Gustaf H. Carlson School
of Chemistry and Biochemistry

Chemistry & Biochemistry Ph.D. Graduate Student Handbook

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Policies and Requirements for Chemistry and Biochemistry Ph.D. Graduate Students

This handbook will inform the entering graduate student of departmental requirements for the degree of Doctor of Philosophy in Chemistry or Biochemistry.

The Gustaf H. Carlson School of Chemistry and Biochemistry offers the degree of Doctor of Philosophy with specialization in several fields of chemistry including biochemistry, inorganic, organic, physical, computational, and materials chemistry. Owing to the small size of the department, emphasis is placed on tailoring programs of study to suit the need and desires of the individual graduate student. However, there are certain requirements that must be met by all graduate students. These requirements are outlined below.

<u>GENERAL PhD PROGRAM REQUIREMENTS</u>

A. Qualifying Exams (Placement Exams) Part I

All entering Chemistry and Biochemistry Ph.D. graduate students must pass placement examinations (by obtaining at least the 50th percentile) in any three of the five major areas of chemistry (analytical, biochemistry, inorganic, organic, and/or physical). These exams will be scheduled 1-week before the semester begins. The purpose of these exams is to determine the student's general level of competence and background in chemistry and/or biochemistry.

The Gustaf H. Carlson School of Chemistry and Biochemistry at Clark University utilizes exams prepared by the American Chemical Society (ACS) in five separate areas of chemistry:

Analytical Chemistry, Biochemistry, Inorganic Chemistry, Organic Chemistry, Physical Chemistry

All ACS exams are multiple choice and last from 1-2 hours each. Each exam is scored individually, with most scores being simply the number of correct answers and compared to ACS normalized scores from universities across the United States. Below are some brief comments on the general areas covered on the exams. For more detailed descriptions on how to prepare for these exams, please feel free to contact individual professors within the department.
Students who fail to pass any of the three ACS examinations have two options to fulfill this entrance requirement:

1. Retake the failed examinations by the end of the first semester and pass, or
2. Enroll in the course(s) at the 300-level for the subject matter that needs to be improved upon and obtain a grade of B- or better. This course(s) has to be completed by the end of the student's first year in the Ph.D. program. Failure to fulfill the entrance requirements will result in dismissal from the program.

B. Research Advisor and Faculty Advisory Committee

The student research and mentoring experience is an important aspect of our Ph.D. graduate program. The student will perform their graduate research under the guidance of a Research Advisor whom the student will choose from the available faculty, likely before they arrive on campus. Students may choose a Research Advisor who is a tenure-track, adjunct, or affiliate member of the faculty in the Gustaf H.

Carlson School of Chemistry and Biochemistry. Since this is a very important decision, the student should put a great deal of time and thought into choosing their Research Advisor and project.

Students have the option of changing Research Advisors, which must be done in consultation with the Department Chair and Graduate Program Coordinator should this need arise.

By the end of their 2nd semester in the Ph.D. program, the student with their Research Advisor will choose two or three other faculty members to serve with the Research Advisor as the student's Faculty Advisory Committee. This committee is responsible for overseeing important decisions concerning the student's progress throughout the graduate program. The committee will meet annually to review the student's progress (scheduled by the Chemistry Office Coordinator), write the student's Secondary Qualifying Exam (more below) and sit in review of the student's Research Proposal and Dissertation (more below). One member of the committee may be from outside the Carlson School of Chemistry and Biochemistry. Please notify the Graduate Program Coordinator and Chemistry Office Coordinator once the Advisory Committee has been formed.

C. Formal Course Work

All students are required to complete 5 x 300-level 1 credit courses that were not used to fulfill the entrance exam requirement. Students also are required to complete a minimum of 4 x 0.25 credit courses, one of which will be a literature review module. (CHEM 389 – Research Methods) toward the completion of their degree. Please note that some individual Research Advisors may require additional course work – please consult with your Research Advisor. We have three tracks from which students may select their 1-credit courses depending on their Ph.D. research – Materials Chemistry, General Chemistry, and Biochemistry. The courses chosen from the following list will depend on the student's research interests and background with consultation from their Advisory Committee. A grade of B- is the minimum passing grade to obtain course credit in the graduate curriculum. Students who achieve unacceptable grades (less than B- or withdrawal from a course) in two courses before obtaining credit for the five-course minimum may be asked to leave the Chemistry or Biochemistry Ph.D. program.

<u>Materials Chemistry Track – Course List</u>

- BCMB 366 – Biomolecular NMR
- CHEM 356 – Inorganic Materials
- CHEM 358 – Crystallography, Diffraction, Scattering
- CHEM 381 – Polymer Science
- CHEM 383 – Polymeric Biomaterials
- CHEM 385 – The Chemistry of Materials that Store Energy
- PHYS 310 – Condensed Matter Physics
- PHYS 343 – Technology of Renewable Energy

<u>General Chemistry Track – Course List</u>

- BCMB 337 – Chemistry and Biology of Medicine
- BCMB 366 – Biomolecular NMR
- BCMB 375 – Protein Chemistry
- BCMB 376 – Chemical Biology
- BCMB 379 – Computer Biochemistry
- CHEM 356 – Inorganic Materials
- CHEM 358 – Crystallography, Diffraction, Scattering

- CHEM 381 – Polymer Science
- CHEM 383 – Polymeric Biomaterials
- CHEM 385 – The Chemistry of Materials that Store Energy
- PHYS 305 – Quantum Mechanics
- PHYS 309 – Statistical Mechanics
- PHYS 310 – Condensed Matter Physics
- PHYS 327 – Advanced Computer Simulation Lab
- PHYS 343 – Technology of Renewable Energy

Biochemistry – Course List

- BCMB 328 – Molecular Genetics
- BCMB 337 – Chemistry and Biology of Medicine
- BCMB 366 – Biomolecular NMR
- BCMB 375 – Protein Chemistry
- BCMB 376 – Chemical Biology
- BCMB 377 - Enzyme Reaction Mechanisms
- BCMB 379 – Computers in Biochemistry
- CHEM 383 – Polymeric Biomaterials
- BIOL 334 – Signal Transduction
- BIOL 338 – Seminar in Cell Biology
- BIOL 336 – Biology of Cancer

D. Teaching Requirements

Chemistry and Biochemistry PhD students are part of the Graduate Student Union. Please follow this link for more information on the terms of the contract as well as FAQs and contact information. https://www.clarku.edu/schools/graduate-arts-and-sciences/graduate-student-union/

Before the start of each semester, all graduate students will receive a letter from the department chair per guidelines from the Dean of Research and Graduate Studies, outlining their TA or RA responsibilities for the semester. Graduate students are required to work as teaching assistants for a minimum of two semesters as part of their program requirement. Teaching assignments will be based on faculty discretion. Normally, all first-year students in the Chemistry or Biochemistry Ph.D. program will serve as teaching assistants. These duties include, but are not limited to, supervising laboratory sections and grading lab reports and may also include grading quizzes from the appropriate lecture section, as well as proctoring exams. The exact nature of your duties will be determined by the faculty member in charge of the course(s) to which you are assigned. Once TA assignments are determined, please contact the faculty member in charge regarding responsibilities, scheduling, and work expectations for the course. Graduate TAs are required to be present at all times necessary to fulfill their TA duties and should not schedule absences during the academic year teaching semesters. Please see the Graduate Program Coordinator or Chemistry Office Coordinator for any clarification on these important policies.

Here is a summary of the responsibilities and expectations of working as a Teaching Assistant in the Gustaf H. Carlson School of Chemistry and Biochemistry:

- TAs are expected to devote 20-hours per week during the semester to lab preparation, lab supervision, office hours, grading, proctoring, etc.– as agreed upon with the faculty in charge.

- All TAs are required to attend safety training led by the Chemistry Department Safety Officer annually.
- TAs will engage and support undergraduate learning of chemical processes.
- When in the laboratory, graduate TAs are required to circulate amongst their students asking questions, checking technique, preparation, and enforcing lab safety protocols and procedures.
- All graduate TAs are responsible for the safety of every student in a teaching laboratory and need to be familiar with good safety practices relevant to their TA duties.
- TAs are expected to return the graded lab reports to the students in a timely fashion, preferably before their next lab reports are due. This is to ensure that the students can receive constructive feedback on ways to improve their lab report writing skills and performance.
- TA use of cell phones for non-emergencies in and during the lab is prohibited.

TAs are evaluated by faculty and students every semester. Any non-satisfactory TA performance or discipline will follow the rules set out in the Collective Bargaining Agreement (CBA) for the Graduate Student Union.

E. Seminars

Weekly seminar attendance is mandatory for all graduate students. The Chemistry and Biochemistry department regularly invites outside speakers from other Universities and/or Industry to share their expertise in a particular field of chemical research. Graduate students will also present research updates as scheduled by the Chemistry Office Coordinator following the timeline below. The schedule will be available at the beginning of each semester.

1. A 10-minute research updates during the 2^{nd}, 3^{rd} and 4^{th} semesters
2. A 30-minute comprehensive research updates during their 3^{rd} and 4^{th} years in the program
3. A 50-minute seminar to defend their original research proposal (scheduled after completing their Qualifying Exam II
4. A 50-minute public seminar for their final Ph.D. dissertation defense

F. Qualifying Exam Part II

The second qualifying exam is created by the student's Faculty Advisory Committee and are comprehensive in scope and subject. These in-depth exams will cover the student's knowledge of their field of study, application of advanced material from graduate courses taken, recent scientific studies from the literature, etc. The format of the questions on each exam is at the discretion of each committee member. The exams will be administered over several days during a period of no longer than 3 weeks. Students are encouraged to communicate with their committee to discuss the topics and subject matter that will be covered on each exam. Graduate students must pass these exams to advance to Ph.D. candidacy.

Students who fail this examination may be retested <u>once and only if the student's Research Advisor and Faculty Advisory Committee deem it appropriate</u>. In addition, the Faculty Advisory Committee may request an oral exam if the written exam(s) is/are not passed. Students who fail to pass this exam will be asked to leave the Chemistry or Biochemistry Ph.D. program.

G. Original Research Proposal

The research proposal can only be attempted after the Qualifying Exam Part II is passed. Each Ph.D. candidate will write an original research proposal, present their proposal in front of the department, and an oral defense of that proposal before the student's Faculty Advisory Committee. It must be an original idea that may be directly/indirectly related to the student's research project without help from any faculty member. The proposal should normally be completed by the end of the third year, and must be completed at least 6 months before the student's final dissertation is defended.

The topic of the original proposal must be approved by the Faculty Advisory Committee before the proposal writing is attempted. The written proposal should be submitted to the Committee at least two weeks prior to the oral defense. The student is encouraged to arrange a "Mock-Defense" before a "Committee" of fellow graduate students in preparation for the public presentation and defense in front of the Faculty Advisory Committee.

The student's research proposal will be judged on:

1. The significance of the research problem
2. The originality and importance of the research proposal
3. Their mastery of the chemical/biochemical principles and experimental techniques to be used
4. The clarity of the proposal (i.e. organization of the proposal, quality of the scientific writing and figures); and
5. Their ability to defend their experimental design, and its rationale, alternative approaches, and expected outcomes of their research proposal.

It is strongly advised that the specific research problem chosen by the student not be so broad that it would require more than three years of time to complete the "actual work" (ideally aiming for a 1-2 year timeline), and not so short that it would only require "one-experiment" to complete. The written proposal must follow the format as required by typical grant funding agencies such as NSF or NIH. Detailed instructions for each granting agency are available on the following websites:

NIH Grant Guidelines
https://grants.nih.gov/grants/how-to-apply-application-guide/format-and-write/write-your-application.htm

NSF Grant Guidelines
https://www.nsf.gov/pubs/1998/nsf9891/nsf9891.htm

> The research problem must be an original idea (i.e., not previously published or attempted by anyone), should be described in sufficient detail to make it clear to the reader while still being concise, and must include an appropriate bibliography and a budget. The proposed budget should include a list of major equipment, special reagents (such as isotope-labeled reagents), and key personnel, for example, numbers of postdoctoral fellows, graduate students, and technicians. A brief justification is needed for the proposed budget."

Students who do not successfully defend their research proposal may be granted one additional attempt at the discretion of their Faculty Advisory Committee.

Ph.D. candidates who have completed their coursework, the second qualifying Exam, and passed their Research Proposal will be awarded an M.S degree. Please speak with the Graduate Program Coordinator or the Chemistry Office Coordinator for more information.

H. Dissertation

All Chemistry and Biochemistry Ph.D. candidates must submit an acceptable dissertation based on the student's original research. A complete dissertation is presented to the student's Faculty Advisory Committee at least two weeks prior to the scheduled defense. The thesis will be defended in front of the Faculty Advisory Committee at the student's final oral examination immediately following the public seminar given by the candidate. At that time the committee may approve the written document, the oral defense, both, or neither. Students may be required to re-defend their dissertation, especially if extensive revision of the written document is required.

It is strongly encouraged that the candidate maintain contact and schedule discussions with their Faculty Advisory Committee during their thesis writing prior to scheduling their defense. This will help to ensure that any potential problems/issues with the candidate's thesis (i.e. thesis organization, as well as the quality of writing, figures, data analysis) may be addressed prior to scheduling the candidate's thesis defense date.

I. Timeline for Chemistry or Biochemistry Ph.D. Degree

The Chemistry Faculty have generated a suggested timeline for completion of the various Chemistry and Biochemistry Ph.D. degree requirements. While this specific timeline can be flexible (with the exception of the preliminary qualifying exams), the faculty strongly recommend and encourage all Ph.D. students to follow and adhere to this timeline so that they may be able to complete their degree in a reasonable timeframe (within 5 years). Please be aware that Ph.D. students in the Chemistry and Biochemistry Ph.D. programs will not receive <u>any</u> financial support after <u>six</u> years of being in the program, whether from the University (as a Teaching Assistant) or from external funds (as a Research Assistant).

Requirement	Suggested Completion Time (in semesters)
Preliminary ACS Qualifying Exams	Written upon arrival – must be passed or obtain a B- or better in the appropriate 300-level course by the end of the 2nd semester
Begin Conducting Research	As early as possible
All Required Course Work	5 x 1 credit courses by the end of the 4th semester 4 x 0.25 credits courses by the end of the 8th semester
Qualifying Exam: Part II	During the 4th semester or immediately after completing the 5 x 1 credit course requirements
Original Research Proposal	Recommended by the end of the 8th Semester, but a minimum of 6 months before thesis defense
Thesis Defense	No sooner than 6 months after passing the Original Research Proposal requirement

J. Terminal Master's Degree

A candidate who terminates their Ph.D. program may obtain a terminal master's degree at the discretion of the department and contingent on the candidate having a Research Advisor. The requirements are: i) obtained a B- or better in a minimum of 4 300-level 1 credit courses in Chemistry or Biochemistry (see Section C), ii) complete at least two semesters as a Teaching Assistant in good standing (see Section D), iii) attend all departmental seminars and present research updates (see Section E), and iv) submit an acceptable thesis based on the student's original research and orally defend it before a departmental committee (see Section H as a guide).

ACADEMIC STANDING

For a student to maintain good academic standing in the Chemistry or Biochemistry Ph.D. programs, the student needs to register and complete four course units per semester and make satisfactory progress through the program milestones in a timely fashion based on the suggested schedule (see Section I). A student also needs to be making good progress on their research project to maintain satisfactory academic standing as deemed by the student's Research Advisor in consultation with their Faculty Advisory Committee. In cases where a student has taken one or more incompletes, the work must be completed satisfactorily by the agreed-upon date.

Students who achieve unacceptable grades (less than B- or withdrawal from a course) in two 300-level courses before obtaining credit for the 5 x 1 credit course minimum will be dismissed from the Chemistry or Biochemistry Ph.D. program.

Students who fail the second qualifying exam (see Section F) may be retested once, only if the student's Research Advisor and Faculty Advisory Committee deem it appropriate. Students who fail to pass this exam will be dismissed from the Chemistry of Biochemistry Ph.D. program.

K. Evaluations of Satisfactory Academic Standing

The Faculty Advisory Committee for the student is responsible for overseeing all important decisions and milestones concerning the student's progress throughout the graduate program and evaluating the academic standing of the student. The student is responsible for setting up an annual meeting with their Faculty Advisory Committee (with the help of the Chemistry Office Coordinator) to review their academic and research progress, write the student's second qualifying exam (see Section F), and to review the student's Original Research Proposal (see Section G) and Dissertation (see Section H). Please refer to section B for guidelines concerning the selection and composition of the Faculty Advisory Committee. If the student or Research Advisor deem it necessary to address issues regarding the student's academic standing and/or progress in the Chemistry or Biochemistry Ph.D. program, the Graduate Program Coordinator and Department Chair should be notified in writing to schedule an emergency meeting with the student's Faculty Advisory Committee. This meeting can be called outside the scheduled annual meeting period.

L. Academic Probation

Students will be placed on academic probation for unsatisfactory progress in their research as deemed by their Faculty Advisory Committee.

Students placed on academic probation will be notified by the Graduate Program Coordinator in writing. Requirements to return to satisfactory progress in research will be determined by the Research Advisor in consultation with the Faculty Advisory Committee and communicated to the Graduate Program Coordinator and Department Chair. Requirements to return to satisfactory progress as a Teaching Assistant will be determined by the Graduate Program Coordinator and Department Chair. Students who do not meet the requirements to be promoted from probation back to satisfactory status in the Chemistry or Biochemistry Ph.D. program within two academic semesters will be dismissed from the program.

M. Change or Loss of Research Advisor

A doctoral student is unable to continue in the program without a Faculty Advisor. The period of transition between advisors is expected to last no longer than one month. In the event that the student is unable to find a Faculty Advisor to work with for longer than one month, the Department Chair will convene a meeting of the Chemistry department faculty to determine whether the student will be allowed to continue in the Ph.D. or terminal Masters graduate programs.

N. Academic Grievance Procedures

Ordinarily, difficulties that may arise between students and faculty are resolved through informal discussions between the individuals involved. When a student believes that such discussions have not led to a fair outcome, the student may ask the Graduate Program Coordinator and the Department Chair to intervene. Again, the faculty members intervening will attempt to resolve the issue informally through discussions with those involved. If the student considers that these methods have failed, the student may ask the Chair to convene a meeting of the Grievance Committee for resolution. Generally, the Committee consists of one standing faculty member, normally the Graduate Program Coordinator. However, the convening of the Grievance Committee necessitates that the Department Chair appoint two additional faculty members. If the aggrieved student believes that one of the faculty members is biased against him or her, the Chair will not appoint that faculty member to the Committee. Students who believe that they have not been treated fairly through such procedures may appeal the department's decision to the Dean of Graduate Studies and Research.

O. Dismissal from the Ph.D. Program

Those who do not fulfill the required academic standing for the program will be dismissed from the Chemistry or Biochemistry Ph.D. program. The decision will be made by the Faculty Advisory Committee. Dismissal may include conferral of a terminal Master's degree, pending satisfactory completion of work recommended by the Faculty Advisory Committee and agreed by the student (see section J). The Research Advisor and Faculty Advisory Committee are not obligated to accept work for a Master's degree. Appeals against dismissal should be addressed to the Dean of Graduate Studies and Research following the procedure as stated in the academic catalog.

Appendix

Study Guides

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, physicochemical operations, and data evaluation. The problem-oriented role of chemical analysis should be emphasized throughout the student's experience.

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 chemistry courses. However, to achieve 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 including 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:

A. Clearly define 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?

B. Wisely select a method, or methods, to achieve the goals discussed in A (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 that will be involved in sample acquisition and preparation and chemical separations. The student must know how to eliminate or compensate for experimental interferences. The student must recognize the critical response parameters for each phase of the determination and be able to identify the sources of error.

C. 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).

D. Understand the theory and operational principles of the fundamental components of instrumentation including:

- Atomic spectroscopy (emission, absorption, x-ray), Molecular spectroscopy (UV-Vis, infrared, fluorescence), and Mass spectrometry

Biochemistry

The ACS examination in biochemistry is used as part of our Chemistry and Biochemistry Ph.D. qualifying exam (Part I). The exam covers material presented in a typical year-long advanced undergraduate curriculum in biochemistry as taught at most American Universities. Students are advised to prepare for the ACS biochemistry exam by studying from a biochemistry textbook and concentrating on basic biochemical principles, key structures, and metabolic intermediates. Since the ACS biochemistry exam is highly problem oriented, studying/working through problem sets at the end of the chapters in a biochemistry textbook is highly recommended.

Topics that can be covered on the ACS biochemistry exam include:

- *Buffers and pH* – ionization of amino acids
- *Protein structure and function* – chemistry of amino acids and peptides, protein structure hierarchy, equilibrium binding of ligands, enzyme catalysis (kinetics, regulation, inhibition), enzyme mechanisms, enzyme cofactors, protein structure determination, methods of analysis
- *Metabolic pathways and regulation* – glycolysis, TCA cycle, pentose phosphate pathway, fatty acid oxidation, gluconeogenesis, amino acid metabolism, nucleotide metabolism, oxidative phosphorylation, cofactor chemistry, feedback inhibition, key intermediates of photosynthesis
- *Thermodynamics* – free energy change, equilibrium concentrations of reactants and products, redox reactions, ATP-coupled reactions, solution properties of macromolecules
- *Carbohydrate structure and function* – common sugars, chemistry of carbohydrates (reducing/non-

reducing), complex carbohydrates, glycoproteins, methods of analysis

- *Nucleic acid structure and function* – chemistry of nucleotides and nucleic acids, 3D structure of DNA and RNA
  DNA replication, RNA transcription and protein translation, regulation of expression of genetic information, methods of analysis, recombinant DNA technology, molecular genetics
- *Lipid and membrane structure and function* – chemistry of lipids, structure of biomembranes, function of plasma lipoproteins, hormones, receptors, molecule transport across membranes

Inorganic Chemistry

The ACS examination in inorganic chemistry is used as part of our Chemistry and Biochemistry Ph.D. qualifying exam (Part I). The exam covers material presented in a typical advanced inorganic chemistry undergraduate course as taught at most American Universities. Students preparing to write the ACS inorganic chemistry exam are advised to study a straight-forward text (i.e. "Basic Inorganic Chemistry" by Cotton, Wilkinson, and Gaus) and fully understand the basics of inorganic chemistry. Typically, the ACS inorganic chemistry exam focuses more on theory than on actual structures or inorganic chemical reactions.

Topics that can be covered on the ACS inorganic chemistry exam include:

- *Periodicity and atomic structure* – electron configurations, trends in various properties (and anomalies), electronegativity, term symbols for atomic ground states
- *Ionic properties* – radii, ionization energies, electron affinities, oxidation states, Born-Haber cycles, lattice energies, crystal packing
- *Systematic chemistry of the elements* – alkalis, alkali metals, alkaline earths, noble gases, halogens, chalcogens, pnictogens, carbon groups, boron groups, transition elements, lanthanides, actinides, polymeric oxides, boranes, sulfur ring systems, silicates, inorganic ring systems
- *Solvents and acid-base chemistry* – acid-base concepts, hard and soft acids, weak and strong acids, superacids, non-aqueous solvent systems, solvation energies
- *Bonding theories* – Lewis structures, hybridization, resonance, valence shell electron pair repulsion (VSEPR) theory, linear combination of atomic orbitals-molecular orbital (LCAO-MO) theory, valence bond theory, bond energies, covalent radii and symmetry
- *Coordination chemistry* – stereochemistry and isomerism, valence bond, ligand field, molecular orbital (MO) theories of bonding, ligand field splitting, ligand field stabilization effects, magnetic properties, absorption spectroscopy of transition metal ions (Tanabe-Sugano diagrams), synthesis, reaction mechanisms, kinetics, trans effect, redox reactions, metal-metal bonds, metal clusters
- *Solid state chemistry* – simple metals (structures and theories of bonding), semiconductors, and band theory
- *Organometallic chemistry* – effective atomic number (EAN) rule, carbonyls and nitrosyls, olefin, acetylene, alkyl, arene complexes, metallocenes, clusters, homogeneous catalysis fluxionality, oxidative addition, reductive elimination

Organic Chemistry

The ACS examination in organic chemistry is used as part of our Chemistry and Biochemistry Ph.D. qualifying exam (Part I). The exam covers material presented in a typical year-long undergraduate curriculum in organic chemistry as taught at most American Universities. Students preparing to write the ACS inorganic chemistry exam are advised any introductory undergraduate organic chemistry textbook for study/review purposes. Since the ACS organic chemistry exam is highly problem oriented, studying/working through problem sets at the end of the chapters of an introductory organic chemistry textbook is highly recommended.

Topics that can be covered on the ACS organic chemistry exam include:

- *Introduction to organic chemistry and basic review* – "why carbon?", electronic orbitals, orbitals and geometry, molecular structure (representations, polarity and formal charges, acid-base definitions), percent composition analysis
- *Functional groups* – multiple bonds, heteroatom substitution, multiple atom fragments
- *Organic reactions* – polar (electrophilic and nucleophilic), radical (initiation, propagation, and termination), pericyclic reactions, rates of reaction, equilibria, energy diagrams, equilibrium constants, intermediates vs. transition states
- *Alkanes* – structure and nomenclature, alkyl groups and trivial names, carbon and hydrogen types, physical properties, conformation, cyclic alkanes (cis/trans isomers)
- *Alkenes* – structure and nomenclature (nature of the double bond, Z/E isomers, conjugation, 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)
- *Alkynes* – structure and nomenclature, reactions (electrophilic additions, hydration, tautomerization, hydroboration, oxidation and reduction, acidity and carbon-based nucleophiles – terminal anion, dianion, synthesis), introduction to multistep syntheses
- *Stereochemistry* – the nature of optical activity, chirality and enantiomers, nomenclature and 3D representations (wedge and hashmark, Fischer projection, Cahn-Ingold-Prelog convention), multiple chiral centers and diastereomers, properties of enantiomers vs diastereomers, stereochemistry and reactions, chirality at sites other than carbon
- *Alkyl halides* – structure and nomenclature, synthesis (from alkanes and olefins, from alcohols), organometallic chemistry reactions (Grignard's, lithium reactions, cuprates), substitution reactions (SN^1 and SN^2), elimination reaction (E^1 and E^2)
- *Cyclic systems* – nomenclature, stability and ring strain, synthesis, cyclohexanes and conformation, polycyclics, stereochemistry
- *Conjugation* – preparation and stability of polyolefins, Hückel molecular orbital (MO) theory, reactions (allylic systems and conjugation addition, kinetic and thermodynamic control, pericyclic reactions)
- *Benzene and aromaticity* – nomenclature, structure, stability, molecular orbital (MO) theory, heterocyclic aromatics, electrophilic and nucleophilic aromatic substitutions, mechanism and electronic control of regiochemistry (inductive effects and reaction rates, mesomeric effects and directing ability), halogenation, nitration, sulfonation, hydroxylation, elimination/addition reactions (the benzyne reaction)
- *Arenes: synthesis and reactions of substituted benzenes* – Friedel-Crafts alkylation and acylation (cation rearrangements, "ways around them"), aromatic side-chain reactions (benzylic activation, halogenation, oxidation), benzene ring reduction (catalytic hydrogenation, Birch reduction), poly-substituted benzenes
- *Alcohols and thiols* – nomenclature, general properties, synthesis (from halides, from olefins, from carbonyl compounds *via* reduction and 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, synthesis and properties of thiols,

- *Phenols* – nomenclature, properties and comparison to alcohols, synthesis, reactions (as nucleophiles to form an ether and/or ester, oxidation reactions, precursors for Claisen rearrangement)
- *Ethers, epoxides and their sulfur analogues* – nomenclature (as ethers, alkoxy substituents, cyclic ethers, epoxides, and thio analogues), physical properties, synthesis of ethers, synthesis of epoxides (from olefins, from halohydrins, from glycols, Darzens glycidic ester synthesis, from ketones), reactions of ethers (*via* acidolysis), reactions of epoxides (*via* ring openings), oxidations of thioethers (sulfoxides and sulfones)
- *Aldehydes and ketones: carbonyl compounds* – nature of the carbonyl group, general reactions (addition of nucleophiles, reduction, replacement of oxygen, nucleophilic substitutions, substitutions and condensations at the alpha site), nomenclature of aldehydes and ketones, synthesis of ketones and aldehydes (*via* oxidation of alcohols, reduction of acyl halides "aka Rosenmund reduction", ozonolysis of olefins, Friedel-Crafts acylation, hydration of alkynes, acyl halides and cuprates, hydrolysis of geminal dihalides, oxidation of glycols), oxidation of aldehydes (Fehling's and Tollen's tests), oxidation of ketones, cyanohydrin formation, addition of nitrogen (imines, enamines, oximes), acetal and ketal formation (protection groups), 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)
- *Amines* – nomenclature, structure and properties, basicity and functionality, reaction with alkyl halides, reaction with sodium azide, Gabriel synthesis, reduction techniques (oxime reduction, nitrile reduction, amide reduction, reductive amination, reduction of nitro compounds), rearrangements of N-carbonyl compounds (Hofmann rearrangement, Curtius rearrangement), reactions of amines (quaternization and salts: optical resolution, Hofmann elimination, acylation, sulfonation – the Hinsberg test, diazotization – the Sandmeyer reaction)
- *Carboxylic acids* – nomenclature, structure and physical properties, synthesis (*via* oxidation, *via* hydrolysis, Grignard reagent), reactions (with salts, reduction, decarboxylation, decarboxylation of diacids)
- *Carboxylic acid derivatives* – nomenclature, acid halide synthesis, acid halide reactions (nucleophilic substitutions, Friedel-Crafts acylation, Grignard addition, reduction), acid anhydride synthesis, acid anhydride reactions, ester properties, ester synthesis (Fischer esterification, from acid halides and anhydrides), ester reactions (substitution/transesterification, reduction, pyrolysis, Grignard addition, polyesters), amide synthesis, amide reactions, nitriles
- *Reaction of an α-carbon 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), reaction of an α-carbon to a nitrile
- *Carbonyl condensation reactions* – aldol condensation, Cannizzaro reaction, Claisen condensation (not rearrangement), Dieckmann cyclization, Michael additions, Robinson annulation, acyloin condensation, Thorpe condensation
- *Spectroscopy* – methods and spectral analysis (infrared, UV-Vis, mass spectrometry, ^{1}H and ^{13}C NMR spectroscopy)

Physical Chemistry

The ACS examination in physical chemistry is used as part of our Chemistry and Biochemistry Ph.D. qualifying exam (Part I). The exam covers material presented in a typical year-long advanced undergraduate curriculum in physical chemistry as taught at most American Universities. Students are advised to prepare for the ACS physical chemistry exam by studying from a physical chemistry textbook (and studying/working through problem sets at the end of the chapters.

Topics that are typically covered on the ACS physical chemistry exam include:

- *Properties of gases* – properties of an ideal gas and mixtures, the barometric distribution law, the van der Waals equation, isotherms of real gases, critical state, the law of corresponding states, 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, 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, thermodynamics of rubber elasticity
- *Equilibrium in pure substances* – chemical potential, phase equilibrium, surface tension, equilibria of condensed phases, phase diagrams, glass phase transition
- *Chemical reactions* – heats of reaction, adiabatic flame temperature, reversible reactions, calculation of equilibrium constants, fugacity of real gases, extent of reaction, 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, electrochemistry
- *Transport properties* – molecular collisions, random walks, diffusion, convection, chromatographic separation, viscosity, 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, enzyme catalysis
- *Quantum theory* – particles and waves, Bohr's atomic theory, postulates of quantum theory, "the particle in a box", the harmonic oscillator, 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, photoelectron spectroscopy
- *Diatomic molecules* – molecular vibrations, rotations, orbital theory, electronic spectroscopy, ionic bonding, dipole moments
- *Polyatomic molecules* – symmetry operations, groups, degenerate representations, bonding theory, symmetry orbitals, selection rules, molecular vibrations, Raman spectroscopy, molecular rotations
- *Structure of condensed phases* – crystallography, diffraction, crystalline solids, synthetic polymers, biopolymers, liquid crystals
- *Magnetic resonance spectroscopy* – principles of magnetic resonance, electron spin resonance (ESR), hyperfine coupling, ESR applications, high resolution NMR spectrometry, chemical shift, spin-spin splitting, second-order effects, ^{13}C NMR spectroscopy, relaxation processes, magnetic resonance imaging

Creating Figures and Slides

Scope

This document is a guide for the Carlson School of Chemistry & Biochemistry's expectations regarding the use of figures in written documents and presentations that are created for a department-wide audience. Specific examples to which these apply include graduate theses, undergraduate theses, graduate research proposals, and graduate literature reviews. Written documents and presentations done in classroom settings or within an individual research group are under the discretion of the professor.

Overall Goals

The major goal of creating a written document or giving a presentation is to tell a story. This story should be one you created, not simply a recreation or retelling of someone else's story. Whether the story is about your own work or about literature, it should show that you understand the material thoroughly and that you can put the material and its context together in a well organized and well thought out manner. Using figures and slides is a good way to supplement your story and help you tell it. As with the written portion of your document, figures and slides should be components that you designed and created to help you tell your story, not simply recreations of someone else's figures. Each figure and all the content within a figure should serve a specific purpose, not just fill space without adding meaningful content to your story. Learning to create useful figures is an important skill.

Fair-Use Copyright & Legal Requirements

Figures, like written documents, are protected by copyright and plagiarism rules. The "fair use" rules provide some exceptions. Although these rules are somewhat open to interpretations, some general themes can be seen. The purpose and intent of the use is important. Non-profit, educational, or scholarly uses favor fair use, but this is not sufficient to cover all material. Transformative uses, meaning using the content for a new purpose or in a new context favors fair use. The type of content is also important. Using facts and data, especially minimally sized small pieces taken from a larger work, favors fair use. In contrast, summaries of large amounts of work or artistic renderings are less likely to be allowed under fair use.

Specific Examples

Data figures

In order to discuss someone else's data and specific results, you should show their actual data, but in a way that incorporates it into your story. This data may take the form of a graph, an image, a precise structure, a spectrum, a chemical reaction, a data table, etc. To make your own figure or slide based on this data, you should take the minimum amount of their figure that contains the required data, and then integrate that data into your figure. Multiple parts of a figure (A, B, C, etc.) should not be copied as a single unit. All the content of your figure should match your story. There should not be any extra content left over from the original figure or any numbers or labels etc. that are specific to the original document. The sizing and format of your figure or slides should be well planned and well matched to your document.

Format, fonts, text sizing etc. should be consistent with your other figures or slides. Text and figure resolution should be readable, and titles and captions etc. should be consistent throughout your document. Each figure or subfigure should be called out at the appropriate time in the text of your document to indicate its relevance. The figure's caption should clearly indicate the original source. (In contrast, for manuscripts to be submitted for publication, you must obtain written permission from the copyright holder to use any copyrighted material.)

Summary Figures

Unlike illustrations of data, summary figures are not something that you should be taking from someone else's document. For example, these types of figures might be used to overview the major points of a paper, summarize its main results, illustrate a major concept, provide a flow chart of a complex procedure, thought process, or multistep reaction sequence, or illustrate a complex biological system. Like a full paragraph of writing, these figures present and describe complex ideas. They take thought and organization to create and often involve some artistic or graphic content. Directly taking one of these figures from someone else's work is analogous to quoting an entire paragraph of text. It is missing the point of creating your own document. Similarly, redrawing your own version of one of these figures without changing the content for your own purpose would be similar to rewriting someone else's paragraph by just changing a couple of words. Even though the words are your own, the ideas and organization are still just copied. Instead, if you want to use a figure to help summarize and present a large amount of content, which is usually a good choice, you should strive to develop your own figure that helps you do this in a clear and effective manner and that is well matched to your purpose.