Chemical Physics

College of Arts and Sciences

Departmental E-mail: gradphys@indiana.edu

Departmental URL: www.chemphys.indiana.edu

(Please note that when conferring University Graduate School degrees, minors, certificates, and sub-plans, The University Graduate School's staff use those requirements contained only in *The University Graduate School Bulletin*.)

Curriculum

Degree Offered

Doctor of Philosophy. A student may also qualify for the Master of Science degree in chemistry or physics.

Special Program Requirements

(See also general University Graduate School requirements.)

Doctor of Philosophy Degree

Admission Requirements

Undergraduate degree in chemistry, physics, or mathematics. Students who have interests in the physical sciences with undergraduate degrees in other fields, such as engineering, are also encouraged to apply; they will be considered on an individual basis. Admission to the program requires that the student first be admitted to the graduate program in chemistry or physics.

Grades

B (3.0) average or higher must be maintained.

Course Requirements

These requirements are flexible, and are planned and approved by the Chemical Physics Committee and the individual student. The guidelines in planning the curriculum are that the student in the program should acquire knowledge of condensed-matter physics, electricity and magnetism, molecular structure, kinetics, atomic and molecular spectroscopy, quantum mechanics, and statistical mechanics. The formal requirements are either those of a major in physical chemistry with a minor in physics or of a major in physics with a minor in chemistry.

Minor

For a minor in physics, 9 credit hours in physics courses at the P501 level or higher are required. For a minor in chemistry, 6 credit hours are required, chosen from the following: C561-C562, C566, C567-C568, C668. Occasionally, courses other than those listed here may be accepted, but such substitutions require approval of the Chemical Physics Committee.

Major

See Ph.D. program descriptions listed under chemistry or physics.

Qualifying Examination

See requirements of the major department, found elsewhere in this bulletin.

Dissertation

Under the direction of a graduate faculty member of the Department of Chemistry or the Department of Physics.

Final Examination

Usually oral, covering dissertation, major, and minor(s).

Faculty

Co-Directors

Professors David Baxter* (Physics), Romualdo de Souza* (Chemistry)

Graduate Faculty

(An asterisk [*] denotes membership in the University Graduate School faculty with the endorsement to direct doctoral dissertations.)

Chancellor's Professor

George Ewing* (Emeritus, Chemistry)

Distinguished Professors

Gary Hieftje* (Chemistry), Peter Ortoleva* (Chemistry), Charles Parmenter* (Chemistry), Victor Viola* (Emeritus, Chemistry)

Robert and Marjorie Mann Chairs

David Clemmer* (Chemistry), Gary Hieftje* (Chemistry), Martin Jarrold* (Chemistry)

Professors

Adam Allerhand* (Emeritus, Chemistry), David Baxter* (Physics), Russell Bonham* (Emeritus, Chemistry), Romualdo de Souza* (Chemistry), Herb Fertig* (Physics), Stanley Hagstrom* (Emeritus, Chemistry, Computer Science), Larry Kesmodel* (Physics), Lawrence Montgomery* (Emeritus, Chemistry), Gerardo Ortiz* (Physics), Roger Pynn* (Physics), Krishnan Raghavachari* (Chemistry), James Reilly* (Chemistry), William Schaich* (Emeritus, Physics), Paul Sokol* (Physics), Philip Stevens* (Public and Environmental Affairs), James Swihart* (Emeritus, Physics)

Associate Professors

Mu-Hyun Baik* (Chemistry), John Carini* (Physics), Bogdan Dragnea* (Chemistry), Srinivasan Iyengar* (Chemistry), Stephen Jacobson* (Chemistry), C. Chick Jarrold* (Chemistry), Dongwhan Lee* (Chemistry), Daniel Mindiola* (Chemistry)

Assistant Professors

Lane Baker* (Chemistry), Dobrin Bossev* (Physics), Amar Flood* (Chemistry), Liang-Shi Li* (Chemistry), Sara Skrabalak* (Chemistry), Steven Tait* (Chemistry)

Graduate Advisors

Professor David Baxter*, Swain West 128, (812) 855-8337; Professor Romualdo de Souza*, Chemistry C230A, (812) 855-3767

Chemistry

College of Arts and Sciences

Departmental E-mail: chemgrad@indiana.edu

Departmental URL: www.chem.indiana.edu

(Please note that when conferring University Graduate School degrees, minors, certificates, and sub-plans, The University Graduate School's staff use those requirements contained only in *The University Graduate School Bulletin*.)

Curriculum

Degrees Offered
Master of Science, Master of Arts in Teaching, and Doctor of Philosophy in Chemical Biology. The department also participates in the biochemistry, chemical physics, information science, library science, SPEA, and molecular and cellular biology programs.

Fields of Study
Analytical, inorganic, materials, organic, physical chemistry, and chemical biology.

Special Department Requirements
(See also general University Graduate School requirements.)

Admission Requirements
Undergraduate degree in chemistry, physics, mathematics, or the biological sciences. Students with undergraduate degrees in other areas of the physical sciences or engineering are also encouraged to apply. Students are admitted to the program only with the approval of the Chemistry Graduate Admissions Committee.

Grades
At least a B (3.0) average in work for the advanced degree. Grades below C (2.0) are not counted toward the completion of degree requirements, but will be counted in determining a student's grade point average.

Master of Science Degree - Chemistry
This degree may be conferred upon the holder of a bachelor's degree or master's degree in another discipline.

Course Requirements

These requirements are flexible and are planned and approved by the graduate committee. A minimum of 30 credit hours in chemistry are required. At least 9 credit hours of course work in the major field offered in fulfillment of the M.S. degree must be in courses numbered 500 or above (excluding thesis work).

Thesis

Required.

Master of Science in Chemistry/Master of Science in Environmental Science (SPEA)
This dual degree may be conferred upon the holder of a bachelor's degree or master's degree in another discipline.

Admission Requirements

The department of Chemistry and the School of Public and Environmental Affairs (SPEA) offer a two-year, 51 credit hour program that qualifies students for two master's degrees. A student must apply to and be accepted by both the Chemistry Department and by the School of Public and Environmental Affairs for study toward an M.S. degree in Chemistry and an M.S. in Environmental Science. The student will receive graduate advising in both the Chemistry Department and SPEA. Both degrees can be conferred upon the holder of a bachelor's degree or master's degree in another discipline.

Course Requirements

A minimum of 51 total credit hours with a minimum of 21 credits required in both chemistry and environmental science, to be distributed among the following six areas of chemistry and environmental science: (1) chemistry core (9 cr.); (2) environmental science core (9 cr.); (3) economics, policy, and law competencies (6-9 cr.); (4) tool skills (3-5 cr.); (5) environmental chemistry concentration (15-18 cr.); and (6) an experiential requirement (3 cr.). One of the 3-credit hour courses must involve team participation in an integrative project that addresses a multidisciplinary problem. This course may be in either of the concentrations or in the tool skill courses.

Experiential Requirement

A minimum of three credits associated with an approved experiential assignment, such as an internship or prior employment, is required.

Thesis

The thesis requirement is waived for the dual M.S. Chemistry/M.S.E.S. degrees.

Master of Arts for Teachers Degree
The Master of Arts for Teachers (MAT) program is a two-year, non-thesis masters and certification program that prepares secondary education teachers. The program consists of graduate coursework in chemistry in combination with education coursework toward certification in the School of Education. Returning teachers with certification usually take only one year to complete graduate chemistry coursework. Students with B.A. or B.S. degrees in chemistry, but with no education background, may complete requirements for a secondary Indiana teaching certificate and strengthen their background in chemistry.

Admission Requirements

Eighteen (18) credit hours of chemistry, including one semester each of general, quantitative, and organic chemistry. Deficiencies must be removed without graduate credit. Continuance in the program will depend upon the performance in coursework taken during the first semester in the program, and continued good standing in the program; alternatively, a qualifying examination may be administered after either one semester or one summer in the program.

General Requirements

A total of 36 credit hours, of which a minimum of 20 credit hours must be in courses in chemistry that carry graduate credit. For students without prior education coursework, the remaining 16 credits are to be fulfilled through School of Education courses. Consult School of Education, Graduate Studies Office (Wright Education Building 4210, [812] 856-8504) for Education coursework requirements.

A maximum of 6 credit hours of undergraduate courses may be applied toward the M.A.T. degree. For a student having an unusually strong undergraduate background in chemistry or biochemistry (e.g., a B.S. degree), some of the required 20 credit hours in advanced chemistry courses may be in other areas of science and

mathematics, if approved in advance by the graduate advisor.

Lecture-Course Requirements

Students are advised to select an area of specialization within chemistry, while developing a broad base of knowledge in several areas. To that end, students will take twelve (12) credit hours in lecture courses, distributed as follows: 6 credit hours in one of the following six areas: analytical, biological, inorganic, materials, organic, or physical chemistry; and 3 credit hours in each of two of the remaining six fields.

Lecture courses may be selected from those at the 500-level or above, or with departmental approval from any of the following undergraduate courses: analytical, A314, C317, C318; biological, C481, C483, C484, C485, B486; inorganic, C430; organic, C342, S342, C443; physical, C360, C361, C362, C460.

Laboratory-Course Requirements

Students are required to have had experience in upper level laboratories in three of the six areas of chemistry. If this requirement was not fulfilled prior to admission into the MAT program, graduate level laboratory courses may be taken to augment students' laboratory experience. Additionally, the following, and comparable courses taken elsewhere, will qualify with departmental approval: A316, C315, C344, P364, C437, P464, C487.

Electives

Additional courses in chemistry may count with departmental approval at the 400-level or above to give a total of at least 20 credit hours (including course work in the preceding two categories). Up to 16 credit hours in courses may count with departmental approval at the 300 level or above in mathematics, biological sciences, physical sciences, or education carrying graduate credit.

Final Examination

Either oral or written, or both.

Master of Library Science/Master of Information Science Degree Information Specialist (Chemistry)

Offered by the Department of Information and Library Science (ILS). Students in this joint program receive the Master of Library Science degree or the Master of Information Science degree, and a Chemical Information Specialization.

Admission Requirements

Bachelor's degree in chemistry or the equivalent.

Course Requirements: M.I.S.

Foundation course requirements (21 credit hours); and Specialization courses (9 credit hours: Z523, Z533, and INFO I571) and additional courses to be chosen in consultation with advisors in Information and Library Science and Chemistry to bring the total graduate credit hours to 42.

Course Requirements: M.L.S.

Foundation courses (18 credit hours); and Specialization courses (9 credit hours: Z523, Z533, and INFO I571) and additional Information and Library Science courses to be chosen in consultation with advisors in Information and Library Science and Chemistry to bring the total graduate credit hours to 36.

Doctor of Philosophy Degree

The program leading to the Ph.D. degree emphasizes the attainment of a high level of competency in a specialized area of chemistry, but also requires the development of broad knowledge and experience. By the time the degree is earned, the student should show promise of becoming a capable and independent investigator in chemistry. The major emphasis for the Ph.D. is on research while in residence on the Bloomington campus. Research should be the student's greatest challenge and the focus of the major portion of his or her energy. The student's attitude toward and progress in research is a most important factor in graduate committee decisions.

Course Requirements

A total of 90 credit hours, of which at least 24 credit hours must be in course work. Students may major in analytical, chemical biology, inorganic, materials, organic, or physical chemistry. Doctoral students majoring in a field of chemistry are required to complete a minimum of 12 credit hours of course work in that field, following a sequence of courses approved by their advisory committee.

A doctoral student in chemistry can choose to minor within the Chemistry department or can elect to minor in some other department. In the latter case, the requirements are specified by the minor department. Students electing to minor within the department must complete a minimum of 6 credit hours in areas of chemistry other than the major area by following the subplans/tracks., otherwise you must create an Individualized Minor which provides additional breadth and depth to the individualized degree. The course work comprising an inside minor must be approved by the advisory committee.

All doctoral students in chemistry are required to enroll in C500 Introduction to Research during their first year of study.

Foreign-Language/Tool-Skill Requirement

The department has no formal foreign language or tool-skill requirement, but Ph.D. advisory committees may consider such courses essential for individual students.

Qualifying Examinations

To remain in good standing, each student must successfully complete the Chemistry seminar course in the chosen major (A800, B800, M800, N800, R800, or P800) during the third and fourth semester, and present a literature seminar by the end of the second year. In the fifth semester, students meet with their advisory committees to review past performance in both the major and minor areas and to evaluate plans for completing the Ph.D. This review includes a seminar, written document, and oral examination. A written exam is included for Chemical Biology majors. Current information concerning probation, termination, and reinstatement policies may be obtained from the departmental graduate office.

Final Examination

Usually oral, covering dissertation, major, and minors, and also a seminar describing the dissertation.

Subplans/Tracks

Analytical: CHEM C501 Chemical Instrumentation; CHEM C611 Electroanalytical Chemistry; CHEM C612 Spectrochemical Methods of Analysis; CHEM C613 Mass Spectrometry and Stable Isotopes; CHEM C614 Chromatography; CHEM C615 Bioanalytical Chemistry; CHEM C620 Measurement Science

Chemical Biology: CHEM C581 Macromolecular Structure and Function; CHEM C582 Biomolecular Analysis and Interaction; CHEM C583 Analysis of Biochemical Literature; CHEM C584 Integrated Biochemistry; CHEM C588 Fundamentals of Biochemical Catalysis; CHEM C589 Enzyme Mechanisms; CHEM C680 Introduction to Quantitative Biology and Measurement; CHEM C681 Introduction to Chemical Biology I; CHEM C682 Introduction to Chemical Biology II; CHEM C687 Seminar Advanced Topics in Biochemistry; CHEM C689 Quantitative and Chemical Biology Journal Club

Inorganic: CHEM C502 Inorganic Spectroscopy; CHEM C630 Structure and Bonding; CHEM C631 Chemical Crystallogrrahy; CHEM C632 Structure, Function, and Spectroscopy of Metal Ions in Biological Stystems; CHEM C633 Inorganic Chemistry of Main Group Elements; CHEM C634 Transition Metal Chemistry; CHEM C635 Mechanisms of Inorganic Chemistry, CHEM C636 Organometallic Chemistry and Catalysis CHEM; C639 Characterization of Paramagnetic Molecules

Materials: CHEM M501 Fundamentals of Materials I: Making, Measuring, and Modeling; CHEM M502 Fundamentals of Materials II: Molecular and Nanoscale Materials; 6 hours from other courses approved by advisor

Organic: CHEM C503 Spectrometric Methods of Structure; CHEM C540 Advanced Organic Chemistry; CHEM C543 Organic Reactions; CHEM C643 Organic Natural Products; CHEM C648 Seminar Organic Chemistry

Physical: CHEM C561 Atomic & Molecular Quantum Theory; CHEM C562 Computational Quantum Chemistry; CHEM C566 Molecular Optical Spectroscopy; CHEM C567 Chemical Statistical Mechanics; CHEM C668 Seminar Physical Chemistry

Minors

A doctoral student in chemistry can choose to minor within the Chemistry department or can elect to minor in some other department. In the latter case, the requirements are specified by the minor department. Students electing to minor within the department must complete a minimum of 6 credit hours in areas of chemistry other than the major area. The course work comprising an inside minor must be approved by the advisory committee.

Ph.D. Minor in Chemistry

Students from other departments who wish to minor in chemistry must complete at least 6 credit hours of graduate course work in one area of chemistry with an average of B (3.0) or above.

Ph.D. Minor in Sustainable Energy Science

Students in Chemistry who wish to minor in Sustainable Energy Science must complete 12 credit hours of study, 9 of which are in coursework that includes (1) GEOG-G542, (2) a course on a specific energy type, and (3) one course on implications of energy use. Contact the departmental Graduate Office for appropriate courses.

Ph.D. Minor in Quantitative Biology (Q.B.)

Students wanting to minor in Q.B. are required to complete 6 credit hours offered in Chemistry, Biology, Biochemistry, Physics and Medical Sciences. Contact the Chemistry Department Graduate Office for appropriate courses. See the chemistry website for further clarification and the link to the minor application. http://www.chem.indiana.edu/graduate/.

Faculty

Chairperson

Professor Stephen C. Jacobson*

Graduate Faculty

(An asterisk [*] denotes membership in the University Graduate School faculty with the endorsement to direct doctoral dissertations.)

Harry G. Day Chair

David R. Williams*

James F. Jackson Associate Professor

Lane Baker*

Luther Dana Waterman & Professor James F. Jackson

Amar Flood*

Robert and Marjorie Mann Chairs

David E. Clemmer*, Gary M. Hieftje*, Martin Jarrold*

Joan and Marvin Carmack Chair

Nicola L. Pohl*

Earl Blough Professor

Trevor Douglas*

Ed Bair Chair

Stephen C. Jacobson*

Lilly Alumni Chair

David P. Giedroc*

Provost Professor

Romualdo T. deSouza*, Bogdan Dragnea*

Vice Provost for Sciences

Jeffrey M. Zaleski*

Rudy Professor/Dean's Fellow

Sara Skrabalak*

Distinguished Professors

Kenneth G. Caulton*, Ernest Davidson* (Emeritus), Gary M. Hieftje*, Ronald Hites* (Public and Environmental Affairs), Milos V. Novotny* (Emeritus), Peter J. Ortoleva*, Charles S. Parmenter* (Emeritus), Victor E. Viola* (Emeritus), David E. Clemmer*, Krishnan Raghavachari*, Richard DiMarchi*

Herman T. Briscoe Professor

Dennis G. Peters*

Standiford H. Cox Professor & Linda & Jack Gill Chair

Richard D. Di Marchi*

Professors

Adam Allerhand* (Emeritus), Russell Bonham* (Emeritus), Ernest Campaigne (Emeritus), Jack Crandall* (Emeritus), Bogdan Dragnea*, Joseph Gajewski* (Emeritus), David P. Giedroc*, Stanley Hagstrom* (Emeritus, Computer Science), Stephen Jacobson*, Caroline Chick Jarrold*, Lawrence K. Montgomery* (Emeritus), Martha Gray Oakley*, James P. Reilly* John Richardson* (Emeritus, Biochemistry), V. Jack Shiner Jr.* (Emeritus), Philip S. Stevens* (Public and Environmental Affairs), Theodore S. Widlanski*, Jeffery M. Zaleski*

Associate Professors

Lane Baker*, Charles Dann III*, Srinivasan S. Iyengar*, Liang-shi Li*, Jeremy Smith*, Steven L. Tait*, Michael VanNieuwenhze*

Senior Scientists

Lyudmila Bronstein, John Huffman* (Emeritus), Maren Pink

Assistant Professors

Michael Kevin Brown*, Silas Cook, Jonathan Raff* (Public and Environmental Affairs), Thomas Snaddon*, Megan Thielges*, Yan Yu*

Graduate Advisor

Amar Flood, Chemistry Building C131, (812) 855-2069

Courses

- **CHEM-C 500 Introduction to Research (2-6 cr.)** Objectives and techniques of chemical research. Assignment to research problem to be completed during two semesters.
- **CHEM-C 501 Chemical Instrumentation (4 cr.)** Electronics as applied to chemical instrumentation; design and construction of instruments used in chemical research, analysis, recording, and control; maintenance and practice in modification to meet special needs.
- **CHEM-C 502 Spectroscopic Methods in Inorganic Chemistry (3 cr.)** P: C361. Chemical applications of group theory and the elucidation of structure and bonding in inorganic molecules and complexes by vibrational, nuclear magnetic resonance, Mossbauer and electronic absorption spectroscopy.
- **CHEM-C 503 Spectrometric Methods of Structure Determination (3 cr.)** P: Graduate standing. Elucidation of molecular structure utilizing IR, UV, and NMR spectroscopy, mass spectrometry, and other methods.
- **CHEM-C 506 Biogeochemistry (3 cr.)** The formation and processing of organic material in natural environments. Microbiology of sediments. The global biogeochemical cycles of carbon, nitrogen, and sulfur. Geochemistry of organic materials. Organic geochemical evidence of evolutionary events.
- **CHEM-C 509 Special Laboratory Problems (1-5 cr.)** P: 8 credit hours of chemistry toward graduate degree, consent of instructor. P or C: 500-level lecture course in research field. Nonmajors only. Participation in scientific research to gain understanding of its philosophy and techniques.
- **CHEM-C 511 Advanced Analytical Methods I (4 cr.)** Theory and practice of analytical separation techniques and analytical spectroscopy; chromatographic methods of separation, fundamentals of gas and liquid chromatography, overview of spectroscopic instrumentation, atomic and molecular spectroscopy for analysis.
- **CHEM-C 512 Advanced Analytical Methods II (4 cr.)** Theory and practice of electrochemical (potentiometric and voltammetric) methods of analysis; introduction to analytical chemistry of the elements and statistics for analytical chemistry.
- **CHEM-C 540 Advanced Organic Chemistry (3 cr.)** P: C362 and C342. Valence and molecule structure, electronic interpretation of organic reactions, stereochemistry.
- **CHEM-C 543 Organic Reactions (3 cr.)** Synthesis of organic compounds, degradation reactions, selected topics in organic reactions.
- **CHEM-C 561 Atomic and Molecular Quantum Theory (3 cr.)** P: Graduate standing or consent of instructor. Elements of quantum theory, solution of elementary problems with chemical applications, approximate methods, atomic structure, molecular symmetry and normal vibrations, the molecular orbital description of molecules.
- **CHEM-C 562 Computational Quantum Chemistry (3 cr.)** P: C561 or consent of instructor. Electronic structure theory at the Hartree-Fock and semiempirical levels, computer calculations on elementary systems, elements of group theory and linear vector spaces, electron correlation, structure of potential surfaces.
- **CHEM-C 565 Nuclear Chemistry (3 cr.)** P: C360 or C361. Introduction to nuclear science covering the properties, structure, and reactions of nuclei. The energetics and kinetics of radioactivity are studied. Models presented include the liquid drop (macroscopic properties) and the shell (microscopic properties) models. Topics covered include: origin of the elements, nuclear power, biological effects of radiation, and radiocarbon dating.
- **CHEM-C 566 Molecular Optical Spectroscopy (3 cr.)** P: C561 or consent of instructor. Interaction of radiation with matter. Spectroscopic probes of the rotational, vibrational, and electronic structure of molecules. Advanced laser methods.
- **CHEM-C 567 Chemical Statistical Mechanics (3 cr.)** P: Graduate standing or consent of instructor. Introduction to equilibrium and nonequilibrium many-body systems using ensemble techniques. Emphasis on molecular systems and systems undergoing chemical transformation or transport. Both qualitative and rigorous approaches.
- **CHEM-C 568 Advanced Statistical Mechanics (3 cr.)** P: C567 or consent of instructor. Selected topics such as pair correlation functions in classical liquids, laser and reaction-transport, nonequilibrium phenomena, critical phenomena, reaction rates,

condensed media, NMR, precipitation and polymer kinetics, Green's function methods, and computational methods.

- **CHEM-C 572 Computational Chemistry and Molecular Modeling (3 cr.)** P: C571 or consent of instructor. Molecular modeling: computer models of molecules and their behavior in gas and condensed phases; implicit and explicit solvation models; quantum and molecular mechanics; search strategies for conformational analysis, geometry optimization methods; information content from Monte Carlo and molecular dynamics simulations. Statistics and chemometrics: multivariate statistics and experimental design, numerical methods, calibration and chemical analysis, optimization methods, artificial intelligence. Molecular design: de novo design techniques; quantitative structure activity relationships (QSAR); comparative molecular field analysis (CoMFA); docking; molecular diversity and combinatorial libraries.
- **CHEM-C 581 Macromolecular Structure and Function (1.5 cr.)** P: BIOC-B501 or consent of instructor. Molecular Biology and Physical Chemisry Review; Recombinant DNA Techniques; Heterologous Protein Expression Systems; Description and Measurement of Stabilizing Forces in Macromolecular Structure; Protein Secondary, Tertiary and Quaternary Structures: Circular Dichroism and Analytical Ultracentrifugation; Nucleic and Structure and Probing; Protein Structure Determination by Neclear Magnetic Resonance (NMR); Protein Structure Determination by X-ray Crystallography; building and refinement of a Protein Structure from Crystallographic Data. Credit given for only one of the following: C581, B530.
- **CHEM-C 582 Biomolecular Analysis and Interaction (1.5 cr.)** P: BIOC-B501 or consent of instructor. Ligand Binding Models; Single Site Binding and Multiple and Competitive Site Binding; and Determination and Measurement of Binding Interactions and Antibody-based Interaction Methods. Credit given for only one of the following: C582, B531.
- **CHEM-C 583 Analysis of Biochemical Literature (1.5 cr.)** P: Concurrent or previous enrollment in B501/C584 or consent of instructor. Critical evaluation of the biochemical literature using selected papers as examples, development of written and oral communication skills in the context of literature analysis. Credit given for only one of the following: C583, C502.
- **CHEM-C 584 Integrated Biochemistry (3-4.5 cr.)** P: Undergraduate biochemistry (equivalent to C483 or C484) or consent of instructor. Basic principles and methodologies of biochemistry: essentials of macromolecular biosynthesis; mechanism-based examination of biochemical aspects of cell biology; material is presented with an integrative approach design to illustrate the interrelationship of biochemical processes. Credit given for only one of the following: C584, B501.
- **CHEM-C 585 Structure and Function of Biological Membranes (3 cr.)** Biochemistry and biophysics of lipids, membranes, and membrane proteins; fundamentals of membrane transport; interfacial catalysis; transmembrane signal transduction. Credit given for only one of the following: C585, B605.
- **CHEM-C 587 Integrated Biochemistry II (1.5 cr.)** P: C584 or consent of instructor. Mechanism-based examination of biochemical aspects of control protein folding and function, signal transduction, and systems biology. Credit given for only one of the following: C587, B506.
- **CHEM-C 588 Fundamentals of Biochemical Catalysis (1.5 cr.)** General properties of enzymes and basic principles of enzymatic reactions are discussed. Enzyme kinetics; inhibitor types, their importance and there effects on enzymatic reaction rates; and specificity of enzymes will be covered. Students will gain facility with thermodynamics, catalytic mechanisms, kinetics and binding equilibria as they apply to proteins. Credit given for only one of the following: C588, B540.
- **CHEM-C 589 Enzyme Mechanisms (1.5 cr.)** P: CHEM-C588 Enzyme mechanisms demonstrate how chemical principles are employed by living organisms. The course will cover several classes of enzymes, for example, hydrolases, phosphorylases, kinases, carboxylases, and transferases. Focus will also be placed on the roles of cofactors in catalysis. Credit given for only one of the following: C589, B541.
- **CHEM-C 611 Electroanalytical Chemistry (1.5-3 cr.)** Theory and practice of electrochemical techniques (such as cyclic voltammetry, chronocoulometry, stripping analysis, thin-layer electrochemistry, and spectroelectrochemistry) used for analysis and for the characterization of inorganic and organic systems. (May be offered in alternate years.)
- **CHEM-C 612 Spectrochemical Methods of Analysis (1.5-3 cr.)** New instrumentation and techniques employed in spectrochemistry; in-depth treatment of commonly used spectrochemical methods. (May be offered in alternate years.)
- **CHEM-C 613 Mass Spectrometry and Stable Isotopes (1.5-3 cr.)** Topics in mass spectroscopic instrumentation and applications and in the natural chemistry of the stable isotopes of C, H, N, O, S, and rare gases. (May be offered in alternate years.)
- **CHEM-C 614 Chromatography (1.5-3 cr.)** Theoretical and practical aspects of chromatographic methods of separation; fundamentals of gas and liquid chromatography, related instrumentation, and selected applications. (May be offered in alternate years.)
- **CHEM-C 615 Bioanalytical Chemistry (1.5-3 cr.)** Survey of modern analytical techniques, including spectrochemical, electrochemical, and separation methods used in biochemical analysis and their applications. (May be offered in alternate years.)
- **CHEM-C 616 Surface Analysis and Surface Chemistry (1.5 cr.)** An overview of the modern instrumental techniques of surface analysis will be presented, together with a survey of their applications to solve surface chemical problems. Topics include electron and ion spectroscopies, SIMS, LEED, thermal desorption spectroscopy,

surface electron and ion microscopies, catalysis, microelectronics fabrication, and corrosion.

- **CHEM-C 619 Seminar: Analytical Chemistry (1 cr.)** P: Consent of instructor. Individual student seminars covering new methods or applications of chemical analysis or characterization. Required of all analytical chemistry majors.
- **CHEM-C 630 Structure and Bonding (3 cr.)** P: C502 and C561. Applications of quantum mechanics to the electronic and geometric structure of inorganic molecules. Advanced ligand field and molecular orbital theories. The Jahn-Teller effects and orbital symmetry studies of stereochemistry. Inorganic photochemistry. (May be offered in alternate years.)
- **CHEM-C 631 Chemical Crystallography (3 cr.)** General understanding and hands-on laboratory experience in crystallography as analytical method. Topics will consist of theory on physics and mathematical concepts used in crystallography, the relation of physical and chemical properties to structure data, common databases, utilization of appropriate software for data work-up, solution, refinement, and visualization structures.
- **CHEM-C 632 Structure, Function, and Spectroscopy of Metal Ions in Biological Systems (3 cr.)** Introduction to the field of bio-inorganic chemistry and spectroscopic methods for determining structure/function relationship of metal ions in biology. Emphasis on oxygen carriers, metal ion transport and storage, as well as oxidoreductases involved in oxygen, hydrogen, and nitrogen metabolism. A discussion of electron transfer proteins, photosystems, and the role of metals in medicine will also be included.
- **CHEM-C 633 Inorganic Chemistry of Main Group Elements (3 cr.)** The syntheses, structure, and industrial application of compounds and materials in which main group elements play a major role. All elements except the d-block transition metals are included as main group elements. This includes the f-block lanthanides and actinides as well.
- **CHEM-C 634 Transition Metal Chemistry (3 cr.)** Survey of the properties of the transition metals with emphasis on common oxidation levels, coordination geometries, and compounds with "classical" ligands; "hard" and "soft" acids and bases; d-orbitals and their energies in different geometries; formation constants and the Chelate Effect; the Jahn-Teller theorem; low-, intermediate-, and high-spin systems; mixed valency; metal-ligand multiple bonding, metal-metal bonds; coordination clusters and their biological relevance.
- **CHEM-C 635 Mechanisms of Inorganic Reactions (3 cr.)** Analysis of the experimental and theoretical basis for our understanding of the reactions associated with main group and transition metal ions and inorganic reagents in solution. Classes of reactions include ligand substitutions, redox reactions, electron transfer reactions, reactions within the coordination sphere of metal ions including catalysis by photochemical and electrochemical activation.
- **CHEM-C 636 Organometallic Chemistry and Catalysis (3 cr.)** Synthesis and reactivity of organo-main group and transition metal compounds, including application to organic synthesis. Predictive principles and generic C-C and C-H bond-forming reactions, including hydrogenation, coupling, addition to olefins or alkynes, and metatheses. These reactions are also extended to reactions on surfaces and solid-state processes.
- **CHEM-C 637 Physical Methods in Structural Chemistry (3 cr.)** Application of X-ray diffraction, dynamic NMR, and mass spectroscopy to structural and mechanistic problems throughout the periodic table, with emphasis on which techniques are optimal for particular questions, as well as the potential weaknesses of each.
- **CHEM-C 638 Seminar: Inorganic Chemistry (1-3 cr.)** P: Consent of instructor. Topics not ordinarily covered by regularly scheduled courses, such as boron hydrides, X-ray diffraction, metal-metal bonds, bioinorganic chemistry, platinum metals chemistry, inorganic photochemistry, etc. (May be offered in alternate years.)
- **CHEM-C 639 Characterization of Paramagnetic Molecules (3 cr.)** Definitions of diamagnetism, paramagnetism, magnetization and magnetic susceptibility; the Curie Law; orbital angular momentum; the Van Vleck equation; zero-field splitting; exchange interactions in dinuclear and polynuclear metal clusters. Basic concepts of paramagnetic NMR; spin delocalization mechanisms and isotropic shifts; contact and dipolar contributions. EPR of transition complexes; g-value anisotropy as a function of coordination geometry.
- **CHEM-C 643 Organic Natural Products (3 cr.)** P: C540 and C543; or consent of instructor. Synthesis and chemical-physical analysis of the structure of alkaloids, antibiotics, bacterial metabolites, plant pigments, steroids, and terpenes. (May be offered in alternate years.)
- **CHEM-C 644 Physical Organic Chemistry (1-3 cr.)** P: C342 and C362. Application of physical-chemical techniques to the study of structure and mechanism of reaction of organic compounds.
- **CHEM-C 648 Seminar: Organic Chemistry (1-3 cr.)** P: Consent of instructor. Recent developments in such areas as sulfur compounds, heterocycles, stereochemistry, polymers, and synthesis. May be repeated.
- **CHEM-C 668 Seminar: Physical Chemistry (1-3 cr.)** P: Consent of instructor. Topics such as chemical applications of matrix algebra and group theory, digital computing techniques, solid state chemistry, high temperature processes, electrochemistry, theory of solutions, spectroscopy, and surface chemistry. May be repeated with different topics.
- **CHEM-C 681 Introduction to Chemical Biology I (1.5 cr.)** Basic elements of chemical biology with a chemistry-centered focus. This course will cover peptide synthesis and ligation methods, oligonucleotide synthesis, diversity-oriented synthesis and combinatorial libraries, bioorthogonal reactions, high-throughput screening methods and their use in drug discovery, and secondary metabolism. Credit given for only one of the following: C681, B680.

- **CHEM-C 683 Advanced Nucleic Acid Biochemistry (1.5 cr.)** Mechanistic analysis of nucleic acid metabolism; specificity and role of DNA polymerases and repair pathways; DNA replication and recombination mechanisms; RNA structural motifs and physical properties; RNA synthesis and processing in gene expression; catalytic RNA molecules; applications of RNA molecules. Credit given for only one of the following: C683, B601.
- **CHEM-C 685 Advanced Macromolecular Structure and Interaction (1.5 cr.)** Supplements and extends B503; emphasis on stability and folding mechanisms of proteins and nucleic acids and detailed thermodynamic analysis of binding interactions. Credit given for only one of the following: C685, B603.
- **CHEM-C 686 Structural Methods (3 cr.)** In biology, structure and function are intimately connected. The aim of this class is to demystify macromolecular structure determination. We will examine X-ray crystallography and EM image reconstruction in detail, solving structures and studying the theoretical underpinnings of each technique. Class will be computer and mathematics intensive. Credit given for only one of the following: C686, B604.
- **CHEM-C 687 Seminar: Advanced Topics in Biochemistry (1-3 cr.)** P: Consent of instructor. Topics vary yearly and include the following: physio-chemical techniques in the study of macromolecules; experimental methods in enzymology; organic chemistry of enzymatic reactions and enzyme models; conformational properties and macromolecules. Credit given for only one of the following: C687, B680.
- **CHEM-C 688 Seminar in Biochemistry (1.5-6 cr.)** P: Consent of instructor. Topic: Introduction to Quantitative Biology and Measurement. General properties of enzymes and basic principles of enzymatic reactions are discussed. Enzyme kinetics; inhibitor types, their importance and there effects on enzymatic reaction rates; and specificity of enzymes will be covered. Students will gain facility with thermodynamics, catalytic mechanisms, kinetics and binding equilibria as they apply to proteins.
- **CHEM-C 689 Quantitative and Chemical Biology Journal Club (1 cr.)** P: Permission from Instructor. Current literature in chemical biology, biological imaging, mass spectrometry and structural biology of biomolecules and biomolecular assemblies will be discussed. May be repeated for a maximum of 10 credits.
- **CHEM-M 501 Fundamentals of Materials I: Making, Measuring, and Modeling (3 cr.)** P: Consent of instructor. Introduces techniques for fabrication, characterization, and modeling of materials with an emphasis on nanostructures. Methods (top down) for the creation and characterization of nanostructures; Band structure, conductivity, optical properties, and quantum confinement; Assembly, liquids, and phase transitions.
- **CHEM-M 502 Fundamentals of Materials II: Nanoscale and Molecular Materials (3 cr.)** P: Consent of instructor. Introduces nanoscale and molecular materials. The first part provides an overview of methods for bottom-up synthesis and assembly of nanostructures. The second part provides case studies from the recent literature; including: nanoparticles; biological applications; molecular electronics and machines; self-assembly in artificial and biological systems.
- **CHEM-M 503 Supramolecular Chemistry (3 cr.)** P: Consent of instructor. A one-semester overview of bottom-up fabrication of functional materials. Emphasis on the chemistry of molecularly defined assemblies and physical properties; recognition, catalysis, sensing, switching, transport, and actuation; electron transfer and energy transfer and energy transfer; interfacial assemblies; mesoporous materials; polymers, dendrimers and liquid crystals.
- **CHEM-M 608 Seminar: Materials Chemistry (1-3 cr.)** P: Consent of instructor. Topics such as electrochemistry, biomaterials, polymers, solid state chemistry, computational chemistry, micro/nanofabrication, and environmental chemistry considered from the perspective of materials chemistry.
- **CHEM-A 800 Seminar: Analytical Chemistry (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-B 800 Seminar: Chemical Biology (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-M 800 Seminar: Materials Chemistry (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-N 800 Seminar: Inorganic Chemistry (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-P 800 Seminar: Physical Chemistry (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-R 800 Seminar: Organic Chemistry (1 cr.)** This course is eligible for a deferred grade.
- **CHEM-C 810 Research: Analytical Chemistry (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-C 820 Research: Materials Chemistry (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-C 830 Research: Inorganic Chemistry (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-C 840 Research: Organic Chemistry (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-C 860 Research: Physical Chemistry (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-C 880 Research: Chemical Biology (arr. cr.)** This course is eligible for a deferred grade.
- **CHEM-G 901 Research (6 cr.)** This course is eligible for a deferred grade.
- **CHEM-C 620 Measurement Science (1-3 cr.)** Topics related to measurement in the chemical sciences and interdisciplinary fields of science and engineering. Special attention to perspectives on advanced instrumentation and application of new hybrid techniques to areas such as biomedical, environmental, energy, or other areas of interest.
- **CHEM-C 680 Introduction to Quantitative Biology and Measurement (1.5 cr.)** Core topics in solution scattering methods, electron microscopy, light microscopy/ imaging, and biological mass spectrometry. Coursefocuses on the capabilities of each type of measurement: data analysis, sensitivity,

resolution, quantitation, and limitations. Introduction to cutting-edge instrumentation available for use in thesis reseach, research findings or new approaches used in (C689).

- **CHEM-C 682 Introduction to Chemical Biology II (1.5 cr.)** Basic elements of chemical biology applications and uses of technology. This course will cover microarray technology, protein labeling, chemical genetics, small molecule interactions with proteins/DNA, modulation of protein-protein interactions, RNA aptamers and molecular evolution. Credit given for only one of the following: C682, B680.

Classical Studies

College of Arts and Sciences

Departmental E-Mail: classics@indiana.edu

Departmental URL: www.indiana.edu/~classics

(Please note that when conferring University Graduate School degrees, minors, certificates, and sub-plans, The University Graduate School's staff use those requirements contained only in *The University Graduate School Bulletin*.)

Curriculum

Degrees Offered

Master of Arts, Master of Arts for Teachers, and Doctor of Philosophy

Special Departmental Requirements

(See also general University Graduate School requirements.)

Placement Examination

All newly admitted students will be required to take a translation examination in Latin and/or Greek for the purpose of placement. This examination will be given in the week preceding initial registration. It is the student's responsibility to arrive on campus in time to take this examination. No student will be permitted to enroll for courses until the results of this placement examination are delivered to the director of graduate studies.

Master of Arts Degree

Admission Requirements

Undergraduate major in Latin or Greek or the equivalent. Graduate Record Examination General Test required.

Course Requirements

A minimum of 30 credit hours of Latin, Greek, or classics courses, of which at least 22 credit hours must be in Latin or Greek. One course involving the writing of a term paper.

Final Examination

Sight translation examination (two hours) in Latin or Greek. Written examination (two hours) on the history of Greek or Latin literature.

Language Requirement

Reading proficiency in one language: French, German, or another approved modern language, or (for students majoring in Latin) classical Greek. The requirement in classical Greek may be satisfied by completing G500-G650. (The latter courses may not be taken for credit by doctoral students majoring in the Department of Classical Studies.) A grade of B or better in G650 fulfills the reading-knowledge requirement in classical Greek.

Master of Arts for Teachers Degree

Admission Requirements

Undergraduate major in Latin or Greek or the equivalent. Graduate Record Examination General Test required.

Course Requirements

The total for the M.A.T. degree is 60 credit hours, of which 24 are in classes designated by the School of Education and 10 in Supervised Student Teaching. Of the remaining 26 hours, 20 are in courses involving Greek and/or Latin language and literature, and 6 in classical civilization and culture.

Final Examination

Sight translation examination (two hours) in Latin. Written examination (two hours) on the history of Latin literature.

Doctor of Philosophy Degree

Admission Requirements

As a prerequisite for admission, a student must (1) have completed at least 24 credit hours of graduate work in classical studies; (2) show proficiency in one modern foreign language; (3) show evidence of scholarly potential as indicated by the submission of a term paper or revised version of a term paper to the Ph.D. admission committee of the department; (4) supply two letters of reference; and (5) take the Graduate Record Examination General Test.

Course Requirements

A total of 90 credit hours, including dissertation (maximum of 28 credit hours). Fifty-three (53) credit hours must consist of the 20 credit hours of core requirements (C501, C502, G536, G537, L536, and L537) and 33 additional credit hours of Latin and Greek reading and seminar courses. The remaining credit hours are distributed among the courses in the minor program.

Minor

A total of 12 to 15 credit hours of course work, to be planned in consultation with the director of graduate studies. Minor programs aim to broaden the student's knowledge in some aspect of classical studies outside the core curriculum. A minor may be taken in a single department (e.g., fine arts, comparative literature, history); in that case, the student should also consult with the director of graduate studies in that department. An interdepartmental minor (examples include "ancient studies" and "mythology studies") combines course work in other departments with appropriate courses in classical studies.

Another possibility is an interdepartmental minor in "related fields," with courses selected from comparative literature, fine arts, folklore, history, history and philosophy of science, linguistics, medieval studies, philosophy, religious studies, Renaissance studies, or any other appropriate department or school (e.g., law or music); the aim of this "related fields" minor is to introduce the student to methodologies and approaches other than