STRUCTURE, AND ATOMIC CHEMICAL BEHAVIOR

Orbital structure of hydrogen atom, principal quantum number n, number of electrons per orbital
Ground state, excited states
Absorption and emission line spectra
Use of Pauli Exclusion Principle
Paramagnetism and diamagnetism
Conventional notation for electronic structure
Bohr atom
Heisenberg Uncertainty Principle
Effective nuclear charge
Photoelectric effect
Alkali metals, alkaline earth metals: their chemical characteristics
Halogens: their chemical characteristics
Noble gases: their physical and chemical characteristics
Transition metals, representative elements, metals and non-metals
oxygen group
Valence electrons
First and second ionization energy (prediction from electronic structure for elements in other rows/areas)
Electron affinity, variation with group and row
Electronegativity, comparative values for elements and important groups
Electron shells and the sizes of atoms & ions
Stoichiometry, molecular weight, empirical vs molecular formula
Metric units commonly used in the context of chemistry
Description of composition by percent mass
Mole concept, Avogadro's number *NA*
Definition of density
Oxidation number, common oxidizing and reducing agents, disproportionation reactions
Description of reactions by chemical equations
Conventions for writing and balancing chemical equations (including redox equations)
Limiting reactants, theoretical yields

## 5A. UNIQUE NATURE OF WATER AND ITS SOLUTIONS

Brønsted–Lowry definition of acid, base
Ionization of water, definition of pH (pH of pure water)
*Kw*, its approximate value (*Kw* = [H+][OH−] = 10−14 at 25°C, 1 atm)
Conjugate acids and bases (e.g., NH4+ and NH3)
Strong acids and bases (e.g., nitric, sulfuric)
Weak acids and bases (e.g., acetic, benzoic)
Dissociation of weak acids and bases with or without added salt
Hydrolysis of salts of weak acids or bases
Calculation of pH of solutions of salts of weak acids or bases
Equilibrium constants *K*a and *K*b: p*K*a, p*K*b
Buffers, influence on titration curves
Ions in Solutions
Anion, cation: common names, formulas and charges for familiar ions (e.g., NH4+ ammonium, PO43− phosphate, SO42− sulfate)
Hydration, the hydronium ion
Solubility, units of concentration (e.g., molarity)
Solubility product constant; the equilibrium expression *K*sp
Common-ion effect, its use in laboratory separations
Complex ion formation, complex ions and solubility
Solubility and pH
Titration (indicators, neutralization, interpretation of the titration curves, redox titration)

## 5B. TRANSLATIONAL MOTION, FORCES, WORK, ENERGY, AND EQUILIBRIUM IN LIVING SYSTEMS

Covalent bonds
Lewis Electron Dot formulas (resonance structures, formal charge, Lewis acids and bases)
Partial ionic character (electronegativity in determining charge distribution, Dipole Moment)
σ and π bonds
Hybrid orbitals: *sp*3, *sp*2, *sp* and respective geometries
Valence shell electron pair repulsion and the prediction of shapes of molecules (e.g., NH3, H2O, CO2)
Structural formulas for molecules involving H, C, N, O, F, S, P, Si, Cl
Delocalized electrons and resonance in ions and molecules
Multiple bonding (effect on bond length and bond energies, rigidity in molecular structure)
Stereochemistry of covalently bonded molecules
Isomers (structural, stereoisomers [diastereomers, enantiomers, cis/trans isomers], conformational isomers
Polarization of light, specific rotation
Absolute and relative configuration (conventions for writing *R*, *S*, *E* and *Z* forms)
Hydrogen bonding
Dipole Interactions
Van der Waals' Forces (London dispersion forces)

## 5C. SEPARATION AND PURIFICATION METHODS

Extraction: distribution of solute between two immiscible solvents
Distillation
Chromatography: Basic principles involved in separation process
Column chromatography (gas-liquid; high pressure liquid)
Paper chromatography and thin-layer chromatography
Separation and purification of peptides and proteins
Electrophoresis
Quantitative analysis (determining how much of a given substance is in the larger sample)
Chromatography (size-exclusion; ion-exchange; affinity)
Racemic mixtures, separation of enantiomers (OC)

## 5D. STRUCTURE, FUNCTION, AND REACTIVITY OF BIOLOGICALLY-RELEVANT MOLECULES

Nucleotides and nucleosides: composition (sugar phosphate backbone, pyrimidine, purine residues)
Deoxyribonucleic acid: DNA; double helix
Amino acids: description, absolute configuration at the α position, dipolar ions
Classification of amino acids (acidic or basic, hydrophilic or hydrophobic)
Synthesis of α-amino acids (Strecker Synthesis, Gabriel Synthesis)
Peptides and proteins: reactions (sulfur linkage [cysteine; cystine], peptide linkage for proteins, hydrolysis)
Primary, secondary, and tertiary structure of proteins
Isoelectric point, conformational stability (hydrophobic interactions solvation layer [entropy])
Quaternary structure, denaturing and folding
Non-enzymatic protein functions: binding, immune system, motor
Lipids: description, types (triglycerides, steroids, phospholipids and phosphatides)
Lipids storage: triacylglycerols, free fatty acids: saponification
Structure of sphingolipids and waxes
Signals/cofactors of: fat-soluble vitamins; steroids; prostaglandins
Carbohydrate nomenclature and classification, common names
Carbohydrate: Absolute configuration; cyclic structure; conformations of hexoses
Epimers and anomers
Hydrolysis of the glycoside linkage
Keto-enol tautomerism of monosaccharides, disaccharides and polysaccharides
Aldehydes and Ketones: description; nomenclature; physical properties
Nucleophilic addition reactions at C=O bond (acetal, hemiacetal, imine, enamine, hydrine, cyanohydrin)
Oxidation of aldehydes, reactions at adjacent positions: enolate chemistry
Keto-enol tautomerism (α-racemization)
Aldol condensation, retro-aldol
Kinetic versus thermodynamic enolate
Effect of substituents on reactivity of C=O; steric hindrance
Acidity of α-H; carbanions
Alcohols: Description, nomenclature; physical properties (acidity, hydrogen bonding)
Alcohol reactions: Oxidation; substitution reactions: SN1 or SN2;
Protection of alcohols; preparation of mesylates and tosylates
Carboxylic Acids: Description, nomenclature, physical properties
Carboxyl group reactions (amides [and lactam], esters [and lactone], anhydride formation
Carboxyl: reduction, decarboxylation, reactions at 2-position, substitution
Acid Derivatives (Anhydrides, Amides, Esters): Description, Nomenclature, Physical properties
Acid Derivative reactions: Nucleophilic substitution; transesterification; hydrolysis of amides
Relative reactivity of acid derivatives
Acid Derivatives: steric effects, electronic effects, strain (e.g., β-lactams)
Phenols: oxidation and reduction (e.g., hydroquinones, ubiquinones): biological 2e⁻ redox centers
Polycyclic and Heterocyclic Aromatic Compounds
Biological aromatic heterocycles

## 5E. PRINCIPLES OF CHEMICAL THERMODYNAMICS AND KINETICS

Enzyme classification by reaction type
Enzyme Mechanism: (Substrates, active site model, induced-fit model, cofactors, vitamins)
Enzyme Kinetics (catalysis, Michaelis-Menten, cooperativity, how local conditions affect activity)
Enzyme Inhibition and Regulation (allosteric, covalently modified)
Bioenergetics/thermodynamics (Free energy/*K*eq, Concentration)
Phosphorylation/ATP (ATP hydrolysis $\Delta G << 0$; ATP group transfers)
Biological oxidation–reduction: (Half-reactions, Soluble electron carriers, Flavoproteins)
Thermodynamic system – state function
Zeroth Law – concept of temperature
First Law - conservation of energy in thermodynamic processes
*PV* diagram: work done = area under or enclosed by curve
Second Law – concept of entropy (measure of "disorder, entropy for gas, liquid, crystal states)
Measurement of heat changes (calorimetry), heat capacity, specific heat
Heat transfer – conduction, convection, radiation
Endothermic/exothermic reactions
Enthalpy, *H*, and standard heats of reaction and formation
Hess' Law of Heat Summation
Bond dissociation energy as related to heats of formation
Spontaneous reactions and $\Delta G°$
Coefficient of expansion
Heat of fusion, heat of vaporization
Dependence of reaction rate on concentration of reactants: (rate law, rate constant, reaction order)
Rate-determining step
Dependence of reaction rate upon temperature
Activation energy: (Activated complex or transition state)
Interpretation of energy profiles showing energies of reactants, products, activation energy, and $\Delta H$
Use of the Arrhenius Equation
Kinetic control versus thermodynamic control of a reaction
Catalysts
Equilibrium in reversible chemical reactions
Law of Mass Action
Equilibrium Constant
Application of Le Châtelier's Principle
Relationship of the equilibrium constant and $\Delta G°$