DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY
QUALIFYING EXAMS

The Department of Chemistry and Biochemistry at Clark utilizes exams prepared by the American Chemical Society (ACS) in five separate areas of chemistry:

- Analytical
- Biochemistry
- Inorganic
- Organic
- Physical

All exams are multiple choice. They last two hours each. To complete the departmental requirement, you must pass four of the five exams within one year and not more than three attempts. Each exam is scored individually, with most scores being simply the number of correct answers, but some involving a penalty for incorrect answers. You will be told before taking the exam how they are scored. In most cases you should try to answer all questions, but in some instances you should only guess when you can narrow the choice to two answers. Below are some brief comments on the general areas covered by the exams. For more detailed descriptions on how to prepare for these exams, please feel free to contact individual professors in the department.

Analytical Chemistry

(Prepared with the help of the ACS Division of Analytical Chemistry)

A sequence of courses designed to cover modern analytical chemistry at the undergraduate level should present an integrated view of the theories and methods for solving a variety of real problems in chemical analysis. Students should receive a coherent and progressive treatment of the various aspects of problem definition, physiochemical operations and data evaluations. The problem oriented role of chemical analysis should be emphasized throughout the student's experiences. (The appendix material for Computers in Chemistry should also be consulted. Additionally, the Analytical Chemistry Subcommittee of the Division of Chemical Education Curriculum Committee has prepared an extensive document with performance objectives for analytical chemistry.)

In addition to a firm foundation in basic chemical reactions involving analytes and ordinary analytical reagents, adequate coverage of modern analytical chemistry should include:

- Distinction between qualitative and quantitative goals of determinations
- Choice of experimental designs
- Sampling methods for all states of matter
- Sample preparation and derivatization procedures

- Availability and evaluation of standards
- Standardization methodology
- Theory and methods of separation
- Physicochemical methods of measurement
- Fundamental characteristics of instruments, including recording devices and data acquisition options
- Comparison and critical selection of methods for both elemental and molecular determinations
- Optimization techniques for various aspects of analysis
- Methods of data evaluation

Individual topics should be presented in the framework as a systematic approach which emphasizes functional roles, facilitates comparison of performance characteristics and provides a pattern the student can use to understand related topics not included in formal course work. The courses should integrate chemical and instrumental concepts; they should include examples from inorganic, organic and biological chemistry. They should emphasize the importance of kinetic and equilibrium aspects of both chemical and physical processes and they should emphasize interactions and resulting interdependencies among different steps in the analytical process. The course should include discussion of methods used to optimize performance characteristics such as selectivity, sensitivity, uncertainty and detection limits. They should examine the trade-offs that are made among these performance characteristics and practical considerations, such as time and cost, which are always associated with real problems, i.e. an industrial process, a clinical problem or an experiment performed in outer space.

Some topics in modern analytical chemistry may not require a thorough background in physics and/or certain areas of physical chemistry. Accordingly, these topics may be introduced in lower division courses. However, in order to achieve finally the desired depth and breadth in modern analytical chemistry at the undergraduate level, the more advanced topics in theory and methods should have as prerequisites calculus based physics, basic inorganic and organic chemistry, an upper level treatment of structure/energy relationships, fundamentals of thermodynamics and electrochemistry and basic chemical dynamics.

While all areas of chemistry utilize the concepts and techniques referred to above, it is the responsibility of the analytical chemist(s) to coordinate and reinforce their presentation. The student should emerge from an undergraduate program of studies in analytical chemistry with the following competencies:

- Define clearly problems of chemical analysis. Is the information required of a qualitative or quantitative nature? If quantitative, what are the acceptable accuracy and precision limits? Is it an elemental or molecular determination? What are the chemical and physical properties unique to the analyte and what matrix effects should be considered in designing the experiments? How is data to be evaluated, interpreted and optimized?

- Select wisely a method, or methods, to achieve the goals (above). This implies that the student should understand the chemical and instrumental options available for both elemental and molecular determinations, as well as equilibrium and kinetic processes.

The student must understand the basic chemical reactions which will be involved in sample acquisition and preparation and separations. The student must know how to eliminate or compensate for interferences. The student must recognize the critical response parameters for each phase of the determination and must be able to identify the sources of error.

- Utilize the proper methods of statistical evaluation of data, including validation and optimization techniques. A thorough understanding of standardization methodology is prerequisite, as is knowledge of the sources of errors, instrumental and chemical.

- Understand the theory and operational principles of the fundamental components of instrumentation for:

  Spectrometry:
    Atomic (AE, AA, x-ray)
    Molecular (UV-Vis, IR, Fluorescence)
    Mass

Biochemistry

The American Chemical Society (ACS) examination in biochemistry is used as part of our qualifying exam (Part I). The exam covers material presented in a typical advanced undergraduate survey course in biochemistry. Useful texts include the most recent edition of "Biochemistry" by (1) Lehninger; (2) Stryer; (3) Matthews and van Holde, or (4) Zubay.

General topics include:

Buffers and pH: Ionization of amino acids.

Protein structure and function: Equilibrium binding of ligands, enzyme kinetics and inhibition, methods of analysis.

Metabolic pathways: Glycolysis, TCA cycle, pentose phosphate pathway, fatty acid oxidation, gluconeogenesis, amino acid metabolism, nucleotide metabolism, oxidative phosphorylation. Photosynthesis – key intermediates. Regulation – enzyme cofactors.

Thermodynamics: Free energy change and equilibrium concentrations of reactant, redox reactions, ATP-coupled reactions.

Carbohydrate structure and function: Common sugars, methods of analysis.

Nucleic acid structure and function: Replication, transcription and translation. Regulation of expression of genetic information. Methods of analysis. Recombinant DNA technology.

The best way to prepare is to study one of the above texts, concentrating on basic principles, key structures and intermediates. The test is highly problem-oriented, so doing problems at the end of chapters is highly recommended.

If biochemistry is not presented as a separate course in the curriculum, then fundamental topics drawn from biochemistry must be covered in the core curriculum, particularly in organic and physical chemistry. Item 1 below is a minimal list of fundamental topics. Following coverage of these fundamental topics, a rigorous survey course in biochemistry, making use of quantitative concepts involving kinetics, thermodynamics and solution properties of macromolecules might serve as an advanced course (Item 2). Especially recommended, however, are more focused courses that provide depth in one or a few specialized areas (Item 3). A survey course in biochemistry to emphasize the metabolic significance of the fundamental topics in biochemistry covered in the core curriculum should be a prerequisite for the specialized courses.

1. <u>Fundamental Topics in Biochemistry</u>

- Chemistry of amino acids and peptides
- Introduction to protein structure and enzyme mechanisms
- Chemistry of nucleotides and nucleic acids
- Introduction to structure of DNA and RNA
- Chemistry of lipids
- Introduction to structure of biomembranes and plasma lipoproteins
- Chemistry of carbohydrates

2. <u>Topical List of a Rigorous, Physical Chemistry Based Survey Course</u>

- Amino acids, peptides, proteins
- Enzymatic kinetics and regulation
- Carbohydrates
- Nucleotides and nucleic acids
- Lipids
- Structure and function of biomembranes and plasma lipoproteins
- Solution properties of macromolecules
- Metabolism, Bioenergetics carbohydrates, amino acids, lipids
- DNA, RNA and protein synthesis
- Recombinant DNA
- Complex carbohydrates, glycoproteins
- Muscle and connective tissue proteins
- Hormones and receptors
- Molecular endocrinology
- Neurochemistry
- Immunochemistry

3. Specialized Areas of Biochemistry Suitable for an Advanced Course

- Enzymatic catalysis
- Molecular genetics
- Recombinant DNA technology

Inorganic Chemistry

The American Chemical Society (ACS) inorganic qualifying exams we use at Clark are based on the typical advanced inorganic chemistry undergraduate course as taught in most American Universities. Textbooks such as the following adequately cover the material tested by the exams.

- Cotton, Wilkinson and Gaus, "Basic Inorganic Chemistry"
- Huheey, "Inorganic Chemistry"
- Mackay and Mackay, "Modern Inorganic Chemistry"
- Butler and Harrod, "Inorganic Chemistry, Principles and Applications"
- Douglas, McDaniel and Alexander, "Concepts and Models of Inorganic Chemistry"
- Porterfield, "Inorganic Chemistry"
- Jolly, "Modern Inorganic Chemistry"
- Moeller, "Inorganic Chemistry"

The topics covered include:

Periodicity and Atomic Structure: Electron configurations, trends in various properties (and anomalies), electronegativity and term symbols for atomic ground states.

Ionic Properties: Radii, ionization energies, electron affinities, oxidation states, Born-Haber cycles, lattice energies and crystal packing.

Systematic Chemistry of the Elements: Alkalis, alkali metals, alkaline earths, noble gases, halogens, chalcogens, pnicogens, carbon groups, boron groups, transition elements, lanthanides and actinides. Polymeric oxides, boranes, sulfur ring systems, silicates and inorganic ring systems.

Solvents and Acid-base Chemistry: Acid-base concepts, hard and soft acids, weak and strong acids, superacids, non-aqueous solvent systems and solvation energies.

Bonding Theories: Lewis structures, hybridization, resonance, VSEPR Theory, LCAO-MO Theory, Valence Bond Theory, bond energies, covalent radii and symmetry.

Coordination Chemistry: Stereochemistry and isomerism, valence bond, ligand field, MO theories of bonding, ligand field splitting, ligand field stabilization effects, magnetic properties, color, absorption spectroscopy of transition metal ions (Tanabe Sugano diagrams), synthesis, reaction mechanisms, kinetics, trans effect, redox reactions, metal-metal bonds and metal clusters.

Solid State Chemistry: Simple metals (structures and theories of bonding), semiconductors and band theory.

Organometallic Chemistry: EAN rule, carbonyls and nitrosyls, olefin, acetylene, alkyl, arene complexes, metallocenes, clusters, homogeneous catalysis fluxionality, oxidative addition and reductive elimination.

The exam consists of multiple choice questions. It is not necessary to have covered all of the above topics, since a pass (50%) requires less that 50% correct answers.

The best way to study is to get a fairly simple textbook (Cotton, Wilkinson and Gaus is probably the best) and fully understand the basics. The exam is based more on theory than on actual structures or reactions, so you should concentrate on this. There is no way you can learn all the specific reactions that might be asked. You should read the chapters on systematic chemistry so that you have at least seen the range of reactions and structures that is possible and hope that you will recall enough to answer any questions. Your aim on this section will generally be to put yourself in a position where you can make an informed guess, not to learn it all.

Organic Chemistry

Any introductory undergraduate organic textbook should be suitable for study/review purposes. Several are listed below, but others should not be excluded.

- Vollhardt, "Organic Chemistry"
- Ege, "Organic Chemistry"
- McMurry, "Organic Chemistry"
- Carey, "Organic Chemistry"
- Morrison and Boyd, "Organic Chemistry"

Topics that should be included in your study are listed below in a "Functional Group Approach" order.

1. Introduction and Basic Review
    - Why carbon?
    - Electronic Orbitals
    - Orbitals and Geometry
    - Molecular Structure
        - Representations
        - Polarity and Formal Charges
        - Acid-Base Definitions
    - Percent Composition Analysis

2. <u>Functional Groups</u>
    - Multiple Bonds
    - Heteroatom Substitution
    - Multiple Atom Fragments

3. <u>Alkanes</u>
    - Structures and Nomenclature
    - Alkyl groups and Trivial names
    - Carbon and Hydrogen types
    - Physical Properties
    - Conformation
    - Cyclic Alkanes - cis and trans isomers

4. <u>Organic Reactions</u>
    - Polar: Electrophilic and Nucleophilic
    - Radical: Initiation, Propagation and Termination
    - Pericyclic Reactions
    - Rates of Reaction, Equilibria and Energy Diagrams
        - Equilibrium Constants
        - Intermediates vs. Transition States

5. <u>Alkenes</u>
    - Structure and Nomenclature
        - Nature of the Double Bond
        - Z/E Isomer
        - Conjugation and Stability
    - Reactions
        - Addition of HX: Markovnikov's Rule and the Hammond Postulate
        - Addition of other Electrophiles
        - Addition of Radicals
        - Oxidation and Reduction
    - Synthesis
        - Dehydrohalogenation
        - Dehydration

6. <u>Alkynes</u>
    - Structure and Nomenclature
    - Reactions
        - Electrophilic Additions
        - Hydration (introductions to tautomers)
        - Hydroboration
        - Oxidation and Reduction

  - Acidity - Carbon Based Nucleophiles
    - Terminal Anion
    - Dianion
    - Synthesis
- Introduction to Multistep Syntheses

7. Stereochemistry
   - The Nature of Optical Activity
   - Chirality and Enantiomers
   - Nomenclature and 3-D Representations
     - Wedge and Hash-mark
     - Fischer Projection
     - Cahn-Ingold-Prelog Convention
   - Multiple Chiral Centers: Diastereomers
   - Properties: Enantiomers vs. Diastereomers
   - Stereochemistry and Reactions
   - Chirality at Sites other than Carbon

8. Alkyl Halides
   - Structure and Nomenclature
   - Synthesis
     - From Alkanes and Olefins
     - From Alcohols
   - Reactions
     - Organometallic Chemistry: Grignards, Lithium Reagents and Cuprates
     - Substitution reactions: SN^1 and SN^2
     - Elimination reaction: E^1 and E^2

9. Cyclic Systems
   - Nomenclature
   - Stability and Ring Strain
   - Synthesis
   - Cyclohexanes and Conformation
   - Polycyclics
   - Stereochemistry

10. Conjugation
    - Preparation and Stability of Poly-olefins
    - Huckel MO Theory
    - Reactions
      - Allylic Systems and Conjugate Addition
      - Kinetic and Thermodynamic Control
      - Pericyclic Reactions

11. Benzene and Aromaticity
    - Nomenclature
    - Structure, Stability and Molecular Orbital Theory
    - Heterocyclic Aromatics
    - Reactions: Electrophilic Aromatic Substitution
        - Mechanism and Electronic Control of Regiochemistry
            - Inductive Effects and Reaction Rates
            - Mesomeric Effects and Directing Ability
        - Halogenation
        - Nitration
        - Sulfonation
        - Hydroxylation
    - Reactions: Nucleohilic Aromatic Substitution
    - Elimination / Addition: The Benzyne Reaction

12. Arenes: Synthesis and Reactions of Substituted Benzenes
    - Friedel-Crafts Alkylation and Acylation
        - Cation Rearrangement
        - Ways around them
    - Reactions of Aromatic Side-chains
        - Benzylic Activation
        - Halogenation
        - Oxidation
    - Reduction of Benzene Rings
        - Catalytic Hydrogenation
        - Birch Reduction
    - Synthesis of Poly-substituted Benzenes

13. Alcohols and Thiols
    - Nomenclature
    - General Properties
    - Synthesis From
        - Halides
        - Olefins
        - Carbonyl Compounds
            - Reduction
            - Addition
        - Preparation of Glycols
    - Reactions of Alcohols
        - As a Leaving Group: Olefins and Halides
        - As a Nucleophile: Ethers and Esters
        - As a Base
        - In Oxidation Reactions
    - Synthesis and Protecting Groups
    - Thiols - Synthesis and Properties

- Phenols
    - Nomenclature
    - Properties: Comparison to Alcohols
    - Synthesis
    - Reactions
        - As Nucleophiles, Ether and Ester Formation
        - Oxidation Reactions
        - Precursors for Claisen Rearrangement

14. Ethers, Epoxides and their Sulfur Analogues
- Nomenclature
    - As Ethers
    - As Alkoxy Substituents
    - Cyclic Ethers
    - Epoxides
    - Thio Analogues
- Physical Properties
- Synthesis
    - Ethers
    - Epoxides
        - From Olefins
        - From Halohydrins
        - From Glycols
        - Darzens Glycidic Ester Synthesis
        - From Ketones
- Reactions of Ethers: Acidolysis
- Reactions of Epoxides: Ring Openings
- Oxidations of Thioethers: Sulfoxides and Sulfones

15. Aldehydes and Ketones: Carbonyl Compounds
- Nature of the Carbonyl Group
- General Reactions
    - Addition of Nucleophiles
    - Reduction
    - Replacement of Oxygen
    - Nucleophilic Substitutions
    - Reactions at the Alpha Site: Substitutions and Condensations
- Nomenclature of Aldehydes and Ketones

- Synthesis
    - Oxidation of Alcohols
    - Reduction of Acyl Halides and Esters (Rosenmund Reduction)
    - Ozonolysis of Olefins
    - Friedel-Crafts Acylation
    - Hydration of Alkynes
    - Acyl Halides and Cuprates
    - Hydrolysis of Geminal Dihalides
    - Oxidation of Glycols
- Reactions
    - Oxidation of Aldehydes: Fehlings and Tollens tests
    - Oxidation of Ketones
    - Cyanohydrin Formation
    - Addition of Nitrogen: Imines, Enamines and Oximes
    - Acetal and Ketal Formation: Protection Groups part 2
    - Reduction
        - With Hydride to give Alcohols
        - Wolff-Kishner Reduction to Alkanes
        - Reduction of Thioacetals
        - Phosphorus Ylides: the Wittig Reaction and Olefin Synthesis
        - Conjugate addition: the Michael reaction

16. <u>Amines</u>

- Nomenclature
- Structure and Properties
- Basicity and Functionality
- Synthesis
    - Reaction with Alkyl Halides
    - With Sodium Azide
    - Gabriel Synthesis
    - Reduction Techniques
        - Reduction of Oximes, Nitriles and Amides
        - Reductive Amination
        - Reduction of Nitro Compounds
    - Rearrangements of N-carbonyl Compounds
        - Hofmann
        - Curtiu
    - Reactions of Amines
        - Quaternization and Salts: Optical Resolution
        - Hofmann Elimination
        - Acylation
        - Sulfonation: The Hinsberg test
        - Diazotization: The Sandmeyer Reaction

17. Carboxylic Acids
    - Nomenclature
    - Structure and Physical Properties
    - Synthesis
        - Via Oxidation
        - Via Hydrolysis
        - Grignard Synthesis
    - Reactions
        - Salts
        - Reduction
        - Decarboxylation
        - Decarboxylation of Vis-diacids

18. Carboxylic Acid Derivatives
    - Nomenclature
    - Acid Halides
        - Synthesis
        - Reactions
            - Nucleophilic Substitutions
            - Friedel-Crafts Acylation
            - Grignard Addition
            - Reduction
    - Acid Anhydrides
        - Synthesis
        - Reactions
    - Esters
        - Properties
        - Synthesis
            - Fischer Esterification
            - From Acid Halides and Anhydrides
        - Reactions
            - Substitution/transesterification
            - Reduction
            - Pyrolysis
            - Grignard Addition
            - Polyesters
    - Amides
        - Synthesis
        - Reactions
    - Nitriles

19. Reaction α to a Carbonyl Group
    - Keto-enol Equilibrium
    - Halogenation of Aldehydes and Ketones
    - Hell-Volhard-Zelinsky Reaction

- Alkylation Type Reactions
    - Enolate Formation
    - Bromoform Reaction
    - Selenation
    - Alkyl Halide Reaction
    - Reaction of Enamines
    - Malonic and Acetoacetic Ester Reactions
- Reactions α to Nitriles

20. Carbonyl Condensation Reactions
    - Aldol Condensation
    - Cannizzaro Reaction
    - Claisen Condensation (not rearrangement)
    - Dieckmann Cyclization
    - Michael Additions
    - Robinson Annulation
    - Acyloin Condensation
    - Thorpe Condensation

21. Spectroscopy
    - Infrared
    - UV-Vis
    - Mass Spec
    - NMR (1H- and 13C-NMR)

Physical Chemistry

The American Chemical Society physical chemistry graduate level placement examinations are base on undergraduate courses taught in most American Colleges and Universities. Text books such as the following cover most of the materials tested by the exams.

- Castellan, G.W., "Physical Chemistry" third edition
- Noggle, J.H., "Physical Chemistry" second edition
- Atkins, P.W., "Physical Chemistry" fourth edition
- Alberty, R.A., "Physical Chemistry" seventh edition
- Moore, W.J., "Basic Physical Chemistry"
- Bromberg, J.P., "Physical Chemistry" second edition
- Berry, Rice and Ross, "Physical Chemistry Parts 1, 2 and 3"
- Fried, Hameka and Blukis, "Physical Chemistry"
- Tinoco, Sauer and Wang, "Physical Chemistry" second edition

The topics covered include:

Properties of Gases: Properties of the ideal gas and mixtures, the barometric distribution law, the van der Waals equation, isotherms of real gases, critical state, the law of corresponding states and the Maxwell velocity distribution law.

First Law of Thermodynamics: Temperature, heat and work, exact and inexact differentials, the Einstein function, heat capacities, internal energy, enthalpy, expansion and compression of gasses and thermochemistry.

Second and Third Laws of Thermodynamics: Carnot heat engines, entropy, calculation of entropy changes, free energy, partial derivatives, equations of thermodynamics, entropy of real substances, and thermodynamics of rubber elasticity.

Equilibrium in Pure Substances: Chemical potential, phase equilibrium, surface tension, equilibria of condensed phases, phase diagrams and glass phase transition.

Chemical Reactions: Heats of reaction, adiabatic flame temperature, reversible reactions, calculation of equilibrium constants, fugacity of real gases, extent of reaction and heterogeneous reactions.

Solutions: Partial molar quantities, Gibbs' Phase Rule, Raoult's Law, Henry's Law, colligative properties, equilibrium in solution, solution of macromolecules, phase diagrams, ionic solutions, Debye-Hückel Theory and electrochemistry.

Transport Properties: Molecular collisions, random walks, diffusion, convection, chromatographic separation, viscosity and sedimentation.

Chemical Kinetics: Rate Laws, effect of temperature on rate constants, theories of reaction rates, multistep reactions, chain reactions, reaction mechanisms, molecular beams, polymerization, surface catalysis and enzyme catalysis.

Quantum Theory: Particles and waves, Bohr's Atomic Theory, postulates of quantum theory, the particle in a box, the harmonic oscillator and angular momentum.

Atoms: Hydrogen atom, electron spin, helium atom, Pauli Exclusion Principle, vector model of the atom, many-electron atoms, spin-orbit coupling, atomic spectroscopy and photoelectron spectroscopy.

Diatomic Molecules: Molecular vibrations, rotations, orbital theory, electronic spectroscopy, ionic bonding and dipole moments.

Polyatomic Molecules: Symmetry operations, groups, degenerate representations, bonding theory, symmetry orbitals, selection rules, molecular vibrations, Raman Spectroscopy and molecular rotations.

Structure of Condensed Phases: Crystallography, diffraction, crystalline solids, synthetic polymers, biopolymers and liquid crystals.

Magnetic Resonance Spectroscopy: Principles of magnetic resonance, electron spin resonance, hyperfine coupling, esr applications, high resolution NMR spectrometer, chemical shifts, spin-spin splitting, second-order effects, C-13 NMR, relaxation processes and Magnetic Resonance Imaging.

The exam consists of multiple choice questions. The time period allowed for the exam may range from 60 to 120 minutes depending on the particular exam set chosen.