Amino Acids
• Description
  o Absolute configuration at the α position
  o Amino acids as dipolar ions
  o Classifications
  ▪ Acidic or basic
  ▪ Hydrophobic or hydrophilic
• Reactions
  o Sulfur linkage for cysteine and cysteine
  o Peptide linkage: polypeptides and proteins
  o Hydrolysis
	CHM 314, 420, 451 &
	BIO 151, 151L, 312, 312L, 403, 403L, 411, 411L, 440

Protein Structure
• Structure
  o 1° structure of proteins
  o 2° structure of proteins
  o 3° structure of proteins; role of proline, cystine, hydrophobic bonding
  o 4° structure of proteins (BIO, BC)
• Conformational stability
  o Denaturing and folding
  o Hydrophobic interactions
  o Solvation layer (entropy) (BC)
• Separation techniques
  o Isoelectric point
  o Electrophoresis
	CHM 420, 451, 462L &
	BIO 151, 151L, 312, 312L, 403, 403L, 411, 411L, 440, 462

Non-Enzymatic Protein Function • Binding • Immune system • Motors	CHM 420, 451, 452 & BIO 151, 151L, 312, 312L, 403, 403L, 411, 411L, 427

Enzyme Structure and Function
• Function of enzymes in catalyzing biological reactions
• Enzyme classification by reaction type
• Reduction of activation energy
• Substrates and enzyme specificity
• Active Site Model
• Induced-fit Model
• Mechanism of catalysis
  o Cofactors
  o Coenzymes
  o Water-soluble vitamins
• Effects of local conditions on enzyme activity
	BIO 151, 151L, 411, 411L, 462 & CHM 420, 451, 452

Control of Enzyme Activity
• Kinetics
  o General (catalysis)
  o Michaelis-Menten
  o Cooperativity
• Feedback regulation
	CHM 420, 451, 452 &
	BIO 151, 151L, 411, 411L, 462

• Inhibition – types o Competitive o Non-competitive o Mixed (BC) o Uncompetitive (BC) • Regulatory enzymes o Allosteric enzymes o Covalently-modified enzymes o Zymogen	
Nucleic Acid Structure and Function • Description • Nucleotides and nucleosides o Sugar phosphate backbone o Pyrimidine, purine residues • Deoxyribonucleic acid (DNA): double helix, Watson–Crick model of DNA structure • Base pairing specificity: A with T, G with C • Function in transmission of genetic information (BIO) • DNA denaturation, reannealing, hybridization	CHM 314, 420, 451, 452 & BIO 151, 151L, 312, 312L, 462
DNA Replication • Mechanism of replication: separation of strands, specific coupling of free nucleic acids • Semi-conservative nature of replication • Specific enzymes involved in replication • Origins of replication, multiple origins in eukaryotes • Replicating the ends of DNA molecules	BIO 151, 151L, 312, 312L, 440, 462, 470 & CHM 452
Repair of DNA • Repair during replication • Repair of mutations	BIO 151, 151L, 312, 312L, 411, 411L, 440, 462 & CHM 452
Genetic Code • Central Dogma: DNA → RNA → protein • The triplet code • Codon-anticodon relationship • Degenerate code, wobble pairing • Missense, nonsense codons • Initiation, termination codons • Messenger RNA (mRNA)	BIO 151, 151L, 312, 312L, 411, 411L, 462 & CHM 452, 462L
Transcription • Transfer RNA (tRNA); ribosomal RNA (rRNA) • Mechanism of transcription • mRNA processing in eukaryotes, introns, exons • Ribozymes, spliceosomes, small nuclear ribonucleoproteins (snRNPs), small nuclear RNA (snRNAs) • Functional and evolutionary importance of introns •	BIO 151, 151L, 312, 312L, 462 & CHM 452

Translation • Roles of mRNA, tRNA, rRNA • Role and structure of ribosomes • Initiation, termination co-factors • Post-translational modification of proteins	BIO 151, 151L, 312, 312L, 462 & CHM 452
Eukaryotic Chromosome Organization • Chromosomal proteins • Single copy vs. repetitive DNA • Supercoiling • Heterochromatin vs. euchromatin • Telomeres, centromeres	BIO 151, 151L, 312, 312L, 442, 462 & CHM 452
Recombinant DNA and Biotechnology • Gene cloning • Restriction enzymes • DNA libraries • Generation of cDNA • Hybridization • Expressing cloned genes • Polymerase Chain Reaction • Gel Electrophoresis and Southern Blotting • DNA sequencing • Analyzing gene expression • Determining gene function • Stem cells • Practical applications of DNA technology: medical applications, human gene therapy, pharmaceuticals, forensic evidence, environmental cleanup, agriculture • Safety and ethics of DNA technology	BIO 151, 151L, 312, 312L, 411, 411L & CHM 462L
Evidence that DNA is Genetic Material	BIO 151, 151L, 312, 312L, & CHM 420, 451, 452
Principles of Bioenergetics • Bioenergetics/thermodynamics o Free energy/Keq ▪ Equilibrium constant ▪ Relationship of the equilibrium constant and ΔG° o Concentration ▪ Le Châtelier's Principle o Endothermic/exothermic reactions o Free energy: G o Spontaneous reactions and ΔG° • Phosphoryl group transfers and ATP o ATP hydrolysis ΔG << 0 o ATP group transfers • Biological oxidation-reduction o Half-reactions	BIO 151, 151L, 411, 411L & CHM 420, 451

○ Soluble electron carriers ○ Flavoproteins	
Carbohydrates • Description ○ Nomenclature and classification, common names ○ Absolute configuration ○ Cyclic structure and conformations of hexoses ○ Epimers and anomers • Hydrolysis of the glycoside linkage • Monosaccharides • Disaccharides • Polysaccharides	BIO 151, 151L & CHM 314, 420, 451
Glycolysis, Gluconeogenesis, and the Pentose Phosphate Pathway • Glycolysis (aerobic), substrates and products ○ Feeder pathways: glycogen, starch metabolism • Fermentation (anaerobic glycolysis) • Gluconeogenesis (BC) • Pentose phosphate pathway (BC) • Net molecular and energetic results of respiration processes	BIO 151, 151L, 403, 403L, 411, 411L & CHM 420, 451
Principles of Metabolic Regulation • Regulation of metabolic pathways (BIO, BC) ○ Maintenance of a dynamic steady state • Regulation of glycolysis and gluconeogenesis • Metabolism of glycogen • Regulation of glycogen synthesis and breakdown ○ Allosteric and hormonal control • Analysis of metabolic control	BIO 151, 151L, 411, 411L & CHM 420, 451, 452
Citric Acid Cycle • Acetyl-CoA production (BC) • Reactions of the cycle, substrates and products • Regulation of the cycle • Net molecular and energetic results of respiration processes	BIO 151, 151L, 403, 403L, 411, 411L & CHM 420, 452
Metabolism of Fatty Acids and Proteins • Description of fatty acids (BC) • Digestion, mobilization, and transport of fats • Oxidation of fatty acids ○ Saturated fats ○ Unsaturated fats • Ketone bodies (BC) • Anabolism of fats (BIO) • Non-template synthesis: biosynthesis of lipids and polysaccharides (BIO) • Metabolism of proteins (BIO)	BIO 151, 151L, 403, 403L, 411, 411L & CHM 420, 452
Oxidative Phosphorylation • Electron transport chain and oxidative phosphorylation, substrates and products, general features of the pathway	BIO 151, 151L, 403, 403L, 411, 411L & CHM 420, 452

• Electron transfer in mitochondria
  o NADH, NADPH
  o Flavoproteins
  o Cytochromes
• ATP synthase, chemiosmotic coupling
  o Proton motive force
• Net molecular and energetic results of respiration processes
• Regulation of oxidative phosphorylation
• Mitochondria, apoptosis, oxidative stress (BC)	

Hormonal Regulation and Integration of Metabolism • Higher level integration of hormone structure and function • Tissue specific metabolism • Hormonal regulation of fuel metabolism • Obesity and regulation of body mass	BIO 151, 151L, 403, 403L, & CHM 420, 452

Plasma Membrane
• General function in cell containment
• Composition of membranes
  o Lipid components (BIO, BC, OC)
  ▪ Phospholipids (and phosphatids)
  ▪ Steroids
  ▪ Waxes
  o Protein components
  o Fluid mosaic model
• Membrane dynamics
• Solute transport across membranes
  o Thermodynamic considerations
  o Osmosis
  ▪ Colligative properties, osmotic pressure (GC)
  o Passive transport
  o Active transport
  ▪ Sodium/potassium pump
• Membrane channels
• Membrane potential
• Membrane receptors
• Exocytosis and endocytosis
• Intercellular junctions (BIO)
  o Gap junctions
  o Tight junctions
  o Desmosomes
	BIO 151, 151L, 403, 403L, 411, 411L, 440 & CHM 124, 420, 451

Membrane-Bound Organelles and Defining Characteristics of Eukaryotic Cells
• Defining characteristics of eukaryotic cells: membrane bound nucleus, presence of organelles,
• mitotic division
• Nucleus
  o Compartmentalization, storage of genetic information
  o Nucleolus: location and function
	BIO 151, 151L, 403, 403L, 440 & CHM 420, 451

o Nuclear envelope, nuclear pores • Mitochondria o Site of ATP production o Inner and outer membrane structure (BIO, BC) o Self-replication • Lysosomes: membrane-bound vesicles containing hydrolytic enzymes • Endoplasmic reticulum o Rough and smooth components o Rough endoplasmic reticulum site of ribosomes o Double membrane structure o Role in membrane biosynthesis o Role in biosynthesis of secreted proteins • Golgi apparatus: general structure and role in packaging and secretion • Peroxisomes: organelles that collect peroxides	
Electrochemistry • Concentration cell: direction of electron flow, Nernst equation	BIO 403, 403L & CHM 124, 420, 451
Biosignalling • Gated ion channels o Voltage gated o Ligand gated • Receptor enzymes • G protein-coupled receptors	BIO 151, 151L, 312, 312L, 440 & CHM 420, 451
Lipids • Description; structure o Steroids o Terpenes and terpenoids	BIO 151, 151L, 403, 403L, 411, 411L & CHM 420, 451, 452
Equilibrium • Concept of force, units • Analysis of forces acting on an object • Newton's First Law of Motion, inertia • Torques, lever arms	PHY 201 & CHM 124, 420, 451
Work (PHY) • Derived units, sign conventions • Mechanical advantage • Work Kinetic Energy Theorem	PHY 201 & CHM 123
Energy • Kinetic Energy: KE = ½ mv^2; units • Potential Energy o PE = mgh (gravitational, local) o PE = ½ kx^2(spring) • Conservation of energy • Conservative forces • Power, units	PHY 201 & CHM 123

Gas Phase • Absolute temperature, (K) Kelvin Scale • Pressure, simple mercury barometer • Molar volume at 0°C and 1 atm = 22.4 L/mol • Ideal gas o Definition o Ideal Gas Law: *PV* = *nRT* o Boyle's Law: *PV* = constant o Charles' Law: *V/T* = constant o Avogadro's Law: *V/n* = constant • Kinetic Molecular Theory of Gases o Heat capacity at constant volume and at constant pressure (PHY) o Boltzmann's Constant (PHY) • Deviation of real gas behavior from Ideal Gas Law o Qualitative o Quantitative (Van der Waals' Equation) • Partial pressure, mole fraction • Dalton's Law relating partial pressure to composition	BIO 411, 411L & CHM 123
Electrochemistry • Electrolytic cell o Electrolysis o Anode, cathode o Electrolyte o Faraday's Law relating amount of elements deposited (or gas liberated) at an electrode to o current o Electron flow, oxidation, and reduction at the electrodes • Galvanic or Voltaic cells o Half-reactions o Reduction potentials, cell potential o Direction of electron flow • Concentration cell • Batteries o Electromotive force, Voltage o Lead-storage batteries o Nickel-cadmium batteries	CHM 124, 420, 451
Light, Electromagnetic Radiation • Concept of Interference; Young Double-slit Experiment • Thin films, diffraction grating, single-slit diffraction • Other diffraction phenomena, X-ray diffraction • Polarization of light • Circular polarization • Properties of electromagnetic radiation o Velocity equals constant c, *in vacuo* o Electromagnetic radiation consists of perpendicularly oscillating electric and magnetic	PHY 202 & CHM 123

o fields; direction of propagation is perpendicular to both • Classification of electromagnetic spectrum, photon energy $E = (hf)$ • Visual spectrum, color	
Molecular Structure and Absorption Spectra • Infrared region o Intramolecular vibrations and rotations o Recognizing common characteristic group absorptions, fingerprint region • Visible region (GC) o Absorption in visible region gives complementary color (e.g., carotene) o Effect of structural changes on absorption (e.g., indicators) • Ultraviolet region o π-electron and non-bonding electron transitions o Conjugated systems • NMR spectroscopy o Protons in a magnetic field; equivalent protons o Spin-spin splitting	CHM 313
Atomic Nucleus • Atomic number, atomic weight • Neutrons, protons, isotopes • Nuclear forces, binding energy • Radioactive decay o α, β, γ decay o Half-life, exponential decay, semi-log plots • Mass spectrometer	CHM 123
Electronic Structure • Orbital structure of hydrogen atom, principal quantum number n, number of electrons per orbital (GC) • Ground state, excited states • Absorption and emission line spectra • Use of Pauli Exclusion Principle • Paramagnetism and diamagnetism • Conventional notation for electronic structure (GC) • Bohr atom • Heisenberg Uncertainty Principle • Effective nuclear charge (GC) • Photoelectric effect	PHY 202 & CHM 123
The Periodic Table - Classification of Elements into Groups by Electronic Structure • Alkali metals • Alkaline earth metals: their chemical characteristics • Halogens: their chemical characteristics • Noble gases: their physical and chemical characteristics	CHM 123

• Transition metals • Representative elements • Metals and non-metals • Oxygen group	

The Periodic Table - Variations of Chemical Properties with Group and Row
• Valence electrons
• First and second ionization energy
  o Definition
  o Prediction from electronic structure for elements in different groups or rows
• Electron affinity
  o Definition
  o Variation with group and row
• Electronegativity
  o Definition
  o Comparative values for some representative elements and important groups
• Electron shells and the sizes of atoms
• Electron shells and the sizes of ions
	CHM 123

Stoichiometry
• Molecular weight
• Empirical versus 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
  o Common oxidizing and reducing agents
  o Disproportionation reactions
• Description of reactions by chemical equations
  o Conventions for writing chemical equations
  o Balancing equations, including redox equations
  o Limiting reactants
  o Theoretical yields
	CHM 123

Acid/Base Equilibria
• Bronsted-Lowry definition of acid, base
• Ionization of water
  o K_w, its approximate value ($K_w = [H^+][OH^-] = 10^{-14}$ at 25°C, 1 atm)
  o Definition of pH: pH of pure water
• Conjugate acids and bases (e.g., NH_4^+ and NH_3)
• Strong acids and bases (e.g., nitric, sulfuric)
• Weak acids and bases (e.g., acetic, benzoic)
  o Dissociation of weak acids and bases with or without added salt
  o Hydrolysis of salts of weak acids or bases
	CHM 124, 420, 451

o Calculation of pH of solutions of salts of weak acids or bases • Equilibrium constants K_a and K_b: pK_a, pK_b • Buffers o Definition and concepts (common buffer systems) o Influence on titration curves	
Ions in Solutions • Anion, cation: common names, formulas and charges for familiar ions (e.g., NH_4^+ ammonium, PO_4^{3-} phosphate, SO_4^{2-} sulfate) • Hydration, the hydronium ion	CHM 123
Solubility • Units of concentration (e.g., molarity) • Solubility product constant; the equilibrium expression Ksp • Common-ion effect, its use in laboratory separations o Complex ion formation o Complex ions and solubility o Solubility and pH	CHM 124
Titration • Indicators • Neutralization • Interpretation of the titration curves • Redox titration	CHM 123, 124, 420, 451
Covalent Bond • Lewis Electron Dot formulas o Resonance structures o Formal charge o Lewis acids and bases • Partial ionic character o Role of electronegativity in determining charge distribution o Dipole Moment • σ and π bonds o Hybrid orbitals: sp^3, sp^2, sp and respective geometries o Valence shell electron pair repulsion and the prediction of shapes of molecules (e.g., NH3, H2O, CO2) o Structural formulas for molecules involving H, C, N, O, F, S, P, Si, CI o Delocalized electrons and resonance in ions and molecules • Multiple bonding o Affect on bond length and bond energies o Rigidity in molecular structure • Stereochemistry of covalently bonded molecules (OC) o Isomers ▪ Structural isomers ▪ Stereoisomers (e.g., diastereomers, enantiomers, cis/trans isomers)	CHM 123, 313

▪ Conformational isomers o Polarization of light, specific rotation o Absolute and relative configuration ▪ Conventions for writing R and S forms ▪ Conventions for writing E and Z forms	
Liquid Phase - Intermolecular Forces ▪ Hydrogen bonding ▪ Dipole Interactions ▪ Van der Waals' Forces (London dispersion forces)	CHM 124
Separations and Purifications • Extraction: distribution of solute between two immiscible solvents • Distillation • Chromatography o Basic principles involved in separation process ▪ Column chromatography, gas-liquid chromatography ▪ High pressure liquid chromatography o Paper chromatography o Thin-layer chromatography • Separation and purification of peptides and proteins (BC) o Electrophoresis o Quantitative analysis o Chromatography ▪ Size-exclusion ▪ Ion-exchange ▪ Affinity • Racemic mixtures, separation of enantiomers (OC)	CHM 313, 420, 451, 462L
Nucleotides and Nucleic Acids • Nucleotides and nucleosides: composition o Sugar phosphate backbone o Pyrimidine, purine residues • Deoxyribonucleic acid: DNA, double helix • Chemistry (OC, BC) • Other functions (OC, BC)	BIO 151, 151L, 312, 312L & CHM 314, 420, 451, 452
Amino Acids, Peptides, Proteins • Amino acids: description o Absolute configuration at the α position o Dipolar ions o Classification ▪ Acidic or basic ▪ Hydrophilic or hydrophobic o Synthesis of α-amino acids (OC) ▪ Strecker Synthesis ▪ Gabriel Synthesis • Peptides and proteins: reactions o Sulfur linkage for cysteine and cystine	CHM 314, 420, 451

o Peptide linkage: polypeptides and proteins o Hydrolysis • General Principles o 1° structure of proteins o 2° structure of proteins o 3° structure of proteins o o Isoelectric point	
The Three-Dimensional Protein Structure • Conformational stability o Hydrophobic interactions o Solvation layer (entropy) • 4° quaternary structure • Denaturing and Folding	CHM 420, 451
Non-Enzymatic Protein Function • Binding • Immune system • Motor	CHM 420, 451
Lipids • Types o Storage ▪ Triacyl glycerols ▪ Free fatty acids: saponification o Structural ▪ Phospholipids and phosphatids ▪ Sphingolipids ▪ Waxes o Signals/cofactors ▪ Fat-soluble vitamins ▪ Steroids ▪ Prostaglandins	CHM 420, 451, 452
Carbohydrates • Description o Nomenclature and classification, common names o Absolute configuration o Cyclic structure and conformations of hexoses o Epimers and anomers • Hydrolysis of the glycoside linkage • Keto-enol tautomerism of monosaccharides • Disaccharides (BC) • Polysaccharides (BC)	CHM 314, 420, 451
Aldehydes and Ketones • Description o Nomenclature o Physical properties • Important reactions o Nucleophilic addition reactions at C=O bond ▪ Acetal, hemiacetal	CHM 314

▪ Imine, enamine ▪ Hydride reagents ▪ Cyanohydrin o Oxidation of aldehydes o Reactions at adjacent positions: enolate chemistry ▪ Keto-enol tautomerism (α-racemization) ▪ Aldol condensation, retro-aldol ▪ Kinetic versus thermodynamic enolate • General principles o Effect of substituents on reactivity of C=O; steric hindrance o o Acidity of α-H; carbanions	
Alcohols • Description o Nomenclature o Physical properties (acidity, hydrogen bonding) • Important reactions o Oxidation o Protection of alcohol o Preparation of mesylates and tosylates	CHM 313
Carboxylic Acids • Description o Nomenclature o Physical properties • Important reactions o Carboxyl group reactions ▪ Amides (and lactam), esters (and lactone), anhydride formation ▪ Reduction ▪ Decarboxylation ▪ Reactions at 2-position, substitution	CHM 314
Acid Derivatives (Anhydrides, Amides, Esters) • Description o Nomenclature o Physical properties • Important reactions o Nucleophilic substitution o Transesterification o Hydrolysis of amides • General principles o Relative reactivity of acid derivatives o Steric effects o Electronic effects o Strain (e.g., β-lactams)	CHM 314
Phenols • Oxidation and reduction (e.g., hydroquinones), ubiquinones: biological $2e^-$ redox centers	CHM 314, 420, 452

Polycyclic and Heterocyclic Aromatic Compounds • Biological aromatic heterocycles	CHM 314

Enzymes
• Classification by reaction type
• Mechanism
  o Substrates and enzyme specificity
  o Active site model
  o Induced-fit model
  o Cofactors, coenzymes and vitamins
• Kinetics
  o General (catalysis)
  o Michaelis-Menten
  o Cooperativity
  o Effects of local conditions on enzyme activity
• Inhibition
• Regulatory enzymes
  o Allosteric
  o Covalently modified
	BIO 151, 151L, 312, 312L, 403, 403L, 411, 411L & CHM 420, 451, 452, 462L

Principles of Bioenergetics
• Bioenergetics/thermodynamics
  o Free energy/K_{eq}
  o Concentration
• Phosphorylation/ATP
  o ATP hydrolysis $\Delta G << 0$
  o ATP group transfers
• Biological oxidation–reduction
  o Half-reactions
  o Soluble electron carriers
  o Flavoproteins
	CHM 420, 451

Phosphorus Compounds • Description, structure of phosphoric acids	CHM 314

Energy Changes in Chemical Reactions - Thermochemistry, Thermodynamics
▪ Thermodynamic system – state function
▪ Zeroth Law – concept of temperature
▪ First Law: $\Delta E = Q - W$ (conservation of energy)
▪ Second Law – concept of entropy
  o Entropy as a measure of "disorder"
  o Relative entropy for gas, liquid, and crystal states
▪ Measurement of heat changes (calorimetry), heat capacity, specific heat
▪ Heat transfer – conduction, convection, radiation (PHY)
▪ Endothermic/exothermic reactions (GC)
  o Enthalpy, H, and standard heats of reaction and formation
  o Hess' Law of Heat Summation
▪ Bond dissociation energy as related to heats of formation (GC)
	CHM 123, 124

▪ Free energy: G (GC) ▪ Spontaneous reactions and ΔG° (GC) ▪ Coefficient of expansion (PHY) ▪ Heat of fusion, heat of vaporization ▪ Phase diagram: pressure and temperature	
Rate Processes in Chemical Reactions - Kinetics and Equilibrium • Reaction rate • Dependence of reaction rate upon concentration of reactants o Rate law, rate constant o Reaction order • Rate-determining step • Dependence of reaction rate upon temperature o Activation energy ▪ Activated complex or transition state ▪ Interpretation of energy profiles showing energies of reactants, products, activation energy, and ΔH for the reaction o Use of the Arrhenius Equation • Kinetic control versus thermodynamic control of a reaction • Catalysts • Equilibrium in reversible chemical reactions o Law of Mass Action o Equilibrium Constant o Application of Le Châtelier's Principle • Relationship of the equilibrium constant and ΔG°	BIO 411, 411L & CHM 124