

techniques for the cultivation of cells, recovery and purification of cell products, biocatalysis, and analytical methods for the quantification of product yields.

81.593 Immunology (3-0)3 Prerequisites: Microbiology, Genetics, Biochemistry. A study dealing with the nature of the immune response with sections on antibody structure, function and production; antigen-antibody reactions; immunogenetics; and immune regulation, protection and injury.

81.595 Immunology Laboratory (1-4)2 A series of basic laboratory exercises dealing with the preparation, isolation and characterization of antigens, antibodies and effector cells. Semester project required.

81.706 Current Literature in Biology (2-0)2 Participants are required to present 2 seminars per semester: a short talk on an assigned journal article or topic, and a lecture-length presentation on an advanced topic or their own original research. A fully documented report must accompany the long seminar. Students are also graded on active participation in discussions and will critique each other's presentations. M.S. students are required to enroll twice for this course.

81.711,712 Graduate Topics in Biology (3-0)3, (3-0)3 Prerequisite: Graduate students only; permission of instructor. Selected topics and recent advances not covered in regular courses. Content varies from year to year so that students may, by repeated enrollment, acquire a broad knowledge of contemporary biology.

81.721, 722, 723 Problems in Biology (0-3)1 to (0-9)3 Prerequisite: permission of instructor. Special research or laboratory projects, or extensive literature surveys, undertaken by the student to expand his/her knowledge in specific fields.

81.733,736 M.S. Project in Biology (0-9)3 or (0-18)6 An independent laboratory project which has been approved by a research advisor as a suitable subject for a Master's Project.

81-743,746,749 M.S. Thesis (0-9)3 to (0-27)9 An in-depth independent investigation of a problem which has been approved by the student's research mentor as a suitable subject for a Master's Thesis.

81.753,756,759 Ph.D. Dissertation (0-9)3 to (0-27)9 Thesis research by Ph.D. students who are in the joint Biochemistry Program Option (between the Chemistry and Biological Sciences Departments) and are conducting research with faculty in Biological Sciences.

DEPARTMENT OF CHEMISTRY

Department Chair

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Faculty

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The Department of Chemistry at the University of Massachusetts Lowell offers both the Master's Degree in Chemistry and the Doctor of Philosophy Degree in Chemistry. The Master's Degree is offered in the following specialties: Analytical, Biochemical, Inorganic, Organic, Physical and Polymer Chemistry. The Doctor of Philosophy Degree is offered in the specialties of Analytical, Inorganic, Organic and Physical Chemistry. In addition, the department offers the Doctor of Philosophy Degree with Options in Biochemistry, Environmental and Polymer/Plastics Engineering. These options allow interdisciplinary study and involve interaction between chemistry and other departments at the University of Massachusetts Lowell. Overall Departmental Entrance Requirements:

1. A Bachelor's Degree in Chemistry or a related discipline (which requires a solid base in Chemistry).
2. An Undergraduate GPA of 3.0 (or its equivalent).
3. A minimum combined score of 1500 on the GRE.
4. A minimum combined GRE Verbal and TOEFL of 1000 (for international students whose native language is not English).
5. Students not meeting these requirements are invited to enroll in the Graduate Certificate Program and retake these entrance exams.

MASTER OF SCIENCE DEGREE PROGRAM

Specializations are offered in biochemistry, analytical, inorganic, organic physical chemistry, and polymer science. This program provides opportunity for advanced study and research training in chemistry, both general and specialized. Provision also is made for the student to elect certain advanced subjects in related fields of mathematics, physics, and engineering.

Credit Requirements

A minimum of 30 credits is required for the Master of Science degree in Chemistry, with 18 credits being earned in courses; and 12 credits earned in graduate research and seminars. Of the 18 course credit minimum, exclusive of research and seminar, a minimum of 15 credits must be taken in chemistry. The

remaining course credits (3 or more) may be taken in chemistry or in related fields such as physics, mathematics, biology or engineering. Credit normally is not allowed for 400 level subjects in chemistry except for those designated in the catalog or approved by a student's advisor. Each graduate program in chemistry must include at least three advanced subjects from three of the following areas: analytical chemistry, biochemistry, inorganic chemistry, organic chemistry, physical chemistry, or polymer chemistry, unless such requirements have been met previously and approved by the department.

Requirements Specialization in Analytical Chemistry

84.514 Advanced Analytical Chemistry

and two courses from the following selection:

- 84.523 Organic Reaction Mechanism
or
84.568 Structural Analysis
84.532 Advanced Physical Chemistry
84.550 Biochemistry I
84.543 Modern Inorganic Chemistry

Specialization in Biochemistry

84.550 Biochemistry
84.551 Biochemistry II

and any two courses from the following selection:

- 84.523 Organic Reaction Mechanisms
84.538 Biochemical Mechanisms
or
84.568 Structural Analysis
84.514 Advanced Analytical Chemistry
84.526 Chromatography

or
84.580 Advanced Analytical Biochemistry
84.532 Advanced Physical Chemistry
84.560 Advanced Physical Biochemistry

Specialization in Organic Chemistry

84.523 Organic Reactions, Mechanisms and Structure

84.524 Organic Synthesis
84.568 Structural Analysis

and at least two courses from the following selection:

- 84.532 Advanced Physical Chemistry
84.521 Physical Organic Chemistry
84.550 Biochemistry I
84.543 Modern Inorganic Chemistry

Specialization in Inorganic Chemistry

84.543 Modern Inorganic Chemistry

84.532 Advanced Physical Chemistry

84.523 Organic Reaction Mechanisms

and one course from the following

- 84.514 Advanced Analytical Chemistry
84.550 Biochemistry I
84.551 Biochemistry II

Specialization in Physical Chemistry

84.531 Statistical Thermodynamics

84.532 Advanced Physical Chemistry

84.513 Spectroscopy

84.523 Organic Reaction Mechanisms

84.543 Modern Inorganic Chemistry

84.540 Chemical Kinetics

Specialization in Polymer Science

Required:

- 97.601/ Polymer Science
602 Seminar
97.603/ Polymer Science
604 Colloquium

plus selections from the following courses:

- 97.503 Advanced Polymer Science I
97.505 Polymer Preparation and Characterization
84.568 Structural Analysis
97.553 Organic Chemistry of Macromolecules
84.532 Advanced Physical Chemistry
84.523 Organic Reaction Mechanisms

Seminar Requirement

Each semester the student is required to attend and participate in the chemistry seminar colloquium program 84.601, 602, 603 and 604. In addition, a master's candidate is required to present one seminar.

Thesis Advisory Committee

An advisory committee should be selected jointly by the student and advisor at the earliest possible opportunity. A minimum of three (3) faculty members are required for the master's thesis committee. The student's advisor will serve as the chairperson of this advisory committee. The purpose of this committee is twofold. First, it will be responsible for ascertaining that the student's research was conducted and presented in final form, in a professional and acceptable

manner. Perhaps of more importance, the committee will serve in an advisory capacity during the course of the research project. In this spirit it is recommended that the student convene a meeting of the selected committee prior to starting his/her research. The purpose of this meeting is to informally present an outline of the proposed research project.

DOCTOR OF PHILOSOPHY DEGREE PROGRAM Analytical, Inorganic, Organic and Physical Chemistry Specializations

The doctoral program in chemistry is designed to provide the students with a background in advanced course work and chemical laboratory techniques that will prepare them to carry out, under the guidance of experienced scientists, an original, independent investigation that will lead to an acceptable contribution to the body of contemporary knowledge.

Plan of Program

The doctoral degree normally requires four years of study beyond the bachelor's degree or a minimum of two to three years beyond the master's degree. The plan of study pursued by each student is dependent on individual requirements and is developed through a conference with the Advisory Committee (or with his or her temporary advisor).

The initial part of the student's program, normally completed at the end of two years of study, is devoted to formal course work. The first year is usually given to subjects in the major branches of chemistry in preparation for area (candidacy) examinations. The second year is devoted primarily to advanced subjects in a special field of concentration.

The second and final part of the program is devoted principally to research leading to the doctoral thesis. However, the student is encouraged to begin research as early as possible in the program of study.

Research Tools Requirements

Students in all Ph.D. programs must acquire facility in two research tools. These research tools may be a second foreign language, a computer language, a statistics course or other skill acceptable to both the Graduate Coordinator and the research advisor of the student. The language(s) selected may not include the native language of a student's country of

origin. Outlined below are the pathways by which these requirements can be satisfied.

I. Completion of a Language Requirement.

Completion of a two-semester undergraduate course sequence in French, German, Japanese or Russian with an average grade of B or better satisfies this requirement. These courses may be taken at the University of Massachusetts Lowell or at another institution. The following courses at the University of Massachusetts Lowell are acceptable: Scientific German I and II (51.113 & 51.114) or Intermediate German I and II (51.211 & 51.212) or Intermediate French I and II (50.211 & 50.212)

II. Completion of Research Tools Requirement

The following courses represent a selection from which a student may choose a research tool:

92.263 Fortran Programming
92.265 Introduction to Pascal
92.383 Introduction to Statistics
92.386 Statistics for Science and Engineering
92.385 Biostatistics
84.529 Chemometrics - if 84.529 is chosen as a research tool, credit for this course can not count toward the 27 course credits needed. Students in Analytical Chemistry may not use this course as a research tool.

Credit Requirements

Of the 45 minimum credit requirements, a minimum of 27 credits in course work, exclusive of thesis and seminar, is required with at least 18 to be taken in chemistry. The remaining course credits (9 or more, with a student's Advisory Committee having the authority to add 6 additional credits to the minimum in special situations) may be taken in chemistry or in a related field such as biology, physics, mathematics or engineering. Credit is not normally allowed for undergraduate subjects in chemistry except for those so designated in the catalog. Research credits and seminars would then make up the remainder of the 45 credit requirements. Planning the program of courses with the student is the responsi-

bility of a student's Advisory Committee.

Course Requirements

Each student in any of the Ph.D. programs in Chemistry shall take both an advanced course in Physical Chemistry and Organic Chemistry and two courses from Advanced Inorganic, Advanced Analytical, Biochemistry, or Polymer Chemistry unless such requirements have been met previously.

Since each division (Analytical, Biochemistry, Organic and Physical/Inorganic) has its own specific course requirements, a student intending to specialize in one of these areas is encouraged to meet with the coordinator of the division.

A. Course Requirements (Ph.D.): Analytical Chemistry Specialization

1. 27 Credits in course work are required

2. Required Courses:

84.514 Advanced Analytical Chemistry
84.523 Organic Reaction Mechanisms or
84.568 Structural Analysis
84.532 Advanced Physical Chemistry
84.543 Modern Inorganic Chemistry
Note: With the exception of 84.514, Advanced Analytical Chemistry, one of the following courses may be substituted for one of the above with the permission of the student's faculty advisor and the analytical coordinator.
84.538 Biochemical Mechanisms
84.550 Biochemistry I
97.511 Biopolymers

Of the remaining 15 credits at least 6 must be in chemistry. The approval of the advisor and analytical coordinator are required for non-chemistry courses. Such courses must be justified as being relevant to the student's course of study.

B. Course Requirements (Ph.D.): Inorganic Chemistry Specialization

Required Courses:
84.532 Advanced Physical Chemistry
84.543 Modern Inorganic Chemistry
84.534 Quantum Chemistry
84.540 Chemical Kinetics
84.523 Organic Reaction Mechanisms and Structures

One course to be selected from:

- 84.514 Advanced Analytical Chemistry
 84.550 Biochemistry I
 84.551 Biochemistry II

The remaining 9 credits may be taken in chemistry, mathematics or engineering.

**C. Course Requirement (Ph.D.):
 Organic Chemistry
 Specialization**

Required Courses:

- 84.515 Chemical Literature
 84.523 Organic Reaction Mechanisms
 84.524 Organic Synthesis
 84.532 Advanced Physical Chemistry
 84.568 Structural Analysis

Two courses selected from the following also are required:

- 84.514 Advanced Analytical Chemistry
 84.534 Quantum Chemistry
 84.538 Biochemical Mechanisms
 84.543 Modern Inorganic Chemistry
 84.550 Biochemistry I

The remaining course requirements may be fulfilled by selecting courses from the following list or from graduate courses offered by other departments.

- 84.516 Advanced Analytical Techniques
 84.521 Physical Organic Chemistry
 84.527 Stereochemistry
 84.563 Chemistry of Natural Products
 84.565 Heterocyclic Chemistry

**D. Course Requirements (Ph.D.):
 Physical Chemistry
 Specialization**

Required courses:

- 84.532 Advanced Physical Chemistry
 84.523 Organic Reaction Mechanisms
 84.543 Modern Inorganic Chemistry
 and a choice from the following:
 84.513 Spectroscopy
 84.514 Advanced Analytical Chemistry
 97.503 Advanced Polymer Science I

Written Area Examinations

Upon admission to the Ph.D. program the student must pass exams in his/her major area of specialization. The method of conducting these area exams is designated by the staff in each field of specialization, as follows:

Analytical Chemistry

The area examinations for analytical chemistry will consist of a series of six (6) examinations. The first will be a qualifying examination to determine if the student is prepared to take the remaining five area examinations. The student will have two opportunities to pass the qualifying examination, which will be administered at the beginning of

the student's second and third semester of residence. The remaining five examinations will be offered annually, commencing in October and administered at monthly intervals. A minimum of 3.0 out of a possible 10.0 points is required for each individual examination and a total of at least 30.0 out of a possible 50.0 points is required for the successful completion of the Written Area Examination. Failure to perform adequately may result in the student being required to complete a master's degree. Continuation towards the Ph.D. degree will be considered on a case by case basis.

Inorganic Chemistry

The area examinations in Inorganic Chemistry will be a series of cumulative examinations. The student is expected to begin the series of exams in the second year of study. The area examinations will consist of a series of five (5) examinations. The examinations are each graded from zero to a maximum of three points. A student must receive a total of eight (8) points to successfully complete the area examinations. Students who do not receive the necessary points may complete a master's degree and with special permission apply for readmission to the Ph.D. program in Inorganic Chemistry.

Organic Chemistry

Organic students take a series of eight cumulative examinations, given once a month (except December), beginning in September of each year. The examinations are graded pass or fail and a student must pass four of the examinations. The examinations must be taken in consecutive months. Typically, a student will start the examinations in the second year of graduate study and must complete these examinations by the end of the third year of graduate study.

Physical Chemistry

By the third year of graduate study, a Ph.D. student in physical chemistry must take a comprehensive examination. This is an all day written examination with questions designed to test the student's physical chemistry background, and ability to set up models and solve them mathematically. The student has two chances to pass the comprehensive examination.

Research Proposal

As part of the area examination(s) a Ph.D. candidate must present an oral defense of an original research proposal

within 6 months of completing the written area examinations although a specific program may require the proposal to be presented at an earlier date. With the aid and advice of the Advisory Committee the student selects a suitable subject for investigation, completes a literature survey, outlines the method of approach, and suggests possible results and conclusions. The oral defense of this proposal is conducted by the student's Advisory Committee with other faculty members in attendance. The proposal is defended by the end of the semester following completion of area exams. The topic of the proposal can not be closely related to or contained within the thesis project.

Chemistry Seminar

During each year of residence the student is required to attend and participate in 84-601,602, Chemistry Seminar, and 84-603,604, Chemistry Colloquium. Each doctoral student is required to present two seminars.

**Candidacy for the Doctorate in
 Chemistry**

To be admitted to candidacy for the doctorate, a student must:

1. Satisfy the 27 course credit requirement, with a minimum Grade Point Average of 3.0.
2. Pass the area examinations, which includes completion of a research proposal.
3. Fulfill the research tools requirements.
4. Inform the graduate coordinator that the above requirements have been completed.

Ph.D. OPTION IN BIOCHEMISTRY

The Departments of Chemistry, Health and Clinical Sciences and Biological Sciences have developed a program in biochemistry which results in the awarding of a Ph.D. in Chemistry.

This program draws upon the special and diverse talents of these faculties, and provides chemistry graduate students with both in-breadth class work and in-depth thesis research. Emphasis is on the application of modern techniques and concepts of physical and chemical science to the solution of problems of current interest in biology and medicine.

Students may choose one of four concentrations in the Biochemistry Option:

- 1) Biochemistry
- 2) Bioprocessing
- 3) Biological Sciences
- 4) Clinical Chemistry

Dissertation research can be conducted in any of the aforementioned departments or in an interdisciplinary setting.

Admission Requirements and Removal of Undergraduate Deficiencies

Admission to the program requires demonstration of an acceptable B.S., B.A., or M.S. degree in chemistry, biology, biochemistry or other related science. Students will be expected to have completed two semesters each of general, organic and physical chemistry as well as introductory biology. Deficiencies must be removed by enrolling in the corresponding undergraduate course during the first year in the program.

Academic Standards for Retention in the Biochemistry Program

The graduate student is expected to maintain an average of 3.0 or better in all his/her graduate-level courses. All other department requirements must also be met.

Research Tools Requirement

These requirements have been previously described.

Degree Requirements

There are 45 credits required for the Ph.D. in Chemistry, Biochemistry Option. A total of 27 of these must be in formal courses while the remaining 18 will be accrued in Doctoral Dissertation. Of the 27 required hours of graduate course work, the Biochemistry Program requires that 15 hours are in the specific courses delineated below:

- 84.550 Biochemistry I
- 84.551 Biochemistry II
- 84.538 Biochemical Mechanisms
- 84.560 Advanced Physical Biochemistry
- 84.580 Advanced Analytical Biochemistry

The remaining courses (a minimum of 12 hours) may be selected from approved graduate courses in the Biology, Chemistry or Clinical Lab Sciences Departments. Course selection should be made in consultation with the advisor. Below is a list of suggested courses.

- 36.506 Biochemistry of Lipids
- 36.550 Human Development and Pathophysiology
- 36.551 Advanced Pathophysiology
- 36.552 Advanced Clinical Biochemistry
- 81.525 Neurobiology

- 81.535 Principles of Cell and Microbe Cultivation
- 81.545 Isolation and Purification of Biotech Products
- 81.567/569 Recombinant DNA Techniques
- 81.576/578 Cell Culture and Hybridoma
- 81.580 Developmental Biology
- 81.593/595 Immunology
- 84.514 Advanced Analytical Chemistry
- 84.526 Chromatography
- 84.543 Modern Inorganic Chemistry
- 84.563 Chemistry of Natural Products

Seminars

During each semester in residence all full-time students must register for a seminar course and attend one seminar each week, as required by the Chemistry Department. The student is required to present two one-hour presentations during his/her residence.

Research

A. Initiation of Research - Preceptor Selection Procedure.

The dissertation research of each graduate student may be initiated at any time but not later than the end of the second semester in the program. The student is advised to make serious efforts, prior to the summer following his/her first entrance to the program, to initiate faculty research interviews and attempt to identify the area of his/her research interest and particular research group which may be suitable for pursuing his/her research goals.

B. Examination Committee.

The examination committee will be composed of four faculty members chosen after consultation by the student with his/her preceptor. Two of these members must be from the Department of Chemistry faculty.

Examinations

A. Comprehensive Examination.

Please contact the biochemistry graduate coordinator concerning details about the comprehensive examination.

B. Oral Research Proposal. Prior to the end of the 4th semester of matriculation, the student will be required to present and defend, orally, a research proposal in an area of biochemistry related to but not identical to that of his/her thesis. A written copy of the proposed research must be distributed to the

Examination Committee at least one week prior to the examination. All members of the university community are welcome to attend these examinations. Failure to perform adequately in either the written proposal or the oral defense may result in the student being required to complete an M.S. degree. Continuation toward a Ph.D. degree will be judged on a case by case basis.

Admission to Candidacy for the Doctorate

To be admitted to candidacy for the doctorate, a student must:

1. Complete all required courses with necessary grade point average. There is an absolute minimum cumulative grade point average (GPA) requirement of 3.0 for all graduate work. At the end of the first semester, if a student is found to be below the minimum GPA, a written warning will be issued. If the cumulative GPA is not raised to 3.0 or higher by the end of the second semester in residence, the student will automatically be dropped from the Ph.D. program but allowed to continue toward a master's degree in Biochemistry with the approval of the graduate committee. While completing the M.S., a candidate must have a minimum GPA of 3.0 and maintain that GPA throughout the remainder of his or her career. Upon successful completion of the Master of Science degree, the student may reapply for admission to the doctoral program. Each case will be reviewed on an individual basis by the Biochemistry Graduate Committee. Students reentering the Ph.D. program will then satisfy all the requirements for the degree including passing the comprehensive examination, presentation of their research proposal, and completion of their research and dissertation defense. Seminar presentations and course work accomplished to complete the master's degree will, of course, be cumulative.
2. Pass the Comprehensive Examination given at the beginning of the fourth semester of full time study.
3. Fulfill the research tools requirement.
4. Successfully present and defend the Oral Research Proposal by the end of the fourth semester of full time study.
5. Present two seminars.
6. Secure approval of his/her research preceptor and the biochemistry committee. When these requirements have been fulfilled, the Biochemistry Graduate Committee will recommend that the

graduate coordinator of the Department of Chemistry notify the Dean of the Graduate School to place the student on the list of candidates for the Ph.D. degree. Admission to candidacy in no way guarantees the granting of the degree.

PH.D. OPTION IN ENVIRONMENTAL STUDIES

This graduate program is designed as an optional course of study to the traditional Ph.D. in Chemistry for students with backgrounds in engineering (civil, environmental and chemical engineering) and other sciences (physics, biology, etc.) as well as chemistry. Candidates will be exposed to advanced course work in chemistry and environmental engineering and will be able to choose an area of specialization that best suits their interests and previous experience. A combination of faculty from Chemistry, Work Environment and Civil Engineering with a variety of research expertise gives this program unique characteristics and affords the student the opportunity to perform practical interdisciplinary research. It is expected that most students will require at least four years beyond the Bachelor's degree and two years past the Master's degree.

Entrance Requirements

In addition to the requirements for admission listed in this catalog, applicant will have an earned bachelor's degree in one of the following fields: chemistry, chemical or civil engineering, biology, environmental sciences, geology or physics. Students will be expected to have satisfactorily completed undergraduate courses in analytical, organic, and physical chemistry, physics and calculus. However, applicants who have not completed courses in these areas of chemistry may remedy their deficiencies while in the program and, therefore, are encouraged to apply. Admissions will be determined by a committee consisting of faculty from the Chemistry, Work Environment, and Civil Engineering Departments.

Program Outline

A total of 48 credits are required for the Ph.D. program. Of these, at least 30 credits must be in course work exclusive of seminar and the rest is usually in thesis research. Courses shown below are divided into three categories: core course requirements (9 credits), areas of special-

ization (12 credits), and elective courses (9 credits). Additional elective courses from other departments may be substituted with the approval of the student's Advisory Committee. In addition, full-time students must register for 84.601/84.602 or 18.502 Environmental/Analytical seminar every semester. Each student will be required to give two seminars on current research topics during their graduate career. Students in the Environmental program must select a thesis advisor by the end of the second semester. At this time, an Advisory Committee is appointed and a plan of study is established. The Advisory Committee must consist of at least four members, including the thesis advisor. A minimum of two chemistry department faculty are required to be on the committee with two other members from any participating Department. An additional member from another department may also be added if agreed upon by the student and thesis advisor. Students must maintain a 3.0 cumulative average in order to continue in the program.

Required Courses (21 credits):

- I. Core Courses (9 credits)
 - 84.514 Advanced Analytical Chemistry
 - 84.532 Advanced Physical Chemistry or
 - 84.575 Physical Chemistry for Environmental Studies
 - 84.523 Organic Reaction Mechanism or
 - 84.568 Structural Analysis
- II. Areas of Specialization (12 credits)
 - a. Analytical /Environment
 - 14.567 Environmental Chemistry I (Aquatic Chemistry)
 - 14.568 Environmental Chemistry II (Fate and Transport)
 - 84.519 Environmental Chemistry III (Marine Chemistry)
 - 84.526 Chromatography
 - b. Water Environment
 - 14.567 Environmental Chemistry I (Aquatic Chemistry)
 - 14.568 Environmental Chemistry II (Fate and Transport)
 - 84.519 Environmental Chemistry III (Marine Chemistry)
 - c. Air Environment
 - 14.562 Groundwater Hydrology
 - 18.571 Air Pollution Phenomenology
 - 18.523 Air Resources Management & Control
 - 18.573 Air Pollution Laboratory

- (Monitoring and analysis)
- 14.568 Environmental Chemistry II (Fate and Transport)
- III. Elective Courses (9 credits)
 - 84.575 Physical Chemistry for Environmental Studies
 - 84.532 Advanced Physical Chemistry
 - 84.523 Organic Reaction Mechanisms
 - 84.568 Structural Analysis
 - 14.567 Environmental Chemistry I (Aquatic Chemistry)
 - 14.568 Environmental Chemistry II (Fate and Transport)
 - 84.519 Environmental Chemistry III (Marine Chemistry)
 - 84.526 Chromatography
 - 84.564 Spectrochemical Analysis
 - 14.562 Groundwater Hydrology
 - 14.561 Physical Chemical Treatment Processes
 - 18.568 Environmental Laboratory
 - 18.571 Air Pollution Phenomenology
 - 18.523 Air Resources Management
 - 18.573 Air Pollution Laboratory (Monitoring and Analysis)
 - 93.415 Advanced Atmospheric Dynamics I
 - 93.416 Advanced Atmospheric Dynamics II
 - 93.430 Atmospheric Diffusion
 - 18.572 Energy and the Environment
 - 92.591 Statistical Modeling and Data Analysis
 - 14.565 Industrial Waste Water Treatment Processes
 - 18.510 Water Resources Management
 - 18.522 Solid Waste Management (Municipal, Industrial and Hazardous)
 - 18.525 Epidemiology for Environmental Studies
 - 18.527 Environmental Law
 - 19.501 Industrial Hygiene
 - 81.xxx Wetlands Ecology
 - 84.515 Chemical Literature
 - 98.501 Radiation Safety and Control
 - 98.503 Radiation Biology
 - 98.508 Environmental Toxicology

Written Area Examinations (Cumulative Examinations)

Beginning in the second year of study, the student must pass examinations in their major area of specialization. The examinations are administered by the faculty associated with the program and are based on course work either completed or in progress as well as seminars, scientific literature and accepted theory in the field of study. Environmental studies students take six cumulative examinations each of

which focuses on a different area of environmental science and analytical chemistry. Students must take the examinations consecutively in a given academic year. The topic, date, time and faculty member in charge of a particular exam in the cumulative examination series will be given to the student prior to the first cumulative exam. Students taking cumulative exams are urged to meet with the individual faculty member preparing an exam for more specific information. If a student misses a cumulative exam a grade of zero will be assigned. There are no make-up cumulative exams.

Research Proposal

A Ph.D. candidate must submit an original research proposal and successfully pass an oral defense of that proposal in their second or third year of study. After consulting with their Advisory Committee, the student selects a suitable subject for investigation, completes a literature survey, outlines the method of approach, and suggests possible results and conclusions. The oral defense of this proposal is conducted by the student's Advisory Committee with other faculty in attendance. The proposal must be defended within three months following completion of the cumulative examinations.

PH.D.OPTION IN POLYMER SCIENCE AND POLYMER SCIENCE/PLASTICS ENGINEERING

Students in the Ph.D. Program in the Department of Chemistry may elect the Polymer Science or the Polymer Science/Plastics Engineering Option. The Polymer Science/Plastics Engineering Option doctoral program is organized jointly with the Department of Plastics Engineering. The program is designed to provide students with a background in advanced course work and laboratory techniques that will prepare them to carry out an original investigation leading to an acceptable contribution to the body of contemporary knowledge in the fields of macromolecules or plastics.

Plan of Program

The doctoral degree normally requires four years of full-time study beyond the bachelor's degree or a minimum of two to three years of full-time study beyond the master's degree. The plan of study pursued by each student is dependent on individual requirements and is developed through conference with his/her Advisory

Committee (or temporary advisor).

All students entering the program must take the American Chemical Society Graduate Level placement examinations in organic, physical and analytical chemistry. An evaluation examination in polymer science is given to those who wish to be exempted from 97-503-504.

Requirements for Admission

Requirements for admission into the program are the same as those for students entering other Ph.D. programs in Chemistry. It is the student's responsibility to satisfy any admission requirements stipulated for the Ph.D. in Chemistry.

Undergraduate deficiencies in the student's background must be remedied promptly, usually by the end of the student's second semester. During this period, the student must also successfully complete graduate courses appropriate to his/her background. Students will not be formally admitted to the Ph.D. program if their grade point average is below B.

Course Requirements

Of the 45 minimum credit requirements a minimum of 27 credits in course work, exclusive of thesis and seminar, is required with at least four courses to be taken in chemistry and polymer science (84 and 97 prefixes). The remaining course credits may be taken in chemistry or in the courses listed below. Credit normally is not allowed for undergraduate subjects in chemistry except for those so designated in the catalog. Research credits (18) would then make up the remainder of the 45 credit requirement. The program of courses is the responsibility of a student's Advisory Committee and must include advanced subjects in the appropriate areas of chemistry, polymers, and plastics. When it is necessary to carry less than the normal credit load of 9 per semester, the student must apply to the chairman of the department through the chairman of his/her Advisory Committee for approval.

Required Courses

The student must take the following core courses: Polymer Science:

84.523	Organic Reaction Mechanisms
84.568	Structural Analysis
84.532	Advanced Physical Chemistry
97.503	Advanced Polymer Science
97.504	Advanced Polymer

97.553	Science II
97.505	Organic Chemistry of Macromolecules
97.506	Polymer Preparation & Characterization I
97.512	Polymer Preparations & Characterization II
26.503	Bulk Properties of Polymers or Mechanical Behavior of Polymers
26.506	Polymer Structure
26.509	Plastics Processing I
26.510	Plastics Processing II
Polymer Science/Plastics Engineering Option:	
84.523	Organic Reaction Mechanisms
or	
84.568	Structural Analysis
84.532	Advanced Physical Chemistry
97.503	Advanced Polymer Science I
97.504	Advanced Polymer Science II
97.553	Organic Chemistry of Macromolecules
97.505	Polymer Preparation & Characterization I
97.506	Polymer Preparations & Characterization II
97.512	Bulk Properties of Polymers
or	
26.503	Mechanical Behavior of Polymers
26.506	Polymer Structure
26.509	Plastics Processing Theory I
26.510	Plastics Processing Theory II
The following course schedule is suggested to prepare the students for the cumulative examinations: First Semester	
97.503	Advanced Polymer Science I
or	
26.503	Mechanical Behavior of Polymers
26.509	Plastics Processing Second Semester
97.503	Advanced Polymer Science II
97.553	Organic Chemistry of Macromolecules
97.510	Plastics Processing II
97.505	Third Semester Polymer Preparation & Characterization

In addition, the student must register for Polymer Seminar 97.601/602 and 97.603/604 Polymer Science Colloquium each semester.

Advisory Committee

Upon admission the student will be assigned a temporary adviser by the Coordinators of the Graduate Polymer Program and Graduate Plastics Program. The student's major thesis adviser will become the chairperson of the permanent Advisory Committee.

For students who elect the plastics concentration, the permanent Advisory Committee will be composed of four members, two from the Department of Chemistry and two from the Department of Plastics Engineering. One of the committee members from the Chemistry Department will have the responsibility of advising the student in course work and research activities in the field of polymers.

The Advisory Committee will meet at least once each semester to monitor the progress of the student's research.

Program Outline

The initial part of the program is devoted to formal course work. The first year usually is devoted to subjects in major branches of chemistry, polymers, and plastics in preparation for the student's area (cumulative) examinations. The student must choose a research adviser before the end of the second semester and is normally expected to start research during the first summer.

Research Tools

Pathways for satisfying these requirements have been described previously under the Chemistry section of this catalog.

Written Area Examinations

Upon formal admission to the Ph.D. program the student is required to pass a series of consecutive cumulative area examinations. This requirement must be completed by the end of the third semester for students entering in the fall semester, and by the end of the fourth semester for students entering in the spring semester. Policy and grading underlying each examination will be announced at the beginning of each academic year.

Each student must also present an oral defense of an original research proposal within six months after the completion of

the last area exams.

Successful performance of an original research project, completion of a written dissertation and subsequent successful public presentation and defense of the dissertation research will culminate in granting of the Ph.D. degree in Chemistry.

Candidacy for Ph.D. Polymer Science/Plastics Engineering Option

To be admitted for candidacy for the doctorate, a student must:

1. Satisfy the 27 course credit requirement with a minimum grade point average of 3.0.
2. Pass the area examinations which includes completion of the research proposal.
3. Fulfill the language requirements.
4. Secure the approval of his/her Advisory Committee and the Graduate Coordinator of the Department of Chemistry.

When these requirements have been fulfilled, the Graduate Coordinator of the Department of Chemistry notifies the Dean of the Graduate School in writing and recommends that the student be placed on the list of candidates for the Ph.D. degree. Admission to candidacy in no way guarantees the granting of the degree.

COURSE DESCRIPTIONS

84.513 Spectroscopy (3-0)3 Prerequisite: 84.431-432 or equivalent. A presentation of molecular spectra and molecular structure is given to illustrate the empirical results and the theoretical background necessary to interpret the results.

84.514 Advanced Analytical Chemistry (3-0)3 Prerequisite: 84-313 and 314 or the equivalent or the permission of Analytical Chemistry Faculty. This course is required of all students in the Analytical Chemistry and Ph.D. Environmental Studies Program. Principles of modern molecular Spectroscopy, and electroanalytical chemistry are covered. The course is designed to prepare a student for advanced courses in the area of Analytical Chemistry.

84.515 Chemical Literature (3-0)1 Use of the chemical library, journals, reference works and other technical publications pertaining to chemical subjects. Exercises in finding, assembling and using such data. The student will be expected to assimilate the use of automated information retrieval and conduct computer assisted literature searches.

84.516 Advanced Analytical Techniques

(1-6)3 Prerequisite: Permission of Instructor. A study of the theory and application of the more advanced techniques and equipment in the preparation and purification of organic compounds, including high efficiency fractionation, vacuum and molecular distillation, hydrogenation and reactions in inert atmosphere.

84.519 Environmental Chemistry (3-0)3 Prerequisite: Permission of Instructor. The chemistry of the oceans, atmosphere and biosphere source and removal mechanisms of natural and anthropogenic substances, thermodynamic and kinetic models in addition to instrumental analytical methods.

84.521 Physical Organic Chemistry (3-0)3 Prerequisite: 84.523, 524 or equivalent. Modern and classical methodology in the study of organic reactions. Linear free energy relationships, tracer methods, orbital symmetry and other selected topics will be covered.

84.523 Organic Reaction Mechanisms and Structures (3-0)3 Prerequisite: Permission of Instructor. Designed to provide insight into how reactions occur and how the reactions mechanism is studied. Emphasis is placed on bonding, substitution and elimination processes, stereochemistry, and conformational analysis.

84.524 Organic Synthesis (3-0)3 Prerequisite: Permission of Instructor. Mechanism, scope and limitations of important selected types of reactions, and designs of synthetic sequences. Emphasis is placed on reduction, oxidation, halogenation, alkylation, and acylation reactions.

84.526 Theory and Applications of Chromatography (3-0)3 Prerequisite: Permission of Instructor. Coverage directed to the performance of the packed and capillary column for gas chromatography and HPLC. Modern injection, detector and pumping systems used in chromatography are also discussed.

84.527 Stereochemistry (3-0)3 The fundamental concepts of optical and geometrical isomerism and the relationship of the stereostructures to the physical and chemical properties of organic compounds.

84.529 Chemometrics (3-0)3 This course is a presentation of mathematical techniques useful for evaluating chemical data. Topics addressed include: parametric statistics, ANOVA, regression analysis, optimization and pattern recognition.

84.531 Statistical Thermodynamics (3-0)3 Prerequisite: 84.432 or equivalent. Fundamentals of equilibrium statistical mechanics, classical and quantum statistics. Molecular theories of gases, crystals and liquids, with emphasis on chemical aspects. Electrolyte and non-electrolyte solutions, polymer and polyelectrolyte systems, chemical equilibria and reaction rate processes.

84.532 Advanced Physical Chemistry (3-0)3 Prerequisite: Permission of Instructor. Extension of introductory physical chemistry.

Emphasis is placed on quantum chemistry of atoms and molecules as well as on classical and statistical thermodynamics.

84.534 Quantum Chemistry (3-0)3

Prerequisite: 84.431 or equivalent. Principles and methods of quantum mechanics with special attention to chemical applications, such as electronic nature of atoms and molecules, vibrations and rotation of molecules, and interaction of radiation with matter.

84.535, 536 Advanced Topics in Physical Chemistry (3-0)(3-0) 6 Selected topics and recent advances in physical chemistry.

Selection of topics is at the discretion of the instructor.

84.538 Biochemistry Mechanisms (3-0)3

Prerequisites: 84-551 or Permission of Instructor. Discussion of various biochemical reactions from the point of view of organic reaction mechanisms. Kinetics, coenzymes and methods of study of enzyme catalysis and mechanisms will be emphasized.

84.540 Chemical Kinetics (3-0)3

Prerequisite: 84.432 or equivalent. The theoretical and empirical treatment of chemical kinetic data as well as the methods of obtaining these data. Determination of the order of reactions, factors influencing rates, application of rate studies in establishing hypotheses for reaction mechanism, collision theory, and absolute rate theory.

84.543 Modern Inorganic Chemistry (3-0)3

Prerequisite: Permission of Instructor. Emphasis is placed on the theory of the chemical bond, bonding in complexes, coordination theory, spectroscopic methods, non-aqueous solvent systems.

84.544 Chemical Applications of Group Theory (3-0)3

Prerequisite: 84.334, 84.543 or equivalent. Properties of groups as applied to chemical systems. Development of the ligand field theory and prediction of electronic and vibrational-rotational spectra.

84.550 Biochemistry I (3-0)3

Prerequisite: Permission of Instructor. An advanced study of the structure and properties of proteins, nucleic acids, carbohydrates and lipids, including kinetics and mechanisms of enzyme action, and detailed description of metabolic pathways of carbohydrates.

84.551 Biochemistry II (3-0)3

Prerequisite: 84.550 or Permission of Instructor. A continuation of 84.550 with emphasis on metabolic pathways of lipids, amino acids and nucleic acid, biosynthesis of proteins and selected topics in molecular biology and specialty areas of biochemistry.

84.560 Advanced Physical Biochemistry

(3-0)3 Prerequisites: Biochem. I 84.550, and P. Chem. 84.334 or equivalent. Physical chemistry encompasses a group of principles and methods helpful in solving many different types of problems. This course will present selected principles of thermodynamics, kinetics, statistical thermodynamics and quantum mechanics as they are applied to biochemical systems. Various experimental techniques

will be discussed in view of their importance in biochemical research.

84.563 Chemistry of Natural Products

(3-0)3 Prerequisite: 84.568, or equivalent. An advanced subject covering the proof of structure of various types of natural products, approaches to the total synthesis of some and also the biosynthetic pathways.

84.565 Heterocyclic Chemistry (3-0)3

Prerequisite: Permission of Instructor. Classification, nomenclature, structure, synthesis and utility of the more important classes of heterocyclic compounds.

84.568 Structural Analysis (3-0)3

Prerequisite: Permission of Instructor. Practical application of instrumental data in the determination of the structure of organic compounds. Includes mass spectroscopy, ultraviolet spectroscopy, infrared spectroscopy and nuclear magnetic resonance spectroscopy.

84.575 Physical Chemistry for Environmental Studies

(3-0)3 Prerequisite: 84.339 or 84.344, 345. This course covers advanced physical chemistry related to environmental systems and measurements. Topics include the fundamental aspects of solution thermodynamics, electrolytes and non-electrolytes, electrochemical theory, surface chemistry, gas laws, kinetics and spectroscopy.

84.580 Advanced Analytical Biochemistry

(3-0)3 Prerequisites: 84.550 or Permission of Instructor. Analytical Biochemistry involves the separation, detection, and analysis of biological molecules. This course addresses advanced theory and applications of contemporary biochemical techniques and instrumentation. Topics covered include chromatographic and electrophoretic separation techniques, detection of biomolecules by spectroscopy and radiochemical methods, biological preparations, and structural analysis of biomolecules.

84.585 Nuclear and Radiochemistry (3-0)3

Prerequisite: Permission of Instructor. This course stresses the fundamentals of radioactivity, atomic nuclei, nuclear reactions, reactors and detection and measurement of radiation. Applications of material and anthropogenic radioactive tracers to oceanic and atmospheric studies are also presented.

84.586 Spectrochemical Analysis

Prerequisite: Permission of Instructor. A study of the instrumentation, theory and practice of atomic absorption, emission, and fluorescence in flames, plasmas, and electrothermal atomizers. Application of these techniques for trace metal analysis in complex samples.

84.587 Laser Based Analytical Methods

Prerequisite: Permission of Instructor. A brief overview and introduction to the laser will be followed by the application of the laser in analytical chemistry. Topics covered will be atomic and molecular spectroscopy. A discussion of instrumentation, brief theory and selected results will be presented.

84.601,602 Chemistry Seminar (1-0)(1-0)2 Required of all graduate students. Presentation

of current topics by graduate students.

84.603,604 Chemistry Colloquium

(1-0)1 Required of all graduate students. Presentation of current topics by visiting scientists and staff.

84.651 Selected Topics in Chemistry(3-0)3

Prerequisite: Permission of Instructor. Advanced topics in various fields of chemistry. Content may vary from year to year so that students may, by repeated enrollment, acquire a broad knowledge of contemporary chemistry.

84.751 Advanced Projects in Chemistry

(0-3)(0-3)2 Special projects laboratory undertaken by a student to expand his or her knowledge in specific fields not necessarily related to his or her thesis. Content of project and hours assigned must be approved by the Department Chairperson.

84.743 Master's Research 3 credits

84.746 Master's Research 6 credits

84.749 Master's Research 9 credits

84.753 Doctoral Research 3 credits

84.756 Doctoral Research 6 credits

84.759 Doctoral Research 9 credits

97.503 Advanced Polymer Science I (3-0)3

Prerequisite: Permission of Instructor. A study of the principles of condensation, free radical, ionic, coordination and ring-opening polymerization. The topics include the effect of polymerization techniques on reaction kinetics and molecular weight, and the evaluation of reactivity ratios in copolymerization reactions.

97.504 Advanced Polymer Science II

(3-0)3 Prerequisite: Permission of Instructor. Introduction to chain statistics and thermodynamics of macromolecular solutions, methods of study of molecular weight and chain conformation, and the properties of polymers in bulk including viscoelasticity and crystallinity.

97.505 Polymer Preparation and Characterization

(0-4)2 Prerequisite: Permission of Instructor. A laboratory course designed to acquaint the graduate student with the techniques used in the synthesis and characterization of macromolecules with the instrumental study of macromolecules by utilization of osmometry, light scattering, gel permeation chromatography, vapor pressure osmometry and infrared spectroscopy.

97.511 Biopolymers (3-0)3

Prerequisite: Permission of Instructor. Exploration of the synthesis, modification and properties of biologically derived macromolecules. Specifically, natural occurring polysaccharides, proteins, polyesters and nucleic acids will be discussed. An interdisciplinary approach between chemistry, polymer science and biology will be used in presenting the course material.

97.512 Properties of Bulk Polymers

(3-0)3 Prerequisite: Permission of Instructor. Structure and properties of bulk polymers in the glassy, rubbery, and crystalline states. Topics covered include chain statistics, rubber elasticity, crystalline polymers, glass tran-

sition, segmental motion and viscoelasticity.

97.549 Physical Chemistry of

Macromolecules I (3-0)3 Prerequisite: 97.503 or equivalent. Physical chemistry of polymers, including structure and conformation, chain statistics, molecular weight distributions and averages, polymerization kinetics and classical and statistical thermodynamics of polymer solutions.

97.553 Organic Chemistry of

Macromolecules (3-0)3 Prerequisite: 97.503, 504. An advanced study in polymer science concerned with the synthesis of macromolecules and their mechanisms of formation.

97.601.602 Polymer Science Seminar

(1-0)1 Required of all Polymer Science graduate students. Presentation of current topics in polymer science by graduate students.

97.603.604 Polymer Science Colloquium

(1-0)1 Required of all Polymer Science graduate students. Presentation of current topics in polymer science by visiting scientists and staff.

97.651 Selected Topics in Polymer Science

(3-0)3 Prerequisite: Permission of Instructor. Advanced topics in various aspects of polymer science. Content may vary from year to year so that students may, by repeated enrollment, acquire a broad knowledge in the field of macromolecules.

97.751 Advanced Projects in Polymer

Science (0-3)1 Special projects undertaken by a student to expand knowledge in a specific field not necessarily related to the thesis. Content of project and hours assigned must be approved by the Department Chairman.

97.753 Ph.D. Research in Polymer Science

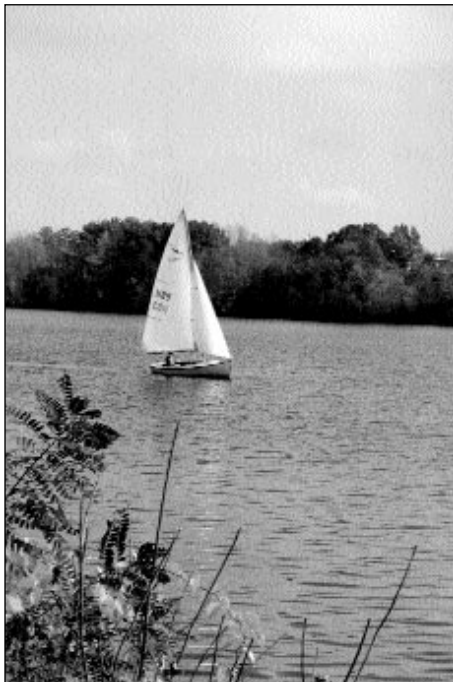
3 credits

97.756 Ph.D. Research in Polymer Science

6 credits

97.759 Ph.D. Research in Polymer Science

9 credits



**DEPARTMENT OF
Computer Science**

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