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# School of Science

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**Associate Dean:** Samuel C. Wait Jr.

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**School of Science Home Page:** <http://www.science.rpi.edu>

The realm of science is a constantly growing and expanding field. Today, more and faster than ever before, new and exciting discoveries are augmenting human knowledge of this world and the vast reaches beyond it. As always, Rensselaer faculty and graduates are leading the way in making many of these important discoveries.

Science and mathematics have been at the heart of Rensselaer since its founding, and most important to maintaining this tradition has been the Institute's commitment to anticipating and generating advancements in all aspects of these fields. In the 1960s, for instance, the School of Science incorporated the then new field of computer science, eventually developing it into a distinct department.

Today, Rensselaer prepares students for a wide variety of careers in the firmly established areas of mathematics and the natural sciences while forging ahead to develop excellent new programs in the emerging field of information science. New curricula in bioinformatics and molecular biology and information technology are meeting the high demand for scientists in these areas. A new biotechnology and interdisciplinary research building will accommodate additional research in these new fields, as will Rensselaer's dedication to attracting leaders in this field to its faculty.

Indeed, the School of Science faculty consists of some of the world's most highly educated and accomplished scientists. Included among them are a Nobel laureate and three National Academy members. In addition, many are fellows in their professional societies, and all have achieved the highest attainable degree in their fields.

At Rensselaer, this esteemed faculty works closely with undergraduates through both instructional and research programs. Rensselaer has a long-standing commitment to undergraduate teaching, and Institute professors have authored some of the most widely used science and mathematics textbooks.

At the graduate level, Rensselaer's School of Science offers opportunities to conduct research in a wide range of areas. These include applied mathematics; astrophysics; biophysics; the chemistry and physics of electronic, optical, and structural materials; bioorganic and biophysical chemistry; environmental science; earth science; mathematical modeling; parallel computation; networking; pervasive computing, computer imaging, and vision; scientific computation; and data science.

Enhancing these research opportunities are the many Rensselaer facilities that expose students to highly advanced equipment and technology. Among the Institute's state-of-the-art computational and laboratory equipment are parallel computers for high speed computation, experimental computer network facilities, an electron microprobe for surface analysis, and molecular beam epitaxy for growing innovative electronic and optical materials, and automated X-ray facilities for studying the structure of crystals. Also impressive are Rensselaer's terahertz imaging capabilities and computer vision and robotics laboratories.

The research activities of many School of Science faculty members are conducted within the Institute's major interdisciplinary research centers, including the Center for Integrated Electronics (CIE), the Nanotechnology Center, the Scientific Computation Research Center (SCOREC), the Terahertz Research Center, and the Center for Pervasive Computing and Networking.

Also providing unique opportunities to its students are a number of School of Science administered research centers. These are the Margaret A. and David M. Darrin '40 Fresh Water Institute, the New York State Center for Polymer Synthesis, the New York State Center for Studies on the Origins of Life, the Rensselaer-Wadsworth Center for Bioinformatics, the Center for Biophysics, and the Center for Inverse Problems. These centers engage graduate and undergraduate students alike in leading-edge research activities.

These centers complement the programs offered through the six departments within the School of Science. These departments are Biology, Chemistry and Chemical Biology, Computer Science, Earth and Environmental Sciences, Mathematical Sciences, and Physics, Applied Physics, and Astronomy. Additionally, the school administers the interdisciplinary Information Technology Program and offers a full complement of interdisciplinary degree programs that are described in detail under the School of Science Interdisciplinary Programs and Research and the Information Technology sections of this catalog.

## Degrees Offered and Associated Departments

<b>Astronomy</b>	Physics, Applied Physics, and Astronomy
<b>Applied Science</b>	Administered by Dean of Science
<b>Biology</b>	Biology
<b>Biochemistry/Biophysics</b>	Biology/Chemistry and Chemical Biology
<b>Bioinformatics and Molecular Biology</b>	Biology/Chemistry and Chemical Biology/ Computer Science and Mathematical Sciences
<b>Chemistry</b>	Chemistry and Chemical Biology
<b>Computer Science</b>	Computer Science
<b>Environmental Science</b>	Earth and Environmental Sciences
<b>Geology</b>	Earth and Environmental Sciences
<b>Hydrogeology</b>	Earth and Environmental Sciences
<b>Mathematics</b>	Mathematical Sciences
<b>Applied Mathematics</b>	Mathematical Sciences
<b>Multidisciplinary Science</b>	Administered by Dean of Science
<b>Natural Sciences</b>	Center for Innovation in Pre-College Education
<b>Physics</b>	Physics, Applied Physics, and Astronomy
<b>Applied Physics</b>	Physics, Applied Physics, and Astronomy
<b>Interdisciplinary Science</b>	Administered by Dean of Science

## Overview of Undergraduate Programs

The School of Science prepares students for a broad range of careers in natural science, computer science, and mathematics, as well as in such diverse areas as management, technological communication, and industry or government agencies, or for graduate studies that may include medical, dental, or law school. The school's educational goals for all of these students, however, are to give them:

- A broad background in their particular field
- Working knowledge of modern research and technological tools

- An appreciation of good theoretical, experimental, and computational research

- Preparation for a lifetime of learning and discovery as both individuals and part of a team.

Students may attain these goals through a variety of majors offered within the six School of Science departments or through interdisciplinary degree programs offered in biochemistry/biophysics, bioinformatics and molecular biology, and environmental science. A major in interdisciplinary science is also available to students wishing more breadth in their program. Additionally, the Information Technology (IT) degree program offers another unique option. The IT core program is coupled with eight courses in another application area that may be chosen from any of the mathematics or science disciplines, as well as other campus programs. For more details on this program see the Information Technology section of this catalog.

All programs offer a large number of electives so that students can emphasize their areas of interest, select one or more minors, or study a wide range of topics in addition to obtaining a strong background in their major field of study.

Selection of a major within the School of Science may take place at any time during the first year of study or during the admissions process. Students who are undecided may defer their choice of major until the sophomore year. With the exception of programs requiring joint admission outside the School of Science, the choice of any approved curriculum within the school is guaranteed. Entering students who have not yet selected a major may choose the department from which their initial adviser is selected.

Advanced placement credit or credit for courses taken in the International Baccalaureate program is possible in those areas where examinations are given. Transfer students are welcome; formalized agreements exist with several community colleges so that students who have followed specified curricula in the community college will have all the standard freshman and sophomore requirements of the science departments at Rensselaer. Students transferring from other colleges will receive credit depending on the courses taken.

### **Core Program in Science**

All Institute undergraduate students are required to complete a core program in science. As part of this program, students must take a minimum of 24 credit hours in physical, life, and engineering sciences, including at least eight credit hours of mathematics. No more than one course of the science core may be taken as Pass/No Credit.

Any of the courses with the following course codes meet the physical, life, and engineering sciences requirement: ASTR, BCBP, BIOL, CHEM, CISH, CSCI, EARTH, MATH, MATP, PHYS. In addition, the following courses also meet these requirements:

IENV-4500 (cross-listed as EARTH-4500)

IENV-4700

ISCI-4500

ENGR-1100 (as Science not Mathematics)

ENGR-1600

ENGR-2090

ENGR-2250

ENGR-2830

ESCE-2100

Other courses may fulfill this requirement and will be reviewed by the associate dean of science on a case-by-case basis. A number of upper-level courses in several engineering disciplines would satisfy the requirement, but generally they have enough prerequisites that the science requirement would already have been satisfied.

### **Transferring Credit Towards the Science Core**

Students entering Rensselaer as first-year students may transfer up to two science courses (up to eight credit hours) toward satisfying their science core requirement.

Students who have advanced placement or who have the International Baccalaureate may be granted credit for all such mathematics and science courses depending on their scores.

Transfer students from an accredited collegiate program who have completed at least one college year but who come to Rensselaer with first year status may qualify for additional core transfers at the discretion of the science core curriculum adviser (currently the associate dean of the School of Science). Transfer students entering Rensselaer at the junior level or above are not limited in the number of courses they may transfer for science core credit.

Students enrolled at Rensselaer who wish to take a science course for core credit or other science credit at another accredited institution must obtain prior approval for the course from the science core curriculum adviser. To apply for approval, a student must furnish a catalog description of the proposed course and a completed copy of Rensselaer's transfer credit approval form to the Science core curriculum adviser. A maximum of eight credit hours of transfers is allowed towards the 24-credit-hour science core.

### **Baccalaureate Programs**

Students entering as freshmen may pursue Bachelor of Science degrees in applied physics, bioinformatics and molecular biology, biology, biophysics/biochemistry, chemistry, computer science, environmental science, geology, hydrogeology, interdisciplinary science, mathematics, and physics. A bachelor's program that combines Information Technology with a concentration in mathematics or science is also available.

Additional options are available in astronomy, biochemistry, biophysics, computing in chemistry, engineering chemistry, geophysics, operations research, polymer science, mathematics of computation, and many others. In these options, students choose courses from a list to make a coherent program of several courses in the same area.

A B.S. in any of these curricula requires between 124 and 128 credit hours.

A minimum of 46 credit hours in science is required for a B.S. degree. Eight of these credit hours must be in mathematics (course codes MATH and MATP), including Calculus I. Each curriculum must include courses in at least four science disciplines, including BIOL-1010, Introduction to Biology. Each curriculum must also contain a culminating experience carrying three or four credits and being taken in the senior year. For this purpose, the course codes MATH (mathematics) and MATP (mathematical programming, probability, and mathematical statistics) are a single discipline.

Each curriculum also offers an option that allows a student to receive up to four hours of course credit for an out-of-classroom experience. Students may exercise this option more than once. This out-of-classroom experience should have intellectual content relevant to the student's educational or career goals. Appropriate experience might include an individual or group research project (on or off campus), an independent study project, a cooperative education assignment, a public service internship, or study abroad. A written proposal and a final written report must be submitted for evaluation to the faculty member designated by each curriculum. This course option may be included in the courses required for the major.

Additional opportunities for undergraduate science students are dual majors and minors. Flexible curricula make dual majors possible between all science majors. In addition, School of Science students may also arrange a dual major in science and humanities or social science or science and management. While the more structured architecture and engineering curricula make dual majors in these areas more difficult, students with advanced placement or advanced standing may be able to satisfy the requirements for dual degrees in these areas.

Students also frequently take minors in one of the science programs or in other Institute programs ranging from philosophy to management to engineering. Minor programs are available in each of the sciences and mathematics, as well as in environmental science and biochemistry/biophysics. Consult the individual department or program descriptions for details of minor programs.

## **Special Undergraduate Opportunities**

### **Accelerated Programs**

The School of Science offers an accelerated physician-scientist program in cooperation with Albany Medical College. Students in this program are recruited directly from high school. An accelerated B.S./Ph.D. program leading to both degrees in six to seven years is also possible in all departments within the School of Science. Students apply to this program after their first year of study at Rensselaer.

### **Undergraduate Research Experience**

At Rensselaer, involving undergraduates in real-world research is of paramount importance. Through the Undergraduate Research Program (URP), described in the Educational Programs and Resources section of this catalog, undergraduates work directly with faculty and/or graduate students on projects requiring critical inquiries. These studies involve exciting areas of leading-edge technological research and have the potential to result in groundbreaking discoveries. Involvement in URPs can be arranged strictly for the experience, for credit, or for pay. Students apply through direct contact with faculty seeking students via Web site or campus advertisements.

### **Cooperative Education**

Students may augment their academic course work with on-the-job experience through the Cooperative Education program. Studies and work assignments are scheduled after consultation with the curriculum adviser. Although many co-op students complete their academic program in four years, some delay graduation for a year to obtain additional work experience. Additional information on Rensselaer's cooperative education programs can be found in the Student Life section of this catalog under the Career Development Center heading.

### **Study Abroad/Exchange Programs**

Although the School of Science does not specifically administer any such programs, the Institute offers a number of study abroad/exchange programs that are open to the student body as a whole. For more information on these Institute-wide programs, see the Educational Programs and Resources section of this catalog.

## Overview of Graduate Programs

Rensselaer's greatest strength—the interface between science and engineering—is a unique feature that particularly benefits graduate students by providing a wide and unique variety of research areas. Graduate students are also key to the Institute's ability to remain in the forefront of research and education in the sciences and to apply its research findings to needs of society.

Considerable personal attention is focused upon graduate students as they enter and develop their programs of study. A graduate adviser guides each student by assisting in the establishment of a suitable program to meet particular needs of that individual. Courses may be pursued for special purposes, as well as be applied to programs leading to a Master of Science or a Doctor of Philosophy degree.

Recognizing that the divisions between basic science disciplines and specializations within particular sciences are not as distinct as they once were, the School has developed many interdisciplinary programs. These programs allow for greater flexibility and situations in which research in one area may serve advanced degree requirements in another. This is especially evident in such areas as applied mathematics with an emphasis on modeling and analysis. Other examples include bioinformatics that spans biology, chemistry, computer science, and mathematics; materials science stressing electronic, optical, polymeric, and structural materials in the New York Center for Polymer Synthesis; environmental research in the Margaret A. and David M. Darrin '40 Fresh Water Institute; the New York Center for Studies on the Origins of Life; the focus on advanced computation in the areas of software, databases, and parallel computation; and the Center for Biophysics foci on natural processes as well as bio-organic chemistry, pharmaceuticals, and biotechnology.

Many science students and faculty also participate in Institute-wide research activities including composite materials, integrated electronics, design, manufacturing productivity, robotics, etc. Still others participate in co-op programs with industry. For more details on graduate cooperative education opportunities, contact the Career Development Center.

Numerous School of Science graduate students hold teaching assistantships, research assistantships, and fellowships while pursuing their degrees. Upon leaving Rensselaer with an advanced degree in mathematics or science, these individuals easily find positions with corporations and government facilities or obtain postdoctoral and faculty positions at the most prestigious universities.

### Master's Programs

The School of Science offers Master of Science (M.S.) degrees in all of its individual departments. In addition, it offers master's programs in applied science and in multidisciplinary science. For more information and specific details on these degree programs, see the Interdisciplinary Programs and Research section within the School of Science section of this catalog.

### Doctoral Programs

Each School of Science department offers programs of doctoral study, and the Ph.D. is awarded in biology, chemistry, computer science, geology, mathematics, and physics. Additional doctoral degree options are also available in a variety of special programs including astrophysics, surface science, mathematical programming, operations research, polymer science, and multidisciplinary science. These programs, particularly the program in multidisciplinary science, are a testament to Rensselaer's commitment to encouraging study programs that cross disciplines within departments and even Institute schools. Detailed information on such programs follow within the School of Science Interdisciplinary Programs and Research section of this catalog.

# Biology

**Chair:** Robert E. Palazzo

**Associate Chair:** Robert Parsons

**Accelerated Program Head:** M.H. Hanna

**Graduate Admissions Coordinator:** Joelle Willis

**Department Home Page:** <http://www.rpi.edu/dept/bio/info/bio.html>

For two decades, the science of biology has been undergoing revolutionary change. Many problems once handled only descriptively are now analyzed molecularly, and biological systems are now characterized in molecular terms. With this trend expected to continue into future advances in biology, Rensselaer is adapting and introducing undergraduate and graduate biology programs to meet this challenge.

All areas of biology require knowledge of chemistry and physics as well. The undergraduate biology curriculum, therefore, thoroughly trains students in the fundamentals of the life sciences and the chemistry and physics of the life processes, providing the background necessary for professional training in research or medicine. Options are available to prepare students for careers in applied biology and in industry. Programs of study in biology may also be combined with specific options in biochemistry, biomedical engineering, bioinformatics, biophysics, biotechnology (genetic engineering), chemical engineering, computer science, management, mathematics, microbiology, and technical communications.

## Research and Innovation Initiatives

### Biochemistry and Biophysics

The study of fundamental problems in modern biochemistry and molecular biochemistry employ a variety of advanced techniques. Current work at the gene and protein levels is being applied in cell biology and physiology. Understandably, a wide range of government agencies and foundations, including the National Institutes of Health, the National Science Foundation, and the American Diabetes Association, is supporting such exciting work.

Research in this area includes developing computer models of how the lens accommodates the human eye. Studies on the lens protein alpha crystalline include biochemical and biophysical characterization. Novel molecular genetics approaches are used to compare properties of alpha crystalline to members of the small heat shock protein family. Another laboratory is researching the involvement of molecular chaperones (heatshock proteins) in the assembly of a large oligomeric enzyme.

In the area of enzymology, projects include work on the nitric oxide synthase isoforms, which are important to signal transduction (e.g., in the central nervous system and for blood pressure control) and as producers of cytotoxic NO in immune responses. Using molecular genetics and biochemical methods, nitrogen fixation and nitrogen cycle enzymes in cyanobacteria are also under investigation. Additionally, molecular modeling techniques are being used in the design of mutants of eukaryotic P450 enzymes.

Much of this research is conducted through collaboration with colleagues in other departments who are members of the Interdisciplinary Program in Biochemistry/Biophysics or the Center for Biophysics and with scientists from other universities.

### Bioinformatics and Molecular Biology

Research in bioinformatics and molecular biology includes both computational work and applications using molecular genetic approaches. In the computational sphere, design and application of database

search and sequence alignment algorithms, molecular modeling, and simulation are used in studies ranging from structural characterization of biomedically relevant proteins to investigations of evolutionary adaptation in marine environment. Problems of protein folding are studied using modeling and data mining from genomic and structural databases. Molecular genetic approaches are used to test the prediction of modeling studies, to design and produce probes, and to obtain sequence information for novel genes. Three laboratories are involved in engineering novel proteins or activities of existing proteins, using molecular gene manipulations.

### **Microbiology and Ecology**

In this program, faculty and their students are conducting ecological, molecular, and genetic studies. Both basic and applied research projects are available, sometimes within the same laboratory. Significant collaboration occurs between these researchers and faculty in other areas of biology, in other Rensselaer departments, and at other institutions around the world. Ecological studies include freshwater ecology, biotransformation of organic compounds, and geomicrobiology. Molecular studies include work on nitrogen fixing symbiotic bacteria and bacteria living in the environment using recombinant DNA technology, and overlap in some cases with genetic studies of prokaryotes and eukaryotes. A variety of graduate courses in microbiology, molecular biology, virology, and immunology are offered. In addition, the Darrin Fresh Water Institute at Lake George is well equipped for studies in microbial ecology.

### **Cell and Molecular Biology**

Research in cell and molecular biology is a high priority in the Biology Department. Four research areas are prominently featured. The first focuses on the biochemical control of cytoskeletal organization, microtubule dynamics, cell polarity, and cell differentiation. The second is centered on the role of extracellular matrix proteins and their control of normal and cancerous cell growth and migration, as well as wound healing. The third is concerned with signal transduction mechanisms controlling cell-cell interactions during tumor cell migration. The fourth focuses on stem cell growth and regulation in the context of tissue engineering. An undergraduate laboratory course that teaches basic research techniques in these areas is available, and students are encouraged to work in research labs upon completion of this course. The department faculty maintains close collaborations with faculty in other departments such as Chemistry, Biomedical Engineering, Mathematical Sciences, and Chemical Engineering.

### **Interdisciplinary Programs**

See also Biochemistry/Biophysics, and Bioinformatics and Molecular Biology, under the Interdisciplinary Programs and Research section.

## **Faculty\***

### **Professors**

**Boylan, C.W.**—Ph.D. (University of Wisconsin); microbial ecology, physiological effects of starvation on microorganisms.

**Diwan, J.J.**—Ph.D. (University of Illinois); cell physiology, bioenergetics.

**Dordick, J.**—Ph.D. (Massachusetts Institute of Technology); (joint appointment with Chemical Engineering).

**Koretz, J.F.**—Ph.D. (University of Chicago); structural biophysics of protein aggregation, computer modeling.

**Lindhardt, R.**—Ph.D. (John Hopkins University); biochemistry, biophysics.

**McDaniel, C.N.**—Ph.D. (Wesleyan University); plant development and cell culture.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

**Nierzwicki-Bauer, S.A.**—Ph.D. (University of New Hampshire); plant molecular biology, subsurface microbiology.

**Palazzo, R.E.**—Ph.D. (Wayne State University); cellular organization, cell replication, cell motility, development and cancer.

**Roy, H.**—Ph.D. (Johns Hopkins University); plant molecular biology and biochemistry.

**Salerno, J.C.**—Ph.D. (University of Pennsylvania); enzymology, spectroscopy, molecular structures, bioinformatics.

**Zuker, M.**—Ph.D. (Massachusetts Institute of Technology); algorithms for predicting RNA and DNA secondary structure (joint appointment with Mathematics).

### Research Professors

**Bedard, D.**—Ph.D. (University of Chicago); environmental microbiology and ecology, microbial molecular biodegradation of halogenated aromatics.

**Lister, B.**—Ph.D. (Princeton University); ecology, undergraduate education (joint appointment with The Anderson Center for Innovation in Undergraduate Education).

### Associate Professors

**Hanna, M.H.**—Ph.D. (University of Illinois); directed evolution of proteins.

**Parsons, R.H.**—Ph.D. (Oregon State University); cellular physiology, epithelial transport.

### Assistant Professors

**Barquera, B.**—Ph.D. (National Autonomous University of Mexico); bioenergetics of *Vibrio cholerae*

**Bystroff, C.**—Ph.D. (University of California, San Diego); genomics, protein structural prediction.

**Finger, F.**—Ph.D. (Yale University); analysis of septin function in *C. Elegans* development.

**Page-McCaw, A.**—Ph.D. (Massachusetts Institute of Technology); genetic and molecular analysis of matrix metalloproteinases during development in *Drosophila melanogaster*.

**Page-McCaw, P.**—Ph.D. (Massachusetts Institute of Technology); genetic analysis of learning and memory in the zebrafish, *Danio rerio*.

**Plopper, G.**—Ph.D. (Harvard); signal transduction in tumor cell biology and tissue engineering.

**Xu, J.**—Ph.D. (Meharry Medical College); signal transduction by extracellular matrix.

### Professors Emeritus

**Ehrlich, H.L.**—Ph.D. (University of Wisconsin); geomicrobiology, mineral transformations by bacteria.

**Pfau, C.J.**—Ph.D. (Indiana University); molecular biology of animal viruses, antiviral drugs.

### Associate Professor Emeritus

**Clesceri, L.S.**—Ph.D. (University of Wisconsin); microbial ecology, biotransformation and biodegradation of natural polymers and pesticides, biotechnology.

### Research Assistant Professor

**Morgan, J.**—Ph.D. (California Institute of Technology).

### Clinical Assistant Professor

**Smith, S.M.E.**—Ph.D. (Rensselaer Polytechnic Institute); bioinformatics, enzyme structure.

### Adjunct Faculty

**Flaherty, L.**—Ph.D. (Cornell University Medical School).

**Manella, C.**—Ph.D. (University of Pennsylvania); mitochondrial membrane transport.

## Undergraduate Programs

Undergraduate students may pursue either a baccalaureate program or an accelerated degree program. Both of these degree programs are explained on the next page.

## Baccalaureate Programs

The undergraduate curriculum in biology is designed to prepare students for admission to graduate or professional school. Recognizing that flexibility is essential for students with specific interests and goals other than those spelled out in the traditional curricula, it is designed to leave many options open to the student. The following is a sample biology curriculum, completion of which requires a minimum of 128 credit hours.

### First Year

#### Fall

	Credit hours
MATH-1010	Calculus I .....4
CHEM-1100	Chem. I.....4
BIOL-1010	Intro. to Biol. ....4
	Hum. or Soc. Sci. Elective .....4
BIOL-1020	Intro. to Biol Lab 1.....1

#### Spring

	Credit hours
MATH-1020	Calculus II .....4
CHEM-1200	Chem. II .....4
BIOL-2120	Intro. Cell and Molec. Biol. ....4
	Hum. or Soc. Sci. Elective .....4

### Second Year

#### Fall

	Credit hours
CHEM-2250	Organic Chem. I .....4
PHYS-1100	Physics I .....4
BIOL-2500	Genetics and Evolution .....4
	Hum. or Soc. Sci. Elective .....4

#### Spring

	Credit hours
CHEM-2260	Organic Chem. II .....4
PHYS-1200	Physics II .....4
BIOL-4620	Molecular Biology .....4
	Hum. or Soc. Sci. Elective .....4

### Third Year

#### Fall

	Credit hours
BIOL-4760	Molecular Biochem. I .....4
	Hum. or Soc. Sci. Elective .....4
	Elective .....4
	Biology Elective. ....4

#### Spring

	Credit hours
	Hum. or Soc. Sci. Elective .....4
	Elective .....4
	Biology Elective .....4
	Elective .....4

### Fourth Year

#### Fall

	Credit hours
	Advanced Lab * .....4
	Biology Elective .....4
	Elective .....4
	Elective .....4

#### Spring

	Credit hours
	Biology Electives ** .....4
	Elective .....4
BIOL-	Culminating Experience*** .....3
	Elective .....4

### Electives

Twelve courses in biology are required for graduation. Careful selection of biology electives and technical electives in the third and fourth years may contribute significantly to preparation for various professional goals. Technical electives include any pertinent courses in biology, other sciences, or mathematics.

A student who anticipates working on a senior thesis is strongly urged to take two of the advanced laboratory courses (BIOL- 4710, BIOL-4720, BIOL-4740) in their junior year, since these courses offer excellent preparation for independent laboratory work.

### Concentrations

Technical and free electives may be chosen to provide a concentration in biochemistry, bioinformatics, biomedical engineering, biophysics, biotechnology (genetic engineering), chemical engineering,

\* Chosen from one of the following three courses: BIOL-4710, BIOL-4720, or BIOL-4740. All three courses are writing intensive.

\*\* One of the biology electives can be chosen from any of the following classes: All BCBP except BCBP-4760, CHEM-2440, CHEM-4300, or CHEM-4330.

\*\*\* Chosen from one of the following three courses: BIOL-49XX, BIOL-4960, or BIOL-4990.

computer science, environmental science, management, mathematics, microbiology, psychology, or technical communication. Program advisers should be consulted.

### Minor Programs

The Biology Department offers minors in biochemistry, biophysics, astrobiology and biology. The biochemistry minor is designed specifically for biology or bioinformatics majors and the biophysics minor is designed specifically for students majoring in biology. The requirements for all department minors are given below.

#### Astrobiology

To complete this minor, students must take a minimum of 16 credits of course work in this field. These courses include ASTR-4510 and ISCI-4500, four credits each, and two semesters of the one-credit course ISCI-4510. Two additional courses outside the major field of study must be selected from the following:

ENVE-2110	Intro. to Environmental Engineering	CHEM-2250	Organic Chemistry I
BIOL-4320	Geomicrobiology	CHEM-4810	Chemistry of the Environment
BIOL-4440	Microbial Ecology	ERTH-4070	Sedimentology
BIOL-4620	Molecular Biology	ERTH-4540	Organic Geochemistry
BIOL-4760	Molecular Biochemistry I	ASTR-2050	Intro. to Astronomy and Astrophysics
BCBP-4810	Biological Spectroscopy		
BCBP-4860	Protein and Nucleic Acid Structure		

The requirement that the two selected courses must be outside the major field of study is reduced to one in the case of a double major, provided both majors are in primary relevant areas of study (i.e., biology, chemistry, geology, and physics).

#### Biochemistry

To complete this minor, a biology major must take BCBP-4770, CHEM-2440, and two of the following courses:

BIOL-4260	Cell Biology	BCBP-4860	Protein and Nucleic Acid Structure
BCBP-4710	Biochemistry Laboratory	CHEM-4310	Bioorganic Mechanisms
BCBP-4310	Genetic Engineering	BCBP-4780	Protein Folding

#### Biophysics

To complete this minor, a biology major must take BCBP-4770, CHEM-2440, and two of the following courses:

MATH-2400	Differential Equations	BCBP-4210	Biophysical Methods
MATH-4720	Mathematics in Medicine and Biology	BCBP-4810	Biological Spectroscopy
BIOL-4270	Human Physiology I	PHYS-2510	Quantum Physics (requires MATH-2400)

#### Biology

Students not majoring in biology may receive a minor in this discipline by taking eight credits of introductory biology. These credits must include BIOL-2120 and either BIOL-2310 or BIOL-1010. Also included are BIOL-2500 and three 4000-level courses of the student's choice.

### Accelerated Program

The Biology Department offers highly motivated students interested in the medical profession the opportunity to combine undergraduate and graduate study to reduce the number of years spent in academic study. The program is described below.

### Physician-Scientist Program

This accelerated biomedical program leads to the B.S. degree from Rensselaer and the M.D. degree from Albany Medical College (AMC). Through this program, both degrees can be obtained within seven calendar years, including some summers.

Admission to the biomedical program is limited to individuals who have not yet initiated full-time undergraduate study and who display the motivation, maturity, and intellectual capacity necessary to pursue this accelerated course of study. Rensselaer conducts initial reviews and then forwards applications of candidates meeting the Institute's program standards to Albany Medical College for further review. Only those applicants with uniformly superior academic credentials and the highest test scores are invited to the required interview at Albany Medical College. Some experience or demonstrated interest in biological or biomedical research during high school is considered as a factor in admission. The interview process assesses the applicant's motivation for medicine, level of maturity, and level of personal development.

The biomedical program seeks and admits students without discrimination based on race, religion, color, gender, age, or handicap as defined in the Rehabilitation Act of 1973, or national or ethnic origin. Ordinarily, admission to the program is limited to citizens of the United States. Candidates must complete secondary school with superior scholastic credentials. Course work must include four years of English, one year each of physics, chemistry, and biology, and mathematics through precalculus. The Scholastic Aptitude Test (SAT) I or ACT examination and SAT II in mathematics (Level I, Level IC, Level II, or Level IIC), writing, and physics, biology, or chemistry are required, and must be completed by the November testing date prior to the proposed September matriculation in the program. Scores of tests taken thereafter will not be considered. Preferably, secondary school applicants will have taken these tests in the spring preceding application. Applications must be filed and completed prior to December 1, which is earlier than application for normal admission.

Provided that the student maintains satisfactory standards of academic achievement, admission leads automatically to entrance into Albany Medical College after three years of study at Rensselaer (six semesters). A minimum grade point average of 3.40 (overall GPA and science/math GPA) is required each semester at Rensselaer. At the completion of the third fall semester, a minimum grade point average of 3.40 is required both in overall course work and in science/math for promotion to the medical portion of the curriculum. All course work at Rensselaer must be satisfactorily completed before beginning the fourth year of study at Albany Medical College. A grade of D or F in any science course generally requires immediate transfer out of this program. Grades of I (Incomplete) are not accepted without justification involving illness or specific course structure. When an Incomplete is granted, the course work must be completed no later than one month after the last day of the examination period of the semester in which the incomplete was received.

Promotion to the medical portion of the curriculum is based not only on academic achievement, but also on the fitness of the student to enter the profession of medicine. Students may transfer into Rensselaer's regular four-year undergraduate program at any time during the premedical portion of the biomedical program. The three years of Rensselaer study include a sound basis in the physical sciences, an introduction to the major concepts and principles of biology and biological research, and ample opportunity to become acquainted with the humanities and social sciences. Students in the biomedical program will take 24 courses at Rensselaer over the three years. During the third summer (the transition between Rensselaer and Albany Medical College), students continue with research projects begun while at Rensselaer. These research projects will be completed during the fourth summer while at Albany Medical College. Students should plan on spending eight weeks of full time study during the summers. Biology course credit will be given for the two courses taken during the third summer and five additional preclinical courses taken at Albany Medical College to complete the undergraduate requirements for the B.S. degree.

Since many biomedical students will enter Rensselaer with advanced placement credit, a large proportion will have undergraduate course work credit in excess of standard requirements. These advanced placement

credits will allow them to take advanced or additional course work, but cannot be used to decrease the length of time allotted to their undergraduate experience or to decrease the number of courses prescribed in the curriculum. All courses specifically named in the curriculum must be taken at Rensselaer, or given AP credit, or transferred in from courses taken prior to admission at Rensselaer. After completing the fourth year of the program, students receive a B.S. degree from Rensselaer. The M.D. degree is received at the end of the seventh year and is dependent upon completing all requirements for the B.S. degree. Requests for further information and applications for admission to this program should be addressed to the Office of Undergraduate Admissions, Rensselaer Polytechnic Institute, 110 8th Street, Troy, New York 12180-3590.

### Seven-year Accelerated Physician-Scientist Program

#### Academic Year I

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I .....	4	MATH-1020	Calculus II .....	4
CHEM-1100	Chemistry .....	4	BIOL-2120	Intro. to Cell and Molec. Biology .....	4
BIOL-1010	Intro. to Biology .....	4	CHEM-1200	Chemistry II .....	4
BIOL-1020	Intro. to Biology Lab .....	1		Hum. or Soc. Sci. Elective .....	4
	Hum. or Soc. Sci. Elective .....	4			

#### Academic Year II

Fall		Credit hours	Spring		Credit hours
PHYS-1100	Physics I .....	4	PHYS-1200	Physics II .....	4
CHEM-2250	Organic Chemistry I .....	4	BIOL-4620	Molecular Biology .....	4
BIOL-2500	Genetics and Evolution .....	4	CHEM-2260	Organic Chemistry II .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

#### Academic Year III

Fall		Credit hours	Spring		Credit hours
BIOL-4760	Molecular Biochemistry I .....	4	BIOL-2410	Embryology .....	4
BIOL-4290	Human Phys. System .....	4	BIOL-2980	Biomedical Research .....	4
	Elective .....	4	BIOL-XXXX	Principles of Research .....	2
	Hum. or Soc. Sci. Elective .....	4	BIOL-XXXX	Seminal Dev. Bmed. Res. ....	2
				Hum. or Soc. Sci. Elective .....	4

#### Summer Session at Albany Medical College

	Credit hours
Research .....	8

#### Academic Years IV–VII (at Albany Medical College)

The following courses are transferred from the Albany Medical College	Credit hours
Research .....	8
Musculoskeletal System .....	6
Nervous System .....	6
Cardiovascular System .....	4
Gastrointestinal System .....	3
Endocrine System/Metabolism .....	4
Total credits transferred from Albany Medical College .....	31

## Graduate Programs

The biology research laboratories at Rensselaer are equipped for graduate study and projects in cell and molecular biology, biochemistry, bioinformatics, biophysics, microbiology and microbial ecology, recombinant DNA and genetics, and vision regulation. In addition, cooperative programs with other organizations provide a wider range of research possibilities. Rensselaer's Darrin Fresh Water Institute at Lake George offers a program on lake ecosystem analysis involving field, laboratory, and computer analysis of biological, chemical, and physical data. An active program in biochemistry and biophysics is jointly sponsored with the Chemistry, Physics, Mathematics, and Chemical Engineering Departments. Students must complete a core curriculum that includes courses in general biochemistry and molecular biology and pass a qualifying exam. Qualified students may take a candidacy examination in their special area of interest and proceed to the Ph.D. under the guidance of the candidacy committee. Other students seeking an M.S. degree must complete a thesis based on original research. Students work toward M.S. and Ph.D. degrees in biology. The detailed curriculum is tailored to the student's background and special interests.

### Master's Programs

Thirty credit hours of course work are necessary to complete the M.S. program. A minimum of six credits and a maximum of nine must be in research. Of the remaining credits, 15 must be in graduate-level courses. A thesis based on an original research project is required.

### Doctoral Programs

Candidates for the Ph.D. must satisfy the requirements of the graduate evaluation committee (GEC), pass the qualifying exam, and pass a candidacy exam. The latter consists of a written and an oral portion, and should usually be taken between the second and the third year of full-time study. A degree candidate also must submit a dissertation based on an original research project. The GEC requires a high level of performance in selected courses and research, and reports its findings during the second full year of full-time study. Additionally, all doctoral candidates are required to participate in teaching for one academic year under the supervision of a faculty member. The student thus gains experience teaching should he or she select an academic career. Sixty credit hours past the M.S. degree are required.

## Course Descriptions

Courses directly related to all Biology curricula are described in the Course Description section of this catalog under the department code BIOL.

## Chemistry and Chemical Biology

**Chair:** Linda B. McGown

**Associate Chair:** Ronald A. Bailey

**Undergraduate Advising:** Charles W. Gillies

**Graduate Admissions:** Wilfredo Colón

**Department Home Page:** <http://www.rpi.edu/dept/chem/index.html>

The Department of Chemistry and Chemical Biology provides courses and programs of study that reflect the central role of chemistry in the science and technology of tomorrow. In addition to a strong focus in the traditional areas of chemistry, such as synthesis, molecular structure, and chemical reactions, the

department offers courses and research programs in the rapidly developing frontiers of modern science. These areas include biochemistry, biophysics and biotechnology, materials and polymer chemistry, and medicinal chemistry. The department offers programs leading to the B.S., M.S. and Ph.D. degrees in chemistry, as well as a minor in chemistry.

Chemistry instruction is delivered in the recently renovated Walker Laboratory, which houses state-of-the-art classrooms and laboratories, and in Cogswell Laboratory, the site of the majority of the department's research activities. Undergraduate laboratories are equipped with modern computer-controlled instruments and provide students with hands-on experience with equipment similar to that found in industrial and research laboratories. Chemistry research laboratories are found in the Cogswell Laboratory, the Materials Research Center, the recently constructed New York State Center for Polymer Synthesis, the nearby Science Center, and, when completed in Fall 2004, the Biotechnology Center.

## Research Innovations and Initiatives

### Analytical Chemistry

Areas of research include the development and application of methods to study *in vivo* processes, particularly the advancement of microdialysis technology. Membrane devices that facilitate mass transport using cyclodextrins are being developed for *in vivo* analysis. Methods of monitoring biochemical reactions at the site of the biomaterials are also of interest. Techniques such as high field and solid state NMR, FTIR, GC-MS, LC-MS and MALDI-TOF mass spectrometry are used in developing analytical procedures to detect, quantitatively determine, and structurally characterize materials in a variety of areas.

### Biochemistry, Biophysical Chemistry, and Biotechnology

Pathways on the primitive earth for the origin of RNA are under investigation as part of the activities of the New York State Center for Studies on the Origins of Life. The goal of this research is to determine if the RNA formed by proposed prebiotic pathways has catalytic activity, a requisite for the first life on earth. Photosynthetic electron transport and biological energy transduction for the mechanisms are studied by electron spin resonance and time-resolved optical and electroabsorption spectroscopies. Biochemical and biophysical research also focuses on the mechanisms of protein folding and aggregation, protein folding defects related to human diseases, and the molecular structures of proteins. Carbohydrate biochemistry and glycobiology are used to understand disease processes and to develop new therapeutic agents. The biochemical aspects of biotechnology including biocatalysis and metabolic engineering are being explored. The methodologies used include kinetic and spectroscopic analysis (NMR, fluorescence, circular dichroism, surface plasma resonance (SPR) and FTIR of protein conformational changes), molecular modeling, computational graphics, and molecular mechanics calculations on peptides and proteins. New methods for the separation of biopolymers are being developed. A new initiative in protein and carbohydrate chemistry is centered on the computer design and organic synthesis of proteins and carbohydrates with novel functionalities and non-natural architectures. The research will provide new capabilities to design purpose-specific proteins such as synthetic enzymes and artificial membrane protein receptors.

### Inorganic Chemistry and Solid-State Chemistry

Inorganic chemistry involves the preparation and investigation of substances ranging from coordination complexes and organometallic compounds to inorganic solids with extended network structures. Materials and solid-state chemistry focuses on the application of both inorganic and organic substances as structural, optical, and electronic materials, and include theoretical studies on the defect structures of

inorganic solids. Syntheses of organometallic compounds and inorganic polymers provide sources of novel solid-state materials, both as molecular solids and as precursors for the pyrolytic preparation of inorganic solids, such as aluminum nitride and silicon carbide.

### **Organic Chemistry, Medicinal Chemistry and Organometallic Chemistry**

Active areas of synthetic organic and medicinal chemistry research include the design and synthesis of novel agents to treat cocaine addiction and carbohydrate-based cardiovascular anti-infection and anti-cancer agents. Research in the areas of transition organometallic chemistry and homogeneous catalysis focuses on synthetic and mechanistic studies of organometallic complexes applicable to the conversion of carbon monoxide and carbon dioxide into organic molecules. The development of molecular modeling programs that evaluate intermolecular electrostatics may result in the deeper understanding of enzyme-substrate interactions.

### **Photochemistry**

Mechanistic and synthetic photochemistry are areas of major emphasis. Investigations involve the photochemical transformations of heterocycles, carbonyl containing compounds, and naturally occurring materials. The atmospheric chemistry of Jupiter and Titan (Saturn's largest moon), and the role of photochemical reactions in the origins of life also are under investigation. Photosynthesis and rearrangement of heterocyclic purines and photochemical reactions of possible prebiotic gases are being studied to elucidate the role of photochemistry in transformations that led to biological molecules on the primitive earth. Photochemical processes used for the generation of polymer thin films, for the photoimaging of lithographic resists, and for novel polymerization processes are also being developed.

### **Polymer Chemistry and Materials Chemistry**

Synthetic and development efforts are under way in the field of high-performance thermally stable polymers, conductive polymer membranes for fuel cell applications, liquid crystalline polymers, block copolymers, and photosensitive thermosets and thermoplastics. Novel synthetic and biorenewable-monomers and methods for their synthesis are being studied. New approaches to polymer preparation, including photochemical, photo-electroinitiated, transition metal catalyzed, and vapor-deposition polymerization are also under study. Development of biologically compatible polymers that can serve as scaffolding for tissue regeneration is an area of recent interest. Polymers are characterized by means of gel permeation chromatography, viscometry, differential scanning calorimetry, scanning and transmission electron microscopy, atomic force microscopy, low-angle light, X-ray, and neutron scattering and mass spectrometry (MALDI TOF and ESI). Surface interactions between immiscible crystallizable polymers are being studied using X-ray photoelectron spectroscopy, polarized light microscopy, electron microprobe methods, and Raman spectroscopy. Properties of multiphase polymer alloys and solutions are being investigated in shear, electric, and magnetic fields. Polymerization processes are being investigated from the aspect of mechanistic organic chemistry. Polymer gels that may function as artificial muscles are also being investigated. Coordination complexes and organometallic compounds are being considered as inorganic polymers and as precursors for the pyrolytic preparation of inorganic solid-state materials.

### **Surface Science**

Topics of current research interest include the study of surface interfacial tensions of liquids and liquid-liquid systems with and without surface-active solutes present. Molecular structure and orientation of liquid and solid surfaces and surface films are being studied through state-of-the-art laser spectrographic techniques. Structure and composition of films with environmental importance on lake and ocean surfaces are also under investigation by direct and remote sensing methods.

### Computational Chemistry and Spectroscopy

Computational chemistry and molecular modeling are being developed and used to understand the relationships between molecular structures and their properties. Specialized electron density reconstruction methods, such as the Transferable Atom Equivalent (TAE) technique, have permitted the construction of predictive models that allow good estimates of the properties of new compounds to be synthesized, as well as predicting the behavior of protein displacers in the biotechnological chromatography of fermentation products. These techniques have been developed as part of the NSF Project DDASSL, together with novel machine learning and drug delivery modeling algorithms. Other theoretical chemistry projects under way emphasize understanding nonlinear optical properties of polymers. Spectroscopic research is directed particularly toward structure and properties problems of a wide range of compounds, with emphasis on vibrational (infrared and Raman), linear and nonlinear laser and microwave spectroscopy, NMR spectroscopy, electronic spectroscopy, and X-ray diffraction. Pulsed-beam Fourier-transform microwave spectroscopy is used to study van der Waals complexes and transient chemical species, with an emphasis upon understanding the mechanisms of simple chemical reactions. Solid-state NMR spectroscopy is used extensively in materials and polymer chemistry research, and in the characterization of catalysts.

### Research Facilities and Equipment

Department research facilities include Cogswell Laboratory, the New York State Center for Polymer Synthesis, the Science Center, and the Materials Research Center. A variety of modern instruments are available in individual laboratories and in the department's Major Instrument Facility, which provides state-of-the-art equipment for nuclear magnetic resonance (both solution and solid state) and other techniques. This equipment, serviced and operated by a professional staff, is available to all researchers in the department. The central mass spectroscopy facility includes GC-MS, MALDI-TOF for macromolecular analysis, and LC-MS (ion trap) equipment. Other instruments available for research include NIR, visible, UV, fluorescence, atomic absorption, surface plasma resonance and FTIR spectrophotometers, G.C. and HPLC equipment, electrochemical equipment, ESR spectrometers, DSC, DTA, TGA, and TMA instruments for thermal studies, and X-ray fluorescence and diffraction instruments. A molecular modeling laboratory contains computer workstations and a variety of sophisticated computer programs for molecular modeling, conformational analysis, energy calculation, and synthesis design.

## Faculty\*

### Professors

**Apple, T.M.**—Ph.D. (University of Delaware); solid-state NMR spectroscopy.

**Bailey, R.A.**—Ph.D. (McGill University); coordination chemistry and chemistry of molten salts.

**Benicewicz, B.C.**—Ph.D. (University of Connecticut); polymer chemistry.

**Breneman, C.M.**—Ph.D. (University of California, Santa Barbara); physical organic chemistry.

**Crivello, J.V.**—Ph.D. (University of Notre Dame); polymer chemistry.

**Cutler, A.R.**—Ph.D. (Brandeis University); organometallic chemistry.

**Interrante, L.V.**—Ph.D. (University of Illinois); inorganic and solid-state materials synthesis.

**Korenowski, G.M.**—Ph.D. (Cornell University); laser spectroscopy, surface science.

**Krause, S.**—Ph.D. (University of California, Berkeley); physical chemistry of macromolecular solutions.

**Linhardt, R.T.**—Ph.D. (John Hopkins University); carbohydrate chemistry, medicinal chemistry and biocatalysis.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

- McGown, L.B.**—Ph.D. (University of Washington); analytical and bioinorganic chemistry.  
**Moore, J.A.**—Ph.D. (Polytechnic Institute of Brooklyn); synthesis and reactions of polymers.  
**Nalamasu, O.**—Ph.D. (University of British Columbia); electronic and photonic polymers, nano-patternings, micro and nano-fabrication, electronic and photonic devices.  
**Wait, S.C., Jr.**—Ph.D. (Rensselaer Polytechnic Institute); spectroscopy, vibrational and electronic spectroscopy.  
**Warden, J.T.**—Ph.D. (University of Minnesota); ESR spectroscopy, biophysical chemistry.  
**Wentland, M.P.**—Ph.D. (Rice University); medicinal chemistry.

#### **Research Professors**

- Ferris, J.P.**—Ph.D. (Indiana University); prebiotic chemistry, origins of life.  
**Wiedemeier, H.A.**—D.Sc. (University of Munster); high-temperature and solid-state chemistry, computational analysis of defect structures in solids.  
**Willis, J.**—Ph.D. (University of Connecticut); bioanalytic chemistry

#### **Associate Professors**

- Choma, C.T.**—Ph.D. (University of Ottawa, Canada); biochemistry, protein design and synthesis.  
**Colon, W.**—Ph.D. (Texas A&M University); biophysical chemistry.  
**Gillies, C.W.**—Ph.D. (University of Michigan); microwave spectroscopy.  
**Stenken, J.A.**—Ph.D. (University of Kansas); bioanalytical chemistry.

#### **Assistant Professors**

- Akpalu, Y.**—Ph.D. (University of Massachusetts, Amherst); polymer physical chemistry.  
**Ryu, C.Y.**—Ph.D. (University of Minnesota); polymer physical and materials chemistry.  
**Zhang, C.X.**—Ph.D. (John Hopkins University); bioinorganic chemistry.

#### **Clinical Assistant Professor**

- Carter, J.H., Jr.**—Ph.D. (University of Oregon); physical chemistry, (Edward P. Hamilton Faculty Fellow).

#### **Adjunct Faculty**

- Bello, S.C.**—M.D. (SUNY Downstate Medical Center); general chemistry, biochemistry.  
**Choe, E.W.**—Ph.D. (Illinois Institute of Technology); organic-polymer chemistry.  
**Eisman, E. D.**—Ph.D. (Northeastern University); Physical Inorganic Chemistry

## **Undergraduate Programs**

The Department of Chemistry and Chemical Biology offers a variety of opportunities to undergraduate students, ranging from four-year and accelerated degree programs to dual majors, minors, and specialization programs. All of these opportunities are explained in detail below.

### **Baccalaureate Programs**

The B.S. in Chemistry curriculum is designed to meet the recommendations of the American Chemical Society Committee on Professional Training. At the same time, it provides ample opportunity for students to select electives that permit them to specialize in particular fields, to explore areas of potential interest, or to take unusual combinations of courses that will suit nontypical career goals. The program emphasizes hands-on laboratory experience in the second and third years, and provides extensive opportunities to participate in research. Besides allowing students to prepare for careers that demand a good background in science and mathematics, the curriculum also offers a sound basis for careers in fields such as law, the health professions, management, and technical communication.

For students transferring from other universities, two-year colleges, or from other curricula at Rensselaer, previous chemistry courses will be evaluated on an individual basis. Normally, these courses will count toward the Rensselaer program. The content of laboratory courses can be adjusted to allow for prior experience. The department makes every attempt to accommodate transfer students whose backgrounds do not permit them to follow the normal course sequence.

Two paths are available leading to the American Chemical Society certified B.S. in Chemistry. One provides a traditional program; the other has an emphasis on biochemistry. Typical curricula, which require 128 credit hours for completion, are shown below.

### Traditional Curriculum

#### First Year

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I.....	4	MATH-1200	Calculus II .....	4
CHEM-1100	Chemistry I <sup>1</sup> .....	4	CHEM-1200	Chemistry II <sup>2</sup> .....	4
PHYS-1100	Physics I.....	4	PHYS-1200	Physics II .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

#### Second Year

Fall		Credit hours	Spring		Credit hours
CHEM-2210	Organic Compounds and Reactions..	4	CHEM-2220	Organic Synthesis .....	2
CHEM-2110	Equilib. Chem. & Quantitative Analysis .....	3	CHEM-2280	Experimental Chemistry II.....	2
CHEM-2120	Experimental Chemistry I.....	2	CHEM-2030	Inorganic Chemistry I.....	4
	Hum. or Soc. Sci.....	4	BIOL-1010	Hum. or Soc. Sci.....	4
MATH-2400	Intro. to Differential Equations .....	4		Intro. to Biology.....	4

#### Third Year

Fall		Credit hours	Spring		Credit hours
CHEM-4410	Macroscopic Physical Chemistry.....	3	CHEM-4110	Instrumental Analysis .....	2
CHEM-4010	Inorganic Chemistry II.....	2	CHEM-4120	Experimental Chemistry IV .....	2
CHEM-4020	Experimental Chemistry III.....	2	CHEM-4460	Microscopic Physical Chemistry.....	4
	Hum. or Soc. Sci.....	4		Hum. or Soc. Sci.....	4
CHEM-4760	Molecular Biochemistry I <sup>3</sup> .....	4		Elective.....	4

#### Fourth Year

Fall		Credit hours	Spring		Credit hours
CHEM-4900	Senior Seminar .....	1	CHEM-4620	Intro. to Polymer Chemistry.....	4
CHEM-4950	Senior Experience.....	3		Electives .....	12
	Electives .....	12			

Twenty eight of these total 128 credit hours required for graduation are completely free electives. Students should select electives in consultation with the adviser to give a balanced program. Some H&SS courses can be deferred until the senior year to allow for earlier electives.

Students planning to pursue graduate studies in Chemistry are recommended to take at least 12 credits in Chemistry courses beyond those required. Research experience such as through CHEM-2950 or URP activities is particularly valuable.

<sup>1</sup> CHEM-1300 may be substituted for CHEM-1100 by students transferring into Chemistry.

<sup>2</sup> ENGR-1600 may be substituted for CHEM-1200 by students transferring into Chemistry.

<sup>3</sup> CHEM-4310 may be substituted for this course.

**Biochemistry Oriented Curriculum****First Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
MATH-1010	Calculus I.....	4	MATH-1200	Calculus II .....	4
CHEM-1100	Chemistry I <sup>1</sup> .....	4	CHEM-1200	Chemistry II <sup>2</sup> .....	4
PHYS-1100	Physics I.....	4	PHYS-1200	Physics II.....	4
	Hum. or Soc. Sci.....	4		Hum. or Soc. Sci.....	4

**Second Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
CHEM-2210	Organic Compounds and Reactions ..	4	CHEM-2220	Organic Synthesis .....	2
CHEM-2110	Equilib. Chem. & Quantitative Analysis .....	3	CHEM-2280	Experimental Chemistry II.....	2
CHEM-2120	Experimental Chemistry I.....	2	CHEM-2030	Inorganic Chemistry I .....	4
BIOL-1010	Intro. to Biology.....	4		Hum. or Soc. Sci.....	4
MATH-2400	Intro. to Differential Equations .....	4	BIOL-2120	Intro. Cell & Molecular Biology.....	4

**Third Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
CHEM-4410	Macroscopic Physical Chemistry.....	3	CHEM-4110	Instrumental Analysis .....	2
CHEM-4760	Molecular Biochemistry I <sup>3</sup> .....	4	CHEM-4120	Experimental Chemistry IV .....	2
	Elective.....	4	CHEM-4460	Microscopic Physical Chemistry.....	4
	Hum. or Soc. Sci.....	4		Hum. or Soc. Sci.....	4
				Elective.....	4

**Fourth Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
CHEM-4900	Senior Seminar .....	1		Hum. or Soc. Sci.....	4
CHEM-4950	Senior Experience.....	3	CHEM-XXXX	Bioanalytical Laboratory .....	4
	Electives .....	12		Electives .....	8

Of the 128 credit hours required for graduation, twenty eight are completely free electives. Students should select electives in consultation with the adviser to ensure a balanced program. Some H&SS courses can be deferred until the senior year to allow for earlier electives.

Students planning to pursue graduate studies in Chemistry are recommended to take at least 12 credits in Chemistry courses beyond those required. Research experience such as through CHEM-2950 or URP activities is particularly valuable.

**Electives**

Students should select electives in consultation with their adviser to ensure a balanced program. Combinations of electives that can provide appropriate depth in specific areas such as environmental chemistry, medicinal chemistry, polymer chemistry, chemical engineering, management, pre-law, and others can be provided by the adviser. Students interested in medicine as a career should include the following courses among their elective choices. They are recommended before the senior year as preparation for the qualifying exams required for admission to medical school.

<sup>1</sup> CHEM-1300 may be substituted for CHEM-1100 by students transferring into Chemistry.

<sup>2</sup> ENGR-1600 may be substituted for CHEM-1200 by students transferring into Chemistry.

<sup>3</sup> CHEM-4310 may be substituted for this course.

BIOL-1020	Introduction to Biology Laboratory
BIOL-2120	Introduction to Cell and Molecular Biology
BIOL-4270	Human Physiology I
BIOL-4280	Human Physiology II
BIOL-4620	Molecular Biology

In addition, two communications courses should be included among Humanities and Social Sciences elective options.

### Dual Major Programs

Students interested in both chemistry and another field may use the elective course options in one program to take the required courses from another discipline to qualify for a dual degree. Examples are a B.S. in chemistry and biology, or chemistry and physics, or chemistry and economics. Combinations with any other science or H&SS discipline are usually easy to arrange, but students should seek counsel from their advisers.

### Minor Programs

The department offers a number of minor options for both chemistry and nonchemistry majors. In addition to the science minors detailed below, chemistry majors may minor in other disciplines through programs offered within other departments.

#### Biochemistry Minor for Chemistry Majors

This program is particularly advisable for chemistry students who wish to pursue scientific careers in medicinal research or at the interface of biology and chemistry. Students should take BIOL-2120, BCBP-4770, and two courses from the following:

BCBP-4710	Biochemistry Laboratory
BIOL-4260	Cell Biology
BIOL-4510	Molecular Genetics
BIOL-4620	Molecular Biology
BCBP-4310	Genetic Engineering
BCBP-4210	Biophysical Methods
BCBP-4860	Protein and Nucleic Acid Structure
CHEM-4310	Biorganic Mechanisms
BCBP-4780 or CHEM-4780	Protein Folding

#### Biophysics Minor for Chemistry Majors

This program is advisable for chemistry students who wish to pursue scientific careers in medicinal research or at the interface of biology and chemistry. For this minor, students should take BIOL-2120, BCBP-4770, and two courses from the following:

MATH-4720	Mathematics in Medicine and Biology
BIOL-4270	Human Physiology I
BCBP-4210	Biophysical Methods
BCBP-4810	Biological Spectroscopy
PHYS-2510	Introduction to Quantum Physics

### **Astrobiology Minor for Chemistry Majors**

Obtaining a minor in Astrobiology requires a minimum of 16 credits of course work that must include ASTR-4510 and ISCI-4500 (four credits each), two semesters of ISCI-4510 (one credit each) and two courses outside of the major field of study selected from the following:

ENVE-2110	Introduction to Environmental Engineering
BIOL-4320	Geomicrobiology
BIOL-4440	Microbial Ecology
BIOL-4620	Molecular Biology
BCBP-4810	Biological Spectroscopy
BCBP-4860	Protein and Nucleic Acid Structure
CHEM-4810	Chemistry of the Environment
ERTH-4070	Sedimentology
ERTH-4540	Organic Geochemistry
ASTR-2050	Introductory Astronomy and Astrophysics

For a double major, the requirement that the two selected courses must be outside the major field of study is reduced to one provided both majors are in the primary relevant areas of study (i.e. biology, chemistry, geology, and physics).

### **Chemistry minor for Non-Chemistry majors**

Students not majoring in chemistry may receive a minor in this discipline by passing 24 credits of courses bearing the CHEM- prefix, 16 of which are at or above the 2000 level and include at least two credits of laboratory. The combination cannot include both CHEM-2150 and CHEM-4530. Independent study, project, or research courses will be acceptable only with special permission.

## **Special Undergraduate Opportunities**

### **Accelerated Programs**

Students may elect to complete their B.S. degree in three years instead of four. To achieve this, they must take courses during the summer semesters and additional electives. Students with advanced placement standing in some courses are especially well situated for such arrangements. It is also possible for those not wishing to remain in Troy over the summer to take equivalent courses elsewhere and receive transfer credit.

An additional option is completion of the requirements in three and a half years. With advanced placement credit and additional courses during some academic semesters, summer work may be minimal.

### **B.S.-M.S. and B.S.-Ph.D. Programs**

A student who is within 18 credit hours of the B.S. can apply for admission to the graduate program. With advanced placement credit, extra courses, and by starting research while still an undergraduate, the time required for the advanced degree can be reduced by a year or more. Students who enter the Chemistry graduate program through the 18-hour rule may be eligible for graduate teaching or research assistantship support.

Highly motivated students who carry out significant research as undergraduates may apply this toward their graduation thesis in a mentored program that can lead to the Ph.D. degree three years after the B.S. degree.

Students contemplating an accelerated program must consult with their adviser early in their careers.

### Undergraduate Research Programs

Chemistry majors at all levels are encouraged to participate in the research program of the department. Research may be taken for credit or supported financially through the Institute URP program and from faculty research funds. Participation may be during academic semesters or in the summer. A senior research experience is required of all majors.

## Graduate Programs

The Department of Chemistry and Chemical Biology offers two graduate degrees—the Master of Science, and the Doctor of Philosophy. The M.S. and the Ph.D. require research and a thesis.

Graduate students typically begin their studies with graduate courses in analytical, inorganic, organic, and physical chemistry. The courses that are required depend on the student's background, area of interest, and performance in entering placement exams. Additionally, in consultation with the adviser, students may select a number of specialized advanced-level courses in chemistry, as well as from offerings in other departments that meet their needs. Chemistry graduate students may also select the biochemistry/ biophysics option described earlier. Each student plans a program with his or her adviser to meet individual professional goals.

The department has well-developed research programs not only in the traditional areas of chemistry, but also in interdisciplinary areas that transcend traditional boundaries and that foster collaborative work with other departments. There are extensive collaborations among Chemistry, Chemical Engineering, and Materials Science and Engineering in the areas of polymers/bio/nano/materials, and collaborative programs with Biology, Computer Science, Physics, and Mathematical Sciences Departments, and the School of Engineering and the Center for Integrated Electronics. These, and off-campus collaborations which include Albany Medical College, the University at Albany, and the New York State Wadsworth Laboratories provide essential connections between Chemistry and other areas vital to modern society. Cooperative programs with industry, national laboratories, and other universities are also part of the department's research activities. Faculty members, visiting scholars, postdoctoral associates, graduate students, and undergraduates all participate in the research efforts of the department.

Supplementing courses and research projects are weekly seminars and colloquia in the various areas of chemistry. Scientists of national and international renown participate in these seminars.

Most first year graduate students receive support as teaching assistants, participating in undergraduate laboratory or workshop- mode chemistry courses under the direction of a faculty member. After they have chosen a research adviser graduate students are eligible for support as research assistants.

### Master's Programs

#### Master of Science

Students must complete 30 credit hours of research and course work, 15 of which must be at the 6000–9990 level. In addition, these students must submit a research thesis.

### Doctoral Programs

To complete the Ph.D., students must meet divisional requirements in areas that their doctoral committee determines and accumulate 90 credit hours (60 beyond the M.S. degree) of research and course work. Satisfactory performance in an oral candidacy examination and a final defense of the doctoral thesis are also requirements. For any Ph.D. degree, the courses required will be specified based on the student's background and research needs.

## Course Descriptions

Courses directly related to all Chemistry curricula are described in the Course Description section of this catalog under the department code CHEM.

## Computer Science

**Chair:** Jeffrey C. Trinkle

**Executive Officer:** Robert P. Ingalls

**Computer Science Home Page:** <http://www.cs.rpi.edu/>

Computer science is the study of the design, analysis, communication, implementation, and application of computational processes. The core subjects of this discipline include software systems (such as operating systems and networks) and programming languages (including design and other language translation tools). They also include computer hardware systems, the design and analysis of data structures and algorithms, and the theoretical basis of computation, in particular the complexity of computation. In addition to these core subjects, various application areas are open to students, including artificial intelligence, computer graphics, databases, scientific and numeric computation, computer vision, data mining, robotics, computational learning, and user-interface design.

At Rensselaer, education in computer science prepares students for solving applied, real-world problems and for conducting research in computer science. The program provides students with a solid grounding in both theory and practice. The undergraduate program also provides a rigorous background in mathematics and science.

Rensselaer's Computer Science Department offers its own well-equipped computer laboratories for instruction and research. There are 20 Sun Ultra 10 workstations running Solaris 9 in a public lab in the Amos Eaton building (room 217) as well as a dedicated Enterprise 450 serving 32 thin clients (room 215). Each of our Ultra 10 workstations includes a PC subsystem, providing Windows 2000 in the public labs. In the Networking and Distributed Simulation lab, there are 41 IBM x220 servers, along with 13 Cisco routers and a Myrinet Cluster for experimenting with different network layouts. Our World Wide Computing lab houses 4 Sun Blade-1000 computers, which are also interconnected via Myrinet. Additionally, our Networking lab contains over 130 interconnected Cisco routers, switches and firewalls, which support a number of networking technologies such as FDDI, HSSI, ISDN, and Ethernet. Numerous other specialized research computers include a Silicon Graphics Origin 2000 with 12 CPUs, a 16 processor IBM pSerial 655 cluster, and a cluster of four Intel Itanium2 quad-processor machines, all interconnected via Myrinet. Also available are two robotics labs, a distributed/parallel computing laboratory, and a multimedia database lab. Student offices contain more than 50 other Unix workstations and PCs. Supporting all of these is a network of file servers with more than 0.75 terabytes of storage, print servers, mail servers, and Web servers. Most offices have a 100Mb dedicated connection to the gigabit Ethernet backbone.

## Research Innovations and Initiatives

### Bioinformatics

Bioinformatics is the science of managing, retrieving, analyzing, and interpreting biological data. Research is being carried out on topics such as multiple sequence alignment, sequence assembly, protein and RNA structure prediction, and regulatory networks. Research also spans emerging areas like microarray data analysis, high dimensional indexing, database support, information integration, and data mining.

### **Data Mining; Machine and Computational Learning; Algorithms for Massive Data Sets**

This research area deals with the theoretical and applied aspects of automated information extraction (knowledge discovery) from data. For large data sets, emphasis is placed on developing efficient, scalable, and parallel algorithms for various data mining techniques in addition to the data management itself. Examples include association rules, classification, clustering, and sequence mining. For small data sets, the emphasis is on robust computational learning systems (supervised, unsupervised, and reinforcement) and their theoretical properties. Application areas include combinatorial optimization, computational biology (bioinformatics, computational genomics), web mining, geographic information systems, and computational finance.

### **Database Systems**

This research area deals with the efficient and effective methods for storing, querying, analyzing, mining, and maintaining data from possibly disparate and heterogeneous resources. Data is used in many different applications from scientific data sets, sensor data, images, video and audio to hypertext documents, biological data, and data on stock market behavior. Research focuses on methods for caching data, querying large and distributed databases, database mining and supporting applications such as computer-aided design and manufacturing, bioinformatics, and collaborative engineering.

### **Discrete Event Simulation**

This work encompasses basic simulation techniques, such as parallel simulation protocols, Time Warp performance improvements, and run-time load balance of distributed simulations. The applications include network monitoring and management, wireless networking, and biological and ecological simulations. The systems developed by faculty and publicly available include TEMPEST for spatially explicit spread of disease modeling, GALE for simulating genetic and evolutionary effects in epidemics, and GENESIS for simulating large communication networks.

### **Networking**

Several projects in the department focus on the challenge of analyzing, managing, and simulating the Internet as well as the Internet measurements and modeling. The Genesis project offers a novel approach to scalability and efficiency of parallel network simulation by integrating independently run domain or AS simulations into a distributed simulation. The ROSS system explores the fundamental functional and performance limits of reverse computation when applied to the modeling of large-scale network models. Based on these and other projects, we are developing software tools for collaborative on-line simulation architecture that provides pro-active and automated control functions for networks. Another investigated area is a hot-potato routing used in networks where the nodes have no buffers to store messages in transit and therefore is well suited for optical networks in which the messages are made from light which is hard to store in any medium. There is also research focusing on network security, from using machine learning for Denial of Service attack detection to security problems in wireless networks.

### **Parallel and Distributed Computing**

Students and faculty members are involved at all phases of parallel computation, from algorithm design to the design of new parallel simulation systems to run-time support for load balance and computation optimization. There are also projects focusing on grid middleware. To support these efforts, the department has a number of parallel (multiprocessor) computers, clusters and grid nodes.

### **Worldwide Computing**

Worldwide computing research involves using a wide area network as a computing and collaboration platform. Current projects include the development of an actor-oriented programming language, an Internet-based infrastructure for mobile and distributed computing, and an adaptive middleware framework for dynamic grid computations.

### **Concepts in Software Engineering**

The goal of research in this area is to provide a solid foundation for development and deployment of software for systems with stringent requirements for security, safety, functional correctness, and efficiency. Principal focuses are generic programming methodology and program analysis techniques. Generic programming is largely an activity of “lifting” of specific computer code to a more widely useful level, while maintaining high standards of efficiency. This process is aided by conceptual classification of software components according to rigorously specified requirements. Results include the C++ Standard Template Library, which is based on joint research with colleagues in industry; new generic sorting and searching algorithms; and new algorithm concept taxonomies. In the program analysis area, new techniques are being developed for different software tasks, including testing, understanding, and verification of object-oriented software. Results include new analyses that have been applied to testing of polymorphism in Java applications, and to testing of recovery code in highly reliable Web service applications. Future directions include greater integration of generic programming and program analysis methodology, with increased emphasis on proof-based approaches. The long-range goal is to meet new challenges that arise from distributed software components, embedded system software updates, Web services, and other software for modern, pervasive computing.

### **Human Computer Interfaces**

Research in this area is fundamental to the design and evaluation of systems that mediate between computers and humans, and ultimately leads to the creation of tomorrow’s exciting new user interface software and technology. The ideal human-computer interface would be one where the user experience is such that the computer is no longer a distracting focus of attention but rather an invisible tool that empowers the individual user and facilitates natural and productive human-human collaboration. Faculty interests include assistive technology, universal access, intelligent user interfaces, interactive computing, multimedia information visualization, and multimodal environments.

### **Computational Science and Engineering**

Students and faculty work on computational approaches and algorithms to solve large-scale problems that arise in natural science and engineering. Current research includes adaptive methods for solving partial differential equations, scientific software libraries, algorithms for medical imaging and tomography, high-performance matrix algorithms, computational biology, and algorithms for high-performance, parallel, and distributed computation.

### **Theory**

Theory of computation provides the foundation needed for effective applications in computer science. The theory group brings together researchers in many different areas to develop novel approaches and solutions to problems in information technology. The theory group research is characterized by close collaboration with researchers in diverse application areas, such as networking; bioinformatics; visualization; pattern recognition, physics and astronomy; digital library; data mining; distributed computing; and experimental algorithmics.

### **Computational Geometry**

Current research in computational geometry concentrates on algorithms for the reconstruction of smooth geometric objects from their samples. Problems of interest include characterizing the conditions on sampling density, which allow a curve to be reconstructed from its samples. The reconstruction is homeomorphic and sufficiently close to the original and the algorithms developed to achieve the reconstruction. Also involved are the dependence of such algorithms on the dimension of the embedding space, related algorithms for the reconstruction of surfaces and manifolds, and finding the most concise representation of a manifold in terms of its samples. A second research track focuses on applications of computational geometry, particularly in robotic motion planning.

## Computer Vision

Computer vision and biomedical image analysis research in the Department of Computer Science covers a wide range of topics. Developing algorithms for registration and change detection, especially in the diagnosis and treatment of diseases of the human retina, is the largest current project; a related project studies the theory and application of robust estimation techniques in computer vision. A second research area focuses on the tracking and segmentation of objects, both in two- and three-dimensional images, using model-based algorithms. The techniques developed are general and may be used in a variety of computer vision tasks; the applications pursued at Rensselaer are mainly focused on biomedical problems, such image-guided radiation therapy. A third track involves the development of stochastic models for the interpretation of video data, for example traffic video.

## Robotics

Research in the Algorithmic Robotics Lab covers many facets of robotics, including planning algorithms for robotic manipulation and motion, development of mathematical models for robotic systems, and techniques for mobile robot navigation and exploration. Current work includes motion planning for industrial assembly and parts feeding tasks, algorithms for multiple robot coordination and control, planning for general dexterous manipulation tasks, control strategies for manipulation from mobile robot platforms, and developing robotics techniques for biomolecular modeling.

## Faculty\*

### Professors

- Flaherty, J.E.**—Ph.D. (Polytechnic Institute of Brooklyn); numerical analysis, scientific computation, parallel computation, and adaptive methods.
- Goldberg, M.K.**—Ph.D. (Institute of Mathematics, Novosibirsk, U.S.S.R.); algorithms for combinatorial optimization experimental algorithm design and analysis, computational learning theory, graph theory.
- Hardwick, M.**—Ph.D. (Bristol University, U.K.); database systems for product modeling and manufacturing applications.
- Luk, F.T.**—Ph.D. (Stanford University); numerical linear algebra, parallel computing, image and signal processing.
- Musser, D.**—Ph.D. (University of Wisconsin); programming methodology, generic software libraries, formal methods of specification and verification, automated theorem proving.
- Spooner, D.**—Ph.D. (Pennsylvania State University); engineering database systems, object-oriented systems, database security, database browsing, and visualization.
- Stewart, C.**—Ph.D. (University of Wisconsin); computer vision, medical applications, robust statistics, computational geometry.
- Szymanski, B.K.**—Ph.D. (National Academy of Sciences, Warsaw, Poland); computer network management, modeling and simulation of computer and biological systems, distributed computing and scientific parallel computation.
- Trinkle, J. C.**—Ph.D. (University of Pennsylvania); robot planning, manufacturing automation, scientific computation, multibody dynamics, computational topology, human-machine interaction.

### Research Professor

- Lawrence, C.**—Ph.D. (Cornell University); bioinformatics, transcription regulation, Bayesian statistics and Markov Chain Monte Carlo algorithms.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

**Associate Professors**

**Adali, S.**—Ph.D. (University of Maryland); multimedia database systems, information integration, query optimization.

**Krishnamoorthy, M.S.**—Ph.D. (Indian Institute of Technology); programming environments, design and analysis of combinatorial algorithms, performance issues in the Internet, analysis of Web documents, compiler design.

**Yener, B.**—Ph.D. (Columbia University); Systems research in data and communications networks; quality of service on the Internet; routing, access control, and security in mobile wireless networks, network design and optimization.

**Zaki, M.**—Ph.D. (University of Rochester); data mining and knowledge discovery in databases, parallel computing, bioinformatics.

**Research Associate Professor**

**Newberg, L.**—Ph.D. (University of California, Berkeley) Bioinformatics, computational modeling of complex systems.

**Assistant Professors**

**Akella, S.**—Ph.D. (Carnegie Mellon University); robotics, computer-aided manufacturing, geometric algorithms.

**Busch, C.**—Ph.D. (Brown University); distributed and parallel systems, communications networks.

**Carothers, C.**—Ph.D. (Georgia Institute of Technology); experimental distributed systems, simulation, wireless networks, computer architecture.

**Drineas, P.**—Ph.D. (Yale University); Randomized and approximation algorithms, linear algebra, information retrieval and data mining.

**Freedman, D.**—Ph.D. (Harvard University); computer vision, image processing, computational geometry, computational topology.

**Huang, W.**—Ph.D. (Carnegie Mellon University); robotic manipulation, mobile robotics, motion planning.

**Kettner, V.**—Ph.D. (Cornell University); computer vision, stochastic models.

**Magdon-Ismael, M.**—Ph.D. (California Institute of Technology); machine learning, computational finance, bioinformatics.

**Milanova, A.**—Ph.D. (Rutgers University) software engineering, programming languages, compilers, program analysis, software testing, verification, reliable software systems

**Varela, C.A.**—Ph.D. (University of Illinois at Urbana-Champaign); Internet computing, concurrent and distributed systems, programming languages, coordination models, mobile code, databases, the Web.

**Lecturer**

**Hollinger, D.L.**—M.S. (Rensselaer Polytechnic Institute); machine learning, AI applications for the World Wide Web, genetic algorithms, Web programming.

**Clinical Professor**

**Danchak, M.M.**—Ph.D. (Rensselaer Polytechnic Institute); human-computer interaction, usability, information visualization, techniques for distance learning and human learning models.

**Professor Emeritus**

**McNaughton, R.**—Ph.D. (Harvard University); automata theory, formal languages, combinatorics of words.

**Adjunct Faculty**

**Ingalls, R.**—Ph.D. (University of Connecticut); systems programming, network programming.

**Kotfila, D.**—M.Div. (Yale University) Director, Cisco Networking Academy.

**Joint Appointment with Mathematical Sciences—Professors**

**Isaacson, D.**—Ph.D. (New York University); applied mathematics, numerical analysis.

**McLaughlin, H.W., II**—Ph.D. (University of Maryland); analysis, differential equations, approximation theory.

**Joint Appointments with Electrical, Computer, and Systems Engineering—Professors**

**Gerhardt, L.A.**—Ph.D. (State University of New York, Buffalo); digital signal processing, communications, voice and image processing, pattern recognition, adaptive systems, computer integrated manufacturing, course development.

**Wozny, M.J.**—Ph.D. (University of Arizona); computer graphics, computer-aided design, digital simulation, rapid prototyping systems.

**Joint Appointments with Electrical, Computer, and Systems Engineering—Associate Professors**

**Franklin, W.R.**—Ph.D. (Harvard University); computational geometry, graphics and CAD algorithms and data structures, parallel algorithms, cartography, expert system verification and validation.

**Kalyanaraman, S.**—Ph.D. (Ohio State University); ATM and Internet traffic management, multimedia networking, IP telephony, performance analysis, Internet pricing.

**Joint Appointment with Mechanical, Aerospace, and Nuclear Engineering—Professor**

**Shephard, M.**—(Cornell University); scientific computation, mesh generation, adaptive and parallel finite element methods.

**Joint Appointment with Mechanical, Aerospace, and Nuclear Engineering—Associate Professor**

**Jansen, K.E.**—Ph.D. (Stanford University); large scale scientific computing with emphasis on fluid dynamics. Topics include turbulence modeling, finite element formulations, error estimation, design of software frameworks, parallel computing.

**Joint Appointment with Cognitive Science—Professor**

**Bringsjord, S.**—Ph.D. (Brown University); logic, philosophical logic, philosophy of artificial intelligence.

## Undergraduate Programs

The undergraduate degree program in computer science provides an excellent background for students entering the work force directly upon graduation and for those pursuing graduate studies. Students majoring in computer science may study such topics as artificial intelligence, computer graphics, theory of computation, operating systems, robotics, data mining, databases, network programming, parallel computing, and scientific numerical computing. A graduating computer science major should:

- be an expert software developer, with knowledge of several programming paradigms
- have a solid understanding of the mathematical/theoretical underpinnings of computer science
- be able to express himself/herself well both orally and in writing
- understand current computing technologies and be prepared to quickly adapt to new technological developments

## Baccalaureate Programs

All computer science students are assigned a faculty adviser to assist them with their interests and career goals throughout their academic career. As the typical 128-credit-hour B.S. curriculum leading the B.S. in computer science shown below exhibits, flexibility is a hallmark of the Rensselaer computer science program. Students may explore related areas such as mathematics, electrical engineering, computer engineering, management, and psychology.

### Computer Science Curriculum

#### First Year

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I .....	4	MATH-1020	Calculus II .....	4
CSCI-1100	Computer Science I * .....	4	CSCI-1200	Computer Science II .....	4
PHYS-1100	Physics I .....	4	MATH-2800	Intro. to Discrete Structures .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

#### Second Year

Fall		Credit hours	Spring		Credit hours
CSCI-2300	Data Struct. and Algorithms .....	4		Mathematics Option .....	4
CSCI-2500	Computer Organization .....	4	CSCI-2400	Models of Computation .....	4
BIOL-1010	Intro. to Biology .....	4		Hum. or Soc. Sci. Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Free Elective .....	4

#### Third Year

Fall		Credit hours	Spring		Credit hours
CSCI-4430	Programming Languages .....	4	CSCI-4210	Operating Systems .....	4
	Computer Science Option .....	4		Free Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
	Science Option .....	4		Free Elective .....	4

#### Fourth Year

Fall		Credit hours	Spring		Credit hours
CSCI-4440	Software Design and Doc. ....	4		Computer Science Option .....	4
	Computer Science Option .....	4		Free Elective .....	4
	Free Elective .....	4		Free Elective .....	4
	Free Elective .....	4		Free Elective .....	4

### Options

#### Science

A four-credit course chosen from the following: astronomy, biology, chemistry, earth and environmental science, and physics. The Pass/No Credit option cannot be used for this course. The course EARTH-1030 cannot be used to satisfy this requirement.

#### Computer Science

Eleven additional credit hours of computing courses at the 4000 or 6000 level. For this purpose, courses in the series CSCI-4xxx, CSCI-6xxx, ECSE-46xx, and ECSE-47xx may be used, excluding reading and independent study courses. The Pass/No Credit option cannot be used for these courses.

\* Students may skip CSCI-1100 and replace it with any other CS course.

### *Mathematics*

One additional mathematics course at the 2000 level or above. The Pass/No Credit option cannot be used for this course. Independent study courses cannot be used to satisfy this option.

### **Dual Major Programs**

Computer science students can obtain a dual major with any other major offered on the Rensselaer campus. In many cases, students can obtain a dual major within the 128 credits of a single degree, since many courses can be counted twice. Among the popular majors often combined with computer science are philosophy, mathematics, physics, management, Electronic Media Arts, and Communication, and engineering (the latter requires additional credits hours).

### **Minor Programs**

A computer science minor requires CSCI-1200, CSCI-2300, and three additional four-credit courses at the 2000 level or above. At least two of these must have a CSCI code and at least two must be at the 4000 or 6000 level. One course may be chosen from the ECSE-x6xx or ECSE-x7xx family. Courses required by name for the student's major cannot be used for the minor.

### **Accelerated Programs**

Students may be admitted to the graduate program in Computer Science when they are within 18 credits of completing their B.S. Students may be able to complete the B.S. and M.S. in a shorter than usual time by using advanced placement credit, taking courses during the summer, or taking extra courses during the academic year. A variety of joint degree programs can be arranged, depending on the student's background, interests, and desired rate of progress. Any joint degree program requires that the student apply to and be accepted to the graduate program.

### **Special Undergraduate Opportunities**

The Computer Science Department strongly encourages students to take part in the following special programs.

#### **Cooperative Education**

Numerous opportunities exist for computer science majors, and students are urged to pursue at least one co-op experience during their academic career. More detailed information on this program is available in the School of Science introduction section and the Educational Programs and Resources section of this catalog.

#### **Undergraduate Research Program**

This program allows students to participate in faculty research activities. The department urges students to take advantage of these opportunities, through which students can earn either pay or course credit. Additional benefits may include being named co-authors on journal papers or the opportunity to make presentations at professional conferences. Additional information is available in the School of Science introduction section and the Educational Programs and Resources section of this catalog.

#### **Cisco Networking Academy**

The Cisco Networking Academy provides extensive hands-on learning in networking. A lab of over 70 routers and switches simulates the backbone of the Internet and is always available for student use. The Academy prepares students for the following certifications: Cisco Certified Network Associate (CCNA), Cisco Certified Network Professional (CCNP), and Cisco Certified Internetwork Expert (CCIE).

## Graduate Programs

The Department of Computer Science offers M.S. and Ph.D. degrees in computer science. The department also offers a computer science M.S. and Ph.D. with a specialization in computational science, and a Ph.D. with specialization in computational molecular biology.

Applications for the M.S. or Ph.D. in computer science should be sent to the Graduate Admissions Office to be received no later than January 15 for fall admission; August 15 for spring admission. Applicants must provide transcripts, two letters of recommendation, a statement of goals, and GRE scores. Each student's background is expected to include courses in discrete mathematics, calculus, data structures, computer organization, and computing languages, none of which can be counted toward the graduate degree. Admission is extremely competitive, and meeting the minimum requirements does not assure admission.

### Master's Programs

#### M.S. in Computer Science

In addition to meeting the degree requirements of the Office of Graduate Education, a candidate must plan a degree program and complete the plan of study form in consultation with a faculty adviser. A degree program must include at least 30 credits, at least 18 of which must be at the 6000 level. It must include two required courses, CSCI-6050 (can be replaced by CSCI-6480) and CSCI-4210 (can be replaced by CSCI-6140). At least two courses must be taken from the computer systems area, and at least one course must be taken from computer theory area and one course from the computer applications area. Finally, it must include a master's thesis and regular attendance at department colloquia.

#### M.S. in Computer Science Specializing in Computational Science and Engineering

Applicants apply to this program in the usual manner. However, student backgrounds are expected to include courses in calculus, elementary linear algebra, elementary differential equations, discrete mathematics, data structures, and numerical computing. Courses in computer organization and computing languages are recommended. Students lacking some of this material may be admitted but will be expected to acquire this knowledge during their studies. This may require taking courses beyond the normal degree requirements.

Students must complete a plan of study that includes 30 credits at the 4000 and 6000 levels with 1) at least six credits in numerical analysis and/or scientific computation; 2) at least eight credits in an area of natural science or engineering; 3) at least one course in each of software and hardware systems; and 4) a significant (three to four credit) software project. At least 18 credits must be at the 6000 level and students should attend the computer science colloquium and the scientific computation seminars.

Students interested in further study within this area should refer to the Ph.D. in Computer Science Specializing in Computational Science and Engineering below.

### Doctoral Programs

#### Ph.D. in Computer Science

Students must demonstrate skill using computational tools and high achievement in scholarship and independent research. During the first year, the student focuses on obtaining a breadth of knowledge in computer science. By the end of the first year, the student must pass a doctoral qualifying examination. This examination covers the material of five courses: CSCI-6050, CSCI-4020, CSCI-6140, CSCI-4250, and CSCI-4430.

The second year is devoted to research exploration and selection of a doctoral committee. By the end of the second year, the student must pass a research qualifying exam demonstrating breadth of knowledge in their research area.

In the third year, the student develops a detailed understanding of the chosen research area and prepares a research proposal. The student must pass an oral candidacy exam by the end of the third year. The candidacy exam is an oral exam focusing on a thesis proposal and administered by the student's doctoral committee. The student begins by presenting the thesis proposal and then is questioned by the committee.

In addition to the above requirements, the student must earn a total of 90 credits beyond the bachelor's level. Between 45 and 60 credits must be course credits. The remaining credits are for dissertation research. All students must have courses in three of the following four areas on their undergraduate or graduate transcript: database systems, artificial intelligence, numerical computing, and computer graphics/user interfaces. In addition, all doctoral students must have had at least three courses in mathematics at the junior/senior level, and they must demonstrate programming ability on a substantial programming project. The area requirements, the mathematics requirement, and the programming requirement can be satisfied by course work completed prior to entering the Ph.D. program. Finally, all doctoral students are expected to have presented at least two public lectures on their research prior to their defense.

#### **Ph.D. in Computer Science Specializing in Computational Science and Engineering**

Students must complete 90 credits of course work and research beyond the B.S. degree, with at least 45 credits in formal course work. They must take 1) at least 12 credits in an area of natural science or engineering; 2) at least nine credits in numerical analysis and/or scientific computation; and 3) at least one course in software systems, hardware systems, and visualization. They must further demonstrate mathematical sophistication by having taken at least eight credits of 4000- or 6000-level mathematics courses (exclusive of numerical analysis) and programming ability by having done a substantial software project.

After one year of study, students must pass a qualifying examination in 1) numerical computing (material equivalent to CSCI-4800), 2) software and hardware systems (material equivalent to CSCI-4020, CSCI-4250, and CSCI-4430), and 3) a scientific or engineering field of specialization.

By the end of the second year the student must pass a research qualifying exam demonstrating breadth of knowledge in their research area. After their third year of graduate study, students are expected to pass an oral candidacy examination that focuses on their research. Subsequent to passing this examination, students must present two public lectures on their research and write and defend a dissertation.

Doctoral course requirements are inclusive of those for the M.S. degree. As with the M.S. degree, applicants apply in the usual manner, but should have backgrounds including courses in calculus, elementary linear algebra, elementary differential equations, discrete mathematics, datastructures, and numerical computing. Courses in computer organization and computing languages are recommended. The mathematical and programming proficiency requirements can be satisfied by work done outside of the Ph.D. degree program.

#### **Ph.D. in Computer Science with a Specialization in Computational Molecular Biology**

The completion of the human genome sequence and related genome resources has revolutionized biology and the biomedical sciences. As a result a great demand for individuals skilled in analyzing genomic data and in developing associated algorithms and database has developed. While the pharmaceutical and biotech industries were the first to begin hiring individuals with this background, the demand from academic institutions subsequently blossomed. To help meet this demand, the Computer Science Department offers a Doctor of Philosophy degree in Computer Science with a specialization in Computational Molecular Biology. This program is a Computer Science degree program with strong cross-disciplinary training in molecular biology / biochemistry, probability and statistics, and bioinformatics. Students will conduct their research and classroom activities under the direction of Computer Science faculty and faculty in other departments.

**Admission:** Students apply to the Computer Science Department in the usual manner. Student backgrounds are expected to include courses in calculus, elementary linear algebra, higher-level computer languages, algorithms & data structures, introductory organic chemistry (CHEM-2210 or equivalent), and introductory biology. Students lacking some of this material may be admitted but will be expected to acquire this knowledge during their studies. This may require taking courses beyond the normal degree requirements.

**Doctor of Philosophy:** Students must complete 90 credits of course work and research beyond the B.S. Degree, with at least 45 credits in formal course work. They must take (1) at least 12 credits in molecular or cell biology / biochemistry, (2) at least nine credits in probability, statistics, machine learning and bioinformatics, and (3) at least 12 credits in Computer Science including at least one course each in software systems, theory of computation, and applications (in addition to courses covered on the qualifying exam, database systems, computational molecular biology, and data mining courses are recommended). They must further demonstrate programming ability by having done a substantial software project.

After one year of study, students must pass an oral qualifying examination in (1) probability and statistics (material equivalent to Course MATP-4600), (2) Computer Science (material equivalent to courses CSCI-4020 Computer Algorithms, and CSCI-4430 Programming Languages, CSCI-6050 Computability, and Complexity), (3) and biochemistry I (BCBP-4760) or molecular biology (BIOL-4620).

By the end of the second year the student must pass a research qualifying exam demonstrating breadth of knowledge in their research area. After their third year of graduate study, students are expected to pass an oral candidacy examination that focuses on their research. Subsequent to passing this examination, students must present at least two public lectures on their research and write and defend a dissertation.

The probability and statistics, programming proficiency, and molecular biology/biochemistry requirement can be satisfied by work done outside of the Ph.D. degree program.

## Course Descriptions

Courses directly related to all Computer Science curricula are described in the Course Description section of this catalog under the department code CSCI.

## Earth and Environmental Sciences

**Chair:** Frank Spear

**Department Home Page:** <http://www.rpi.edu/dept/geo>

Over the past few decades, the earth sciences have undergone major changes. Primarily stimulating these changes have been the reinterpretation of Earth history and processes with regard to plate tectonics, along with the more recent challenges of local, regional, and global environmental problems. Highly cognizant of these changes, Rensselaer's instruction in modern earth science is wide ranging and offers many courses and opportunities for individual study.

At Rensselaer, students learn about the Earth using techniques ranging from seismological and satellite-tracking investigations of crustal motions to state-of-the-art geochemical instruments. The latest techniques for simulating Earth processes include high-pressure experimentation and computer modeling. A broad choice of courses is available, ranging from quantitative, computer-oriented aspects of the geological to field experience and geochemical approaches. The program includes the study of the

Earth's component materials, the development of its structures and surface features, the processes by which these change with time, and the origin, discovery, and protection of its resources—water, fuels, and minerals.

The Troy area is well situated for field-based study of problems in hard-rock and surficial geology, as well as ground and surface water science. The department enjoys fruitful relationships with nearby university, industrial, and government geoscience groups within 10 miles of the campus. All students have access to these resources as well as to the laboratory and computer facilities of the Institute, which has a strong commitment to education and research in science and engineering.

There are numerous opportunities for students to engage in field-oriented projects. In addition, students may obtain summer employment with oil, geological engineering, or hydrologic consulting companies, or they may participate in a Rensselaer faculty member's field-oriented research project.

## Research Innovations and Initiatives

The diverse interests of the Earth and Environmental Sciences faculty lead to a wide variety of projects that stimulate educational programs at both the graduate and undergraduate levels. Undergraduate students are encouraged to enroll in the Undergraduate Research Program (URP), which involves them in front-line research for credit or pay. Graduate students pursue specialized study in consultation with their faculty advisers, whose research interests are matched on an individual basis.

### Geochemistry and Petrology

Ongoing studies in geochemistry include the distribution of trace elements between minerals in metamorphic and igneous systems, the physics and chemistry of fluids transport in the crust and mantle, experimental studies of chemical reactions and transport deep in the Earth, and accessory minerals as geochronometers. The tectonic evolution of mountain belts is being investigated through the examination of metamorphic rocks in diverse regions such as New England, the Adirondacks, the Alps, and British Columbia.

### Geophysics

Research in geophysics includes field studies of the seismology and tectonics of Asia, Indonesia, the western U.S., and the southwestern Pacific. Using the Global Positioning System (GPS), plate motions and earthquake strains are monitored and computer models of plate motions and faulting are developed. Seismic tomography is used to reveal deep structures of the lithosphere and mountain belts. Seismic, magnetic, geodetic, and gravity methods are used to probe local structures, including ancient faults and hydrologic conduits.

### Hydrogeology and Environmental Geochemistry

Ongoing research includes investigations of organic pollutant transport, dispersion, and degradation in surface and groundwater. Also under way are studies of heavy-metal-contamination histories of local water bodies, development of methods for tracing and predicting contaminant behavior, and the use of stable isotopes as fingerprints and traces of environmental contamination.

### Research Facilities

Students have access to the department's electron microprobe, gamma spectrometer, gas chromatographs, spectrophotometers, differential thermal apparatus, gravimeter, magnetometer, 12-channel seismograph, electrical resistivity equipment, GPS receivers, and seismograph stations. Also available are X-ray diffraction and fluorescence equipment, atomic absorption and optical emission spectrometers, and scanning electron microscopes as well as two isotope ratio mass spectrometers with dual microinlet, an

elemental analyzer, and gas chromatographic sample introduction systems for continuous flow and compound-specific analyses. PCs, Macs, and Unix workstations in the department are linked to the Institute's computer network

## Faculty\*

### Institute Professor

**Watson, E.B.**—Ph.D. (Massachusetts Institute of Technology); experimental geochemistry and petrology.

### Professors

**Abrajano, T.A.**—Ph.D. (Washington University); isotope and environmental geochemistry.

**McCaffrey, R.**—Ph.D. (University of California, Santa Cruz); tectonics, seismology, geodesy.

**Roecker, S.**—Ph.D. (Massachusetts Institute of Technology); geophysics, seismology, and geodesy.

**Spear, F.S.**—Ph.D. (University of California, Los Angeles); petrology, geochemistry.

### Associate Professor

**Bopp, R.F.**—Ph.D. (Columbia University); environmental geochemistry.

**Sharma, A.**—Ph.D. (SUNY Binghamton); experimental biogeochemistry, mineral-microbe-third interaction

### Professors Emeriti

**Bayly, M.B.**—Ph.D. (University of Chicago); structural geology, rheological properties of earth materials.

**Friedman, G.M.**—Ph.D. (Columbia University); D.Sc. (University of London); sedimentology.

**Gaffey, M.J.**—Ph.D. (Massachusetts Institute of Technology); planetary science.

**Katz, S.**—Ph.D. (Columbia University); seismology, geophysics.

**LaFleur, R.G.**—Ph.D. (Rensselaer Polytechnic Institute); geomorphology, glacial geology, water resources.

**Miller, D.S.**—Ph.D. (Columbia University); geochemistry, isotope geology, fission track research.

### Research Associate Professors

**Cherniak, D.**—Ph.D. (University at Albany); geochemical kinetics.

**Wark, D.A.**—Ph.D. (University of Texas, Austin); igneous petrology, volcanology.

### Research Assistant Professor

**Shuster, E.**—Ph.D. (Rensselaer Polytechnic Institute); environmental geology, hydrogeology.

### Research Scientists

**Price, J.**—Ph.D. (Oklahoma University); experimental petrology.

**Pyle, J.**—Ph.D. (Rensselaer Polytechnic Institute); metamorphic petrology, trace element geochemistry.

**Williams, C.**—Ph.D. (University of Arizona); geophysics, tectonics.

## Undergraduate Programs

The undergraduate curricula are flexible so that students may work in interdisciplinary areas while maintaining emphasis in earth and environmental sciences. Students are encouraged to take electives in their field of interest, including some outside the department. These should form a coherent group and be approved by their adviser. Students are encouraged to use the flexibility available to their own advantage. The department adviser will consult with each student individually to arrange an optimal program in geology, hydrogeology, geochemistry, geophysics, or environmental geoscience.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

Students transferring from other curricula can graduate with their class provided that they enter the department by the beginning of the third year and that they have maintained satisfactory grades in their first two years.

### Baccalaureate Programs

Each of the programs shown below require a total of 124 credit hours. The first program leads to a B.S. in Geology and the second to a B.S. in Hydrogeology.

#### Geology Curriculum

##### First Year

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I .....	4	MATH-1020	Calculus II .....	4
CHEM-1100	Chemistry I .....	4	CHEM-1200	Chemistry II .....	4
ERTH-1100	Geology I .....	4	ERTH-1200	Geology II .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

##### Second Year

Fall		Credit hours	Spring		Credit hours
MATH-2010	Multivar. Calc. and Matrix Algebra ..	4	ERTH-2140	Introduction to Geochemistry .....	4
PHYS-1100	Physics I .....	4	PHYS-1200	Physics II .....	4
ERTH-2330	Earth Materials .....	4		Biology Requirement* .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

##### Third Year

Fall		Credit hours	Spring		Credit hours
ERTH-2210	Field Methods .....	2	ERTH-2100	Introduction to Geophysics.....	4
ERTH-2120	Structural Geology .....	4		Elective .....	4
ERTH-4xxx	Geology Group Option .....	4	ERTH-4xxx	Geology Group Option .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
	Elective .....	2-4			

##### Fourth Year

Fall		Credit hours	Spring		Credit hours
ERTH-xxxx	Electives .....	16		Culminating Experience .....	3-4
				Elective.....	10-11

#### Geology Group options (Two courses from the following group)

ERTH-4190	Environmental Measurements
ERTH-4340	Igneous and Metamorphic Petrology
ERTH-4540	Organic Geochemistry
ERTH-4690	Aqueous Geochemistry
ERTH-4650	Seismology
ERTH-4710	Groundwater Hydrology
ERTH-4750	Geographic Information Systems in the Sciences

#### Culminating Experience

ERTH-4970	Out of Classroom Experience in Earth Science
ERTH-4980	Senior Field Thesis
	Undergraduate Research Program (URP)

\* Biology Requirement: BIOL-1010 if taken in the second year, but may be BIOL-4320 if taken in the third or fourth year.

## Electives

The following are recommended as electives for the geology curriculum:

BIOL-4850	Principles of Ecology
CHEM-2210	Organic Compounds and Reactions
CHEM-4450	Macroscopic Physical Chemistry
CIVL-2630	Introduction to Geotechnical Engineering
CIVL-4150	Soil Mechanics
ENVE-4310	Applied Hydrology and Hydraulics
MATH-2400	Introduction to Differential Equations
MATH-4600	Advanced Calculus
MATH-4700	Foundations of Applied Mathematics
MATH-4800	Numerical Computing
MATH-4820	Introduction to Numerical Methods for Differential Equations
MTLE-2020	Introduction to Ceramic Materials
MTLE-4100	Thermodynamics of Materials
WRIT-4120	Technical and Professional Communication

## Hydrogeology Curriculum

### First Year

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I .....	4	MATH-1020	Calculus II .....	4
CHEM-1100	Chemistry I .....	4	CHEM-1200	Chemistry II .....	4
ERTH-1100	Geology I .....	4	ERTH-1200	Geology II .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
MATH-2010	Multivar. Calc. and Matrix Algebra ..	4	MATH-2400	Differential Equations .....	4
PHYS-1100	Physics I .....	4	PHYS-1200	Physics II .....	4
CSCI-xxxx	Computer Science Elective .....	4		Biology Requirement* .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Third Year

Fall		Credit hours	Spring		Credit hours
ERTH-2210	Field Methods .....	2	ERTH-2140	Intro. to Geochemistry .....	4
ERTH-2120	Structural Geology .....	4		Elective .....	4
	Elective .....	2-4		Elective .....	4
	Hum. or Soc. Sci. Electives .....	4		Hum. or Soc. Sci. Elective .....	4

### Fourth Year

Fall		Credit hours	Spring		Credit hours
ERTH-4710	Groundwater Hydrology .....	4		Culminating Experience .....	3-4
ENVE-2110	Intro. to Environmental Engr. ....	4		Electives .....	10-11
ERTH-4190	Environmental Measurements .....	4			
	Elective .....	4			

\* Biology Requirement: BIOL-1010 if taken in the second year, but may be BIOL-4320 if taken in the third or fourth year.

### Electives

A total of 30 credit hours of free electives is required. These electives should be designed to provide a depth of understanding in a subdiscipline of hydrogeology (e.g., geology, mathematics, chemistry, physics, biology, computer science, engineering, etc.). A limited list of suggested courses for free electives includes the following:

ERTH-2100	Introduction to Geophysics	CHEM-4810	Chemistry of the Environment
ERTH-4070	Sedimentology	CIVL-4240	Finite Element Methods
ERTH-4540	Organic Geochemistry	CSCI-1200	Computer Science II
ERTH-4690	Aqueous Geochemistry	DSES-4140	Statistical Analysis I
BIOL-4320	Geomicrobiology	DSES-6110	Introduction to Applied Statistics
BIOL-4620	Molecular Biology	ECSE-4510	Discrete Time Systems
BIOL-4700	Fresh Water Ecology Laboratory	ENVE-4220	Environmental Law
CHEM-2210	Organic Compounds and Reactions	MATP-4600	Probability Theory and Applications
CHEM-2220	Organic Synthesis	MATP-4700	Math. Models of Operations Research
CHEM-4450	Macroscopic Physical Chemistry	PHYS-2350	Experimental Physics
CHEM-4460	Microscopic Physical Chemistry		

### Minor Programs

The department offers opportunities to minor in the following:

#### Geology

Students not majoring in geology may take a minor by completing from the EARTH group at least 16 credit hours, eight of which should be at the 4000 level. EARTH-1030 and 1040 (Natural Sciences) do not count towards the minor.

#### Astrobiology

The Earth and Environmental Sciences Department participates in a multidisciplinary minor in astrobiology for students majoring in geology or other disciplines. To complete this minor, students must take a minimum of 16 credits of course work in this field. These courses include ASTR-4510 and ISCI-4500, four credits each, and two semesters of the one-credit course ISCI-4510. A further two courses outside the major field of study are also required, selected from the following:

ASTR-2050	Intro. to Astr. and Astrophysics	BIOL-4760	Molecular Biochemistry I
BCBP-4810	Biological Spectroscopy	CHEM-2250	Organic Chemistry I
BCBP-4860	Protein and Nucleic Acid Structure	CHEM-4810	Chemistry of the Environment
BIOL-4320	Geomicrobiology	ENVE-2110	Intro. to Environmental Engineering
BIOL-4440	Microbial Ecology	ERTH-4070	Sedimentology
BIOL-4620	Molecular Biology	ERTH-4540	Organic Geochemistry

The requirement that two selected courses must be outside of the major field of study is reduced to one in the case of a dual major, provided that both majors are in the primary relevant areas of study (i.e., biology, chemistry, geology, and physics).

#### Hydrogeology

Students not majoring in hydrogeology may take a minor by taking EARTH-4710, EARTH-4180, and electing from the EARTH group at least two additional courses except for EARTH-1030 and EARTH-1040).

#### Interschool Minor in Energy

Students interested in developing a broad, multidisciplinary background in energy to complement their more focused major program should consider this minor. See the Interdisciplinary Programs and Research Section of the School of Humanities and Social Sciences portion of this catalog for details.

## Accelerated Programs

An accelerated program with emphasis in geophysics is available for students interested in combining a B.S. and an M.S. in geology. Students interested in developing an accelerated course of study in this or another area of geological sciences should consult their advisers.

## Special Undergraduate Opportunities

The department has several unique educational opportunities that are detailed below.

### Out-of-Classroom Experience

In consultation with his or her adviser, each hydrogeology student may select and engage in an out-of-classroom experience for up to four hours of course credit. The experience should have intellectual content relevant to the student's educational or career goals. Envisioned as a summer activity, this experience usually occurs after the sophomore or junior year, although it could also occur during the fall or spring terms.

Appropriate experiences might include an individual or group research project (on or off campus), an independent study project, a co-op assignment, a public service internship, or study abroad. A written proposal and a final written report submitted for evaluation to the Earth and Environmental Sciences Department Undergraduate Curriculum Committee is required.

### Environmental Science Concentration

The environmental science degree program is offered to students with an interest in a broad interdisciplinary degree directed toward understanding and finding solutions for the environmental challenges that face modern civilization. The environmental science degree has a core science requirement of 38 credit hours (10 courses). The student then selects from one of several concentration areas, one of which is geology.

### Environmental Studies Program

Building on the unusual strength and breadth of Rensselaer's synthesis of engineering, science, and the humanities and social sciences, the Environmental Studies Program offers students a unique educational opportunity to develop a truly multidisciplinary approach to environmental studies.

Participating students take a broad range of basic courses in their first two years and then choose one of five majors: economics (with a concentration in a specific area of science), hydrogeology, science, technology, and society (with an environmental focus). To complement their major program, students may earn a wide variety of minors. All the majors in the program offer their own environmental minors, and the Schools of Architecture and Management offer special environmental courses as well. Graduates of the Environmental Studies Program will not be narrow specialists; they will receive the kind of multidisciplinary education that is required to address environmental problems.

See Interdisciplinary Programs and Research in the School of Humanities and Social Studies for a complete description of the program.

## Graduate Programs

Research programs leading to the M.S. and Ph.D. degrees are available in geochemistry, geophysics, hydrogeology, and igneous and metamorphic petrology. Interdisciplinary research takes place with other groups, including the Darrin Fresh Water Institute and the Departments of Biology, Physics, Civil and Environmental Engineering, and Materials Science and Engineering. Recently the department has been involved in the interdisciplinary Origins of Life initiative. Applicants to degree programs must arrange for

their Graduate Record Examination (GRE) general test scores to be sent to the department. Those who cannot take the test because of illness, residence overseas, etc., should attach explanations to their applications.

### **Master's Programs**

The department offers M.S. degrees in geology and hydrogeology and a professional master's degree in applied groundwater science.

Candidates for the M.S. degrees in geology and hydrogeology must complete 30 hours of graduate study based on an approved plan of study. A thesis based on original research is usually submitted. This requirement may be waived at the discretion of the candidate's adviser.

For the professional master's degree in applied groundwater science, candidates must also complete 30 credit hours of graduate study based on an approved plan of study. However, no thesis is required.

### **Doctoral Programs**

Candidates for the Ph.D. degree must fulfill the requirements of the Office of Graduate Education. Evidence of success in graduate-level study and research must be shown. There is no language requirement.

## **Course Descriptions**

Courses directly related to all Earth and Environmental Sciences curricula are described in the Course Description section of this catalog under the department code EARTH.

## **Mathematical Sciences**

**Chair:** Donald Drew

**Chair of the Graduate Committee:** Victor Roytburd

**Departmental Home Page:** <http://www.math.rpi.edu/index.html>

Through the centuries, mathematics has been a central feature of our intellectual and technological development. Today its role in the physical sciences and engineering is well established. Its role in the life and social sciences, medicine, management, and the arts is undergoing remarkable growth—a virtual mathematization of the culture. The Department of Mathematical Sciences is directly engaged in this process through its educational and research programs. Our focus is the study and development of mathematical and computational methods and their application to problems of contemporary significance to our society.

The Department of Mathematical Sciences provides an in-depth education in both the foundations of mathematical thought as well in the applications of mathematics to real-life phenomena. For this reason, we offer a baccalaureate degree with a specialization in mathematics, applied mathematics, mathematics of computation, or operations research. The department's programs are also designed to provide a broad spectrum of opportunities for students. This flexibility allows students and advisers to tailor programs to individual objectives and talents. As a result, the curricula are equally advantageous for individuals who will seek immediate employment upon graduation, for those who plan graduate-level education in the mathematical sciences, and for those who will apply their education to pursuits outside the mathematical arena. Our graduates have entered careers in law, medicine, engineering, management, and psychology, as well as in pure and applied mathematics, computer science, and operations research.

At the graduate level, Rensselaer is especially well-known as a center for advanced study and research in applied mathematics. The department's M.S. and Ph.D. programs emphasize:

- Methods of applied mathematics, including ordinary and partial differential equations, approximation theory, asymptotic analysis, functional analysis, and numerical analysis;
- Applications in the physical sciences, biological sciences, and engineering;
- Scientific computing;
- Mathematical programming, including nonlinear, combinatorial, and multiple objective optimization and their applications.

At the highest level, continual interplay between the construction of the mathematical model and the solution of the resulting mathematical problem characterizes applied mathematics. The ideal applied mathematician, therefore, must be knowledgeable both in mathematics and in at least one field in which problem areas are found. A sound knowledge of the application area assists in constructing suitable models, and a high level of mathematical judgment and expertise may be required to solve the resulting mathematical problems.

## Research Innovations and Initiatives

Faculty research activities in the Department of Mathematical Sciences center on applied mathematics, analysis, scientific computing, mathematical programming, and operations research. The faculty's interest in applied research often leads to a synthesis of techniques from two or more research areas. Further, the formulation, solution, and interpretation of a problem often contain ideas that can be applied to problems in other areas. Focusing different research areas on real problems and the diversity of applications of real problem solutions creates an atmosphere of interaction and cooperation within the department and the university, as well as with other major research institutions.

### Numerical Analysis and Scientific Computation

Investigations range from the study of fundamental problems in linear algebra to the development and analysis of numerical schemes for solving particular physical or life science problems. Research activities include the numerical solution of optimization problems, inverse eigenvalue problems, and free-boundary problems; finite difference and finite element methods for stiff initial and boundary-value problems; and methods of resolving problems involving composite materials. Applications of these studies include reacting flows, shockwave propagation, semiconductor performance, biomathematics, acoustic signal propagation, and incompressible flow in various geometries.

### Inverse Problems

This research involves the recovery of internal biological, mechanical, electric, or magnetic properties of a system from boundary, spectral, or scattering data. The physical system is modeled by a partial differential or ordinary differential equation with specific unknown terms representing, for example, stiffness in an elastic system or electric permittivity in an electromagnetic system. The goal of this work is to find the unknown properties from indirect measurements. Rensselaer has established a center for Inverse Problems at RPI. Current research applies functional analysis, perturbation theory, numerical analysis, and optimization to determine optimal datasets, to study the nonlinear dependence of the unknown physical quantities on the available data, and to obtain approximations of the nonlinear operators that will yield efficient reconstruction algorithms. There is a significant role for modeling, analysis, scientific computation, and algorithm development to obtain solutions to these problems.

### **Dynamical Systems**

This research concentrates on the theory of dynamical systems and its applications in physics and engineering. Dynamical systems arise as mathematical models in various applications such as mechanics, optics, electric circuits, solid-state physics, fluid dynamics, optimal control, neural science and other fields. This research aims to discover and explain new and important phenomena found in experimental and numerical studies. Often involved is modeling a real-life problem by a dynamical system and then applying the ideas and methods of the theory to explain and predict complex behavior. Theoretical research is conducted in chaotic dynamics, Hamiltonian systems (KAM theory and applications, theoretical mechanics), bifurcation theory, and related fields. Mathematical methods used come from analysis, topology, differential geometry, combinatorics, and other fields. Computation may be used as an experimental tool.

### **Wave Propagation**

These studies focus on the behavior of acoustic wave propagation. A major area of interest is underwater sound transmissions. Mathematical models are being developed and analyzed to describe the influences of ocean environmental features (such as internal waves and sediment variations) on the study of the propagation of signals in both frequency and time domains, and to improve the accuracy of known numerical methods. Improved numerical and asymptotic methods are derived and tested, providing new ways to extract information from complex propagation environments. Stochastic propagation effects are modeled and analyzed, and results are used to explain variability observed by ocean scientists. Results are extended and applied to acoustic propagation environments ranging from the atmospheres of Jupiter and the Earth to the upper layer of the Earth's crust.

### **Mathematical Programming and Operations Research**

Mathematical programming endeavors to find optimal solutions for a broad range of problems including medical, financial, scientific, and engineering problems. Research is conducted on the development, evaluation, and comparison of serial and parallel algorithms for a variety of mathematical programming problems. Current research topics include interior point methods for linear, integer, and nonlinear programming; branch-and-bound and branch-and-cut approaches to integer programming problems; column generation methods; financial optimization; and genetic algorithms and tabu search. Also under investigation are mathematical programming approaches to problems in artificial intelligence such as machine learning, neural networks, support vector machines, pattern recognition, and planning. This research also considers combining operations research and artificial intelligence problem-solving methods, scalability of these methods to large problems in data mining, mathematical programming approaches to other areas in computer science such as database query optimization, and stochastic programming.

### **Biomathematics**

Mathematical biology is a very active area of applied mathematical research. This is an interdisciplinary endeavor, with a strong interaction with biological and biomedical scientists. Projects of current interest include cardiac imaging and the use of computer graphics to construct pictures of the heart, mechanoreception, mathematical modeling of biological systems that transform mechanical stimuli (e.g., sound, touch, etc.) into ionic or neural signals and molecular systems in cells. Also being studied are nonlinear ionic diffusion in polyelectrolytic gels and the mechanics of multiphasic tissues like cartilage and the cornea. Numerical analysis, asymptotics, and functional analysis are used to investigate mathematically posed problems resulting from the models.

**Fluid Mechanics**

Methods of applied mathematics are being used to study how fluids behave under a wide spectrum of conditions. The physical problems usually lead to partial differential equations, which may be linear or nonlinear. Current problems deal with fluid mechanics in engineering systems, the flow and stability of two-phase mixtures, the transition from laminar to turbulent flow in boundary layers, fluid mechanical models of atmospheric events and the theory of flow in a gas centrifuge. Studies also include the evolution of non-Newtonian (e.g., polymer) fluid flow.

**Combustion Theory**

Investigations include mathematical modeling of combustion and flame propagation phenomena, and analysis of the resulting systems of nonlinear ordinary and partial differential equations. Topics of current interest are bifurcation and stability of reactive systems, evolution and interaction of waves in reactive gases, combustion and vortex breakdown in swirling flows, and transition from deflagration to detonation in granular explosives.

**Applied Geometry**

Included are problems dealing with surface design, curve design, robot path planning, packing, tiling, computational geometry, and artificial intelligence as it applies to geometry. Students take advantage of related courses in electrical engineering, mechanical engineering, computer science, and mathematics.

**Approximation Theory**

This branch of mathematics strives to understand the fundamental limits in optimally representing different signal types. "Signals" here may mean a database of digital audio signal, a collection of digital mammograms, solutions of a class of integral equations, or triangulated compact surfaces acquired by a 3-D scanner. These signals are typically modeled mathematically based on their intrinsic smoothness or oscillatory characteristics. Current research effort involves the design and analysis of various multiresolution techniques that have provable optimality properties for these models. Such optimal representations are invariably the key ingredients to successful data compression, estimation, and computer-aided geometric design. Exploited tools range from mathematical analysis (e.g., Littlewood-Paley theory) to fast numerical algorithms, to information theory, to algebraic and differential geometry, and to spline and subdivision theory.

**Complex Systems**

This includes an investigation into nonlinear phenomena that arise in such diverse areas as semiconductor laser theory, nonlinear and fiber optics, surface water waves, acoustic waves and gas lasers. Although these topics are seemingly disconnected and have different physical characteristics, they all can be viewed as complex systems composed out of interacting particles or waves. There is a general theoretical framework for their description called weak turbulence theory. The research in this area involves development of weak turbulence theory and how to use this theory to study complex systems.

**Bioinformatics**

The massive volume of new data being produced by genome sequencing projects point to an increasing need for bioinformatics. This is a highly interdisciplinary field, involving faculty in mathematical sciences, biology, computer science, chemistry and several departments in the school of engineering. Rensselaer has established a joint bioinformatics center with the nearby Wadsworth Laboratories in the New York state Department of Public Health. Current activities at Rensselaer comprise the development and application of algorithms that aim to solve biological problems using DNA and amino acid sequence, structure, and related information. Some of the problems addressed are the search for patterns in biomolecular sequences

that are functionally important, such as transcription binding sites; the prediction of structure or function from nucleic acid or protein sequence data; the development of methods and databases to classify large amounts of biological information, and the development of algorithms and software that are important for current biotechnology applications.

## Faculty\*

### Professors

- Boyce, W.E.**—Ph.D. (Carnegie Institute of Technology); applied mathematics, mathematics education (emeritus).
- Cheney, M.**—Ph.D. (Indiana University); inverse problems, wave propagation, applications in engineering and biology, partial differential equations.
- Drew, D.A.**—Ph.D. (Rensselaer Polytechnic Institute); applied mathematics, fluid mechanics, mathematical biology.
- Ecker, J.G.**—Ph.D. (University of Michigan); mathematical programming, multiobjective programming, geometric programming, mathematical programming applications, ellipsoid algorithms.
- Fleishman, B.A.**—Ph.D. (New York University); nonlinear differential equations, mathematics education (emeritus).
- Habetler, G.J.**—(Carnegie Institute of Technology); functional analysis, numerical analysis (emeritus).
- Handelman, G.H.**—Ph.D. (Brown University); applied mathematics, elasticity, wave propagation, mathematical biology (emeritus).
- Herron, I.**—Ph.D. (Johns Hopkins University); applied mathematics, fluid mechanics, hydrodynamics, stability.
- Holmes, M.**—Ph.D. (University of California, Los Angeles); perturbation methods, biomathematics, nonlinear continuum mechanics.
- Isaacson, D.**—Ph.D. (New York University); mathematical physics, biomedical applications.
- Jacobson, M.J.**—Ph.D. (Carnegie Institute of Technology); applied mathematics, acoustic and electromagnetic wave propagation (emeritus).
- Kapila, A.**—Ph.D. (Cornell University); applied mathematics, combustion, fluid mechanics.
- Lim, C.C.**—Ph.D. (Brown University); mathematical modeling, vortex dynamics, applications of graph theory.
- McLaughlin, H.W.**—Ph.D. (University of Maryland); applied geometry.
- McLaughlin, J.R.**—Ph.D. (University of California, Riverside); inverse bioelasticity problems, inverse vibration and inverse scattering problems, wave propagation, analysis, applied mathematics.
- Mitchell, J.E.**—Ph.D. (Cornell University); mathematical programming, integer programming, interior point methods, column generation methods, financial optimization, stochastic programming.
- Pang, J.S.**—Ph.D. (Stanford University); applied and computational mathematics, mathematical programming, variational inequality and complementarity problems, contact problems, computation of equilibria, financial options pricing, financial optimization, optimal design problems, energy modeling.
- Roytburd, V.**—Ph.D. (University of California, Berkeley); applied mathematics, combustion theory.
- Rubinfeld, L.A.**—Ph.D. (New York University); applied mathematics, mathematics, science education.
- Siegmann, W.L.**—Ph.D. (Massachusetts Institute of Technology); applied mathematics, wave propagation.
- Zuker, M.**—Ph.D. (Massachusetts Institute of Technology); bioinformatics.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

### Associate Professors

**Bennett, K.P.**—Ph.D. (University of Wisconsin); mathematical programming, operations research, machine learning, data mining, artificial intelligence.

**Kovacic, G.**—Ph.D. (California Institute of Technology); applied mathematics, nonlinear dynamics, nonlinear optics.

**Piper, B.R.**—Ph.D. (University of Utah); computer-aided geometric design, numerical analysis, computer graphics.

**Schwendeman, D.W.**—Ph.D. (California Institute of Technology); applied mathematics, scientific computing.

### Assistant Professors

**Giladi, E.**—Ph.D. (Stanford University); scientific computing, numerical methods for high frequency wave propagation, finite element methods, iterative methods, numerical analysis.

**Kramer, P.R.**—Ph.D. (Princeton University); turbulent diffusion, stochastic processes.

**Lvov, Y.**—Ph.D. (University of Arizona); mathematical physics and nonlinear phenomena.

**Yu, T.P.-Y.**—Ph.D. (Stanford University); wavelets and applications in signal and image reconstruction.

### Clinical Assistant Professors

**Kiehl, M.**—Ph.D. (Rensselaer Polytechnic Institute); biomathematics.

**Schmidt, D.A.**—Ph.D. (Rensselaer Polytechnic Institute); graph theory, qualitative matrix analysis, mathematics education.

### Research Assistant Professor

**Nolan, C.J.**—Ph.D. (Rice University); medical and seismic imaging using microlocal analysis.

### Joint Appointments with Computer Science—Professors

**Flaherty, J.E.**—Ph.D. (Polytechnic Institute of Brooklyn); scientific computation, numerical analysis, applied mathematics.

**Rogers, E.H.**—Ph.D. (Carnegie Institute of Technology); VLSI architecture, computer applications (emeritus).

## Undergraduate Programs

Mathematics has always been the cornerstone of scientific development. Rensselaer's aim is to provide an education in mathematics, both as a subject in itself and as a discipline to aid in the development of other social and scientific fields. The undergraduate mathematics program educates students in a variety of mathematical areas. The flexibility in this program, with its numerous options, permits selection of courses ranging from pure theory (which builds a foundation for more advanced studies), to applied subjects focusing on mathematical modeling and the solution of real-world problems. In particular, Rensselaer's Department of Mathematical Sciences is one of the few American programs with a strong faculty orientation toward mathematics applications. Reflecting this emphasis are the many undergraduate courses dealing with areas of mathematical applications and the applied flavor with which department faculty typically teach them.

### Baccalaureate Programs

Four curricula leading to a B.S. in Mathematics have been designed to permit the construction of programs that reflect individual student interests and career objectives. These curricula include:

- Mathematics—a traditional program emphasizing the elements of pure and applied mathematics.
- Applied Mathematics—emphasizing both the modeling of physical phenomena and methods of analyzing the resulting mathematical problems.

- Mathematics of Computation—a program bridging mathematics and computer science, with emphasis on numerical methods for solution of problems in science and engineering.
- Mathematics of Operations Research—emphasizing the use of mathematics in developing and studying analytical models of discrete systems, especially those that arise in management, engineering, and social sciences.

These four curricula share several common features. First, they each contain eight free electives that permit students to design unique programs. These electives also allow students to concentrate on a subject in addition to mathematics, to obtain a broad-based education, or to complement their mathematics program. A second common feature is the Humanities and Social Sciences requirement of 24 credits. Finally, completion of all four curricula requires a total of 124 credits.

An immediate choice among these four curricula is not necessary, since for the first two years, all mathematics students follow the same basic curriculum. This initial two-year course of study is outlined below and is followed by sample junior/senior curricula for each of the department’s four undergraduate programs. Additional details and up-to-date descriptions of the mathematics courses, including special topics courses, are available at the department’s Web site, <http://www.math.rpi.edu/index.html>.

**The First Two Years**

**First Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CSCI-1100	Computer Science I .....	4		Science Elective .....	4
PHYS-1100	Physics I* .....	4		Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
MATH-1900	Art and Science of Math I .....	1	MATH-1910	Art and Science of Math II .....	1

**Second Year**

<b>Fall</b>		<b>Credit Hours</b>	<b>Spring</b>		<b>Credit Hours</b>
MATH-2010	Multivar. Calc. and Matrix Algebra ..	4	MATH-2400	Intro. to Differential Eqns. ....	4
	Elective .....	4		Science Elective .....	4
BIOL-1010	Intro to Biology* .....	4		Elective (MATH-2700 suggested) ...	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

In the above curriculum, the first-year seminar courses MATH-1900 and MATH-1910 are not required, but are strongly recommended. This weekly seminar course for math majors presents interesting and challenging mathematical problems and ideas for discussion. Also deserving particular attention is MATH-2700, a second semester sophomore course that provides a good background for junior and senior mathematics courses.

The science electives should be courses from the School of Science outside of math. Note that mathematical science includes all courses with MATH and MATP codes (and any course cross-listed with a MATH or MATP course).

\* The courses BIOL-1010 and PHYS-1100 may be taken in any semester they are offered and in either order.

## Mathematics Curriculum

### Third Year

Fall		Credit hours	Spring		Credit hours
MATH-4200	Mathematical Analysis I .....	4	MATH-4210	Mathematical Analysis II .....	4
	Mathematics Option .....	4	MATH-4010	Abstract Algebra. ....	4
	Elective .....	4		Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective. ....	4

### Fourth Year

Fall		Credit hours	Spring		Credit hours
	Mathematics Option.....	4		Mathematics Option.....	4
	Mathematics Option.....	4		Elective .....	4
	Culminating Experience** .....	4		Elective .....	4
	Elective .....	4			

The above curriculum provides a broad and basic education in mathematics. It is especially suited to those intending to continue on to graduate education in mathematics or some other scientific and engineering field. Considerable flexibility is built into this program to allow students and their advisers to tailor programs to individual objectives. As a result, by choosing appropriate mathematical options, the curriculum is equally useful to those seeking immediate employment upon graduation.

Students should note that the mathematics options listed above are any 4000-level or higher course from the Department of Mathematical Sciences. Those planning to go on to graduate work should be sure to take MATH-4100.

## Applied Mathematics curriculum

### Third Year

Fall		Credit hours	Spring		Credit hours
MATH-4200	Mathematical Analysis I .....	4		Mathematics Option.....	4
MATH-4800	Numerical Computing .....	4		Mathematics Option .....	4
	Elective .....	4		Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Fourth Year

Fall		Credit hours	Spring		Credit hours
MATH-4700	Foundations of Applied Math I .....	4		Mathematics Option.....	4
	Mathematics Option.....	4		Elective .....	4
	Culminating Experience** .....	4		Elective .....	4
	Elective .....	4			

The above curriculum stresses courses that involve the construction, analysis, and evaluation of mathematical models of real-world problems and those areas of mathematics most widely used to solve them. Thus, it prepares students to deal with mathematical problems that arise in science, engineering, or management. Applied mathematics students enjoy considerable flexibility, but are urged to acquire a solid background in the three principal areas of applied mathematics, which are modeling, analysis or solution methods, and numerical analysis.

Students should note that the mathematics options listed above are any 4000-level or higher course from the Department of Mathematical Sciences. It is recommended that students take PHYS-1100 and PHYS-1200 and those who may continue on to graduate school should consider taking MATH-4210 and MATH-4100.

\*\* The culminating experience is a course or project to be chosen with the approval of the Mathematical Sciences department.

## Mathematics of Computation Curriculum

### Third Year

Fall		Credit hours	Spring	Credit hours	
MATH-4200	Mathematical Analysis I .....	4	Computation Option .....	4	
MATH-4800	Numerical Computing .....	4	CSCI-xxxx	CS Option .....	4
	Elective .....	4		Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Fourth Year

Fall		Credit hours	Spring	Credit hours
	Mathematics Option .....	4	Mathematics Option .....	4
CSCI-xxxx	CS Option .....	4	Elective .....	4
	Culminating Experience** .....	4	Elective .....	4
	Elective.....	4		

Computers and computational methods play an important role in all fields of science and engineering. Thus, the above curriculum focuses on the mathematical development, analysis, and application of numerical methods. Surrounding this main focus are courses that build mathematical expertise in analysis, modeling, and applications. This curriculum also allows the flexibility to pursue courses in computer science and other fields of science and engineering.

Students should note that the mathematics options listed above are any 4000-level or higher course from the Department of Mathematical Sciences. The computation option is either MATH-4820 or MATP-4820. The CS options are any 2000-level or higher courses from Computer Science (i.e., courses coded CSCI and not cross listed with any math course).

It is also recommended that students take PHYS-1100, PHYS-1200, and CSCI-1200. Those planning to continue on to graduate school should consider taking MATH-4210.

## Mathematics of Operations Research Curriculum

### Third Year

Fall		Credit hours	Spring	Credit hours
MATH-4200	Mathematical Analysis I .....	4	Elective .....	4
MATP-4700	Math Models of Operations		Hum. or Soc. Sci. Elective .....	4
	Research .....	4	Mathematics Option.....	4
	Elective.....	4	MATP-xxxx OR Option.....	4
	Hum. or Soc. Sci. Elective .....	4		

### Fourth Year

Fall		Credit hours	Spring	Credit hours
	Mathematics Option.....	4	Mathematics Option.....	4
	Mathematics Option.....	4	Elective.....	4
	Culminating Experience** .....	4	Elective.....	4
	Elective .....	4		

The above curriculum emphasizes the use of mathematics for developing and studying analytical models of systems. These models are used to form better decisions in areas such as management, engineering, and the social sciences. In mathematical programming, a problem is modeled as an objective function with constraints on the possible solutions, then the resulting model is optimized. The models are solved using computer programs. Algebra, analysis, and discrete mathematics all play a role in analyzing the models and in developing computer algorithms to solve them. Frequently, the inputs and outcomes of the model are not known with certainty, thus probability and statistics are used.

\*\* The culminating experience is a course or project to be chosen with the approval of the Mathematical Sciences department.

Students should note that the mathematics options listed above are any 4000-level or higher course from the Department of Mathematical Sciences, plus up to two 4000-level or higher courses from Decision Science (DSES) or Computer Science (CSCI). In other words, of the four mathematics options, a minimum of two must be coded MATH or MATP.

Also, the OR option in this curriculum is either MATP-4600 or MATP-4820.

### **Minor Programs**

Students not majoring in mathematics may receive a minor in math by taking four courses at the 4000 level or above from the MATH and MATP course groups. These courses should form a coherent program and have the prior approval of the chairman of the Department of Mathematical Sciences.

### **Dual Major Programs**

The requirements for a dual major are described in the section on Academic Information and Regulations. Interest in such programs is increasing, and recent combinations have included math and physics, math and computer science, and math and psychology. Typical schedules for such combinations can be found at the department's Web site under dual majors.

### **Accelerated Programs**

Qualified students may earn a B.S. and M.S. degree in the same or different areas in a shorter-than-usual time. They may do so through the use of advanced placement credit, by taking additional courses during the fall and spring semesters, and/or by taking summer courses.

For example, a student with advanced placement credit for Calculus I and II may earn the B.S. and M.S. degrees within four years by taking an additional course each regular fall and spring semester. Since a student may take up to 21 credit hours per semester at no additional charge, it may be possible to earn both degrees for the cost of a B.S. alone. As a second example, rather than taking more courses during the academic year, a student may earn two degrees in four years by taking eight courses distributed over three summers.

Such a joint degree program requires that the student apply to and be accepted by the Office of Graduate Education at an appropriate stage. A wide variety of joint degree programs can be arranged depending on the student's background, interests, and desired rate of progress. The interested student should consult the faculty adviser to design an optimum program.

## **Graduate Programs**

The Department of Mathematical Sciences offers programs leading to the M.S. and Ph.D. degrees. Each curriculum is highly flexible, and each student's program of study is individually designed.

A departmental colloquium series, in which both mathematics faculty and guest lecturers present current research work, supplements course work. In addition, graduate students organize a weekly seminar, in which they present material from their research. Moreover, each semester, faculty and students organize informal seminars that explore topics of mutual interest. In a special course called Introduction to Research in Mathematics, each week a faculty member discusses his or her research program and describes current problems for graduate students to investigate. In addition, through formal course work and individual contact with the faculty, students become familiar with all departmental research activities. The department's Web site also provides an overview of these research activities and lists the faculty working in each area.

Undergraduates with backgrounds in mathematics or any related major with significant mathematical content are admissible to the graduate program.

## Master's Programs

The department offers the M.S. degree in both Applied Mathematics and Mathematics.

### Applied Mathematics

The emphasis of this program is on mathematics and how it is employed to study science, engineering, or management problems. It stresses construction, analysis, and evaluation of mathematical models of real-world problems, and those areas of mathematics that are most widely used to solve them. The requirements for this degree allow students to prepare for entry into the Ph.D. program in applied mathematics or for employment in business, industry, or government.

The student must meet the Office of Graduate Education requirements and follow a plan of study acceptable to this office and the Department of Mathematical Sciences. Each student's program of study must include:

- At least four graduate (6000) level courses of four credits each, of which at least two must be in math (MATH- 6xxx or MATP-6xxx)
- At least four courses coded MATH or MATP of four credits each
- At least one three- or four-credit course at the 4000 or 6000 level outside the department (i.e., not coded MATH or MATP and not cross listed with any department course), selected in consultation with the math adviser
- Each student must participate in a capstone professional experience, by registering for and completing one of the following alternatives: 1) a Master's Project in Mathematics, MATH-6980; 2) a Master's Practicum, MATH-6970, such as a graduate cooperative internship or active participation in the Applied Mathematics Industry Workshop (a department faculty member must approve your plans in advance and must certify its satisfactory completion); 3) two 6000-level MATH courses, with second digit either 4, 5, 6, 7 or 8 (one may be an appropriate Special Topics course MATH-696x, subject to adviser's approval); 4) two 6000-level MATP courses (one may be an appropriate Special Topics course MATP-696x, subject to adviser's approval).

### Mathematics

The student must meet the Office of Graduate Education requirements and follow a plan of study acceptable to this office and the Department of Mathematical Sciences. The plan of study should represent a reasonably broad program in mathematics and must contain:

- At least four graduate (6000) level courses of four credits each, of which at least two must have numbers in the range MATH-6000 to MATH-6390
- At least four courses coded MATH or MATP of four credits each
- Each student must participate in a capstone professional experience, by registering for and completing one of the following alternatives: 1) a Master's Project in Mathematics, MATH-6980; 2) a Master's Practicum, MATH-6970, such as a graduate cooperative internship (a department faculty member must approve your plans in advance and must certify its satisfactory completion).

## Doctoral Programs

Students working for the doctorate must demonstrate high achievement both in scholarship and in independent research. All programs must follow the general rules of the Office of Graduate Education.

The Ph.D. degree results from following a program of study in mathematics or in applied mathematics. In either case, the student's program of study must include:

- At least six, four-credit (nonthesis) graduate mathematics courses (i.e., those with numbers MATH-6xxx or MATP-6xxx)
- At least one three- or four-credit course at the graduate (6000) level outside the department (i.e., not coded MATH or MATP and not cross listed with any department course), selected in consultation with the math adviser
- At most 30 thesis/research credits
- All doctoral students must pass a written preliminary exam as well as an oral qualifying examination, and complete an oral candidacy presentation. Descriptions of these requirements can be found on the department's Web site.

In addition, the course MATH-6591 Research in Mathematics is strongly suggested. Any deviations from these requirements must have the approval of the Department's Graduate Committee.

## Course Descriptions

Courses directly related to all Mathematical Sciences curricula are described in the Course Description section of this catalog under the department code MATH or MATP.

# Physics, Applied Physics, and Astronomy

**Chair:** Gwo Ching Wang

**Associate Chair:** Philip A. Casabella

**Department Home Page:** <http://www.rpi.edu/dept/phys/physics.html>

Physics is the source of new concepts about the nature of the universe and is a driving force for new technologies. The fundamental physics research of one generation frequently leads to the applied physics and technology of the next.

The Department of Physics, Applied Physics, and Astronomy programs prepare undergraduate students to contribute to these new concepts and technologies through innovative teaching methods that combine student-faculty interactions, computer-based education, and "hands-on" experience in modern laboratories. The curricula are flexible so that students can prepare for either technical employment upon graduation or for graduate study in physics, applied physics, or engineering. Physics also provides an excellent foundation for a nontechnical career. Another important aspect of the physics program is student-faculty research projects involving collaboration between physics undergraduates and faculty on a variety of research topics at the forefront of the field.

The Department of Physics, Applied Physics, and Astronomy's graduate programs lead to the M.S. and the Ph.D. in physics. These degrees are available in several research areas that are summarized below. For graduate students specializing in Astronomy and Astrophysics, the M.S. degree is available either in astronomy or physics with specialization in astrophysics.

Rensselaer's graduate study in physics prepares students for a variety of careers including industrial research and development, government laboratory research, and university research and teaching. The department conducts both fundamental and applied research, often in collaboration with researchers from other Rensselaer departments, other universities, industry, or the National Laboratories. Characterizing the Physics Department's intellectual climate are lively interactions between theorists and experimenters with common research interests. Colloquia and department seminars supplement course work. As an important part of their graduate education, students collaborate with faculty members to make original research contributions in their area of specialization.

## Research Innovations and Initiatives

### Astronomy and Astrophysics

Research in the astrophysics group includes astrobiology, the chemistry of the interstellar medium, and many areas of galactic and extragalactic astronomy. Research in astrobiology and interstellar chemistry describes how interstellar clouds evolve into new solar systems. Current interest focuses on spectroscopic detection of organic molecules in interstellar dust and gas and their contribution to the organic inventory of protoplanetary disks. Theoretical projects include simulations of protostellar collapse, multifluid magnetohydrodynamic shock waves, and shock chemistry. Research in galactic and extragalactic astronomy includes the structure and formation of the galactic halo, metallicity gradients in the galactic thick disk, properties of stars with strong Balmer absorption, optical properties of quasars, and astronomical data mining. The astrophysics group makes use of ground-based telescopes located at world class observing sites in Hawaii, Australia, Chile, and South Africa. Rensselaer also has access to data from major satellite facilities including the Hubble Space Telescope, Chandra, and the Infrared Space Observatory; and large ground-based astronomy projects, including the Sloan Digital Sky Survey and the Two Micron All Sky Survey (2MASS).

### Biophysics

Current work focuses on cells in tissue culture. When mammalian cells are cultured on small gold electrodes, changes in the cells' morphology and motion can be inferred from the measured impedance of the electrodes. This method, in addition to the study of cell behavior in vitro, can be used effectively as a biosensor. Now under investigation are cell migration, toxicology, and metastatic potential of cancer cells.

### Condensed Matter Physics

This research program concentrates on three areas: surfaces, interfaces, and nanostructures; optical and electronic materials; and electronic transport. New research concepts, materials, and techniques are developed for high technology applications. Many research projects are interdisciplinary.

Experimental and theoretical work on surfaces, interfaces, and nanostructures involves the deposition, growth, and characterization of metals, semiconductors, and insulators from monolayers to multilayers. The phenomena that are studied include homo- and hetero-epitaxy, initial stages of epitaxy, nucleation of thin films, surface phase transitions, and interface (solid-solid and solid-liquid) structure and bonding. Techniques include Auger electron spectroscopy, X-ray photoelectron spectroscopy, high resolution low-energy electron diffraction, reflection high-energy electron diffraction, atomic force microscopy, scanning tunneling microscopy, ballistic-electron-emission microscopy, X-ray absorptions spectroscopy, X-ray crystallography, and ellipsometry. The department's major facilities include ultrahigh vacuum evaporation, III-V group IV molecular beam epitaxy, and the extensive facilities of the Microelectronics Clean Room. Theoretical work also includes applications of statistical physics and large-scale simulations to study the dynamics of natural, artificial, and social systems, including ecological systems, agent-based models, and social networks.

The optical and electronic materials under study include wide bandgap semiconductors, photonic crystals, polymers, semiconductor nanoparticle composites, dielectrics, and magnetic thin films. Optical characterization facilities include Raman, Brillouin, and Rayleigh scattering, photomodulation spectroscopy, photothermal deflection spectroscopy, magneto-optic Kerr effect, and Faraday rotation.

Electron transport in semiconductor and metallic materials are under way. This research is expected to enhance understanding of transport in nanostructures. The experimental work includes studies of ballistic electron transport in ultrathin epitaxial multilayers, electrical resistance of metallic films, and plasma wave electronics in high electron mobility transistors. The electron transport in nanoscale systems (single molecule to atomic wire to carbon nanotube) is studied using the state of the art first principles calculation. The current research includes spin assisted transport (Spintronics) at the nanoscale. The

computational facilities in the theory group include in house Linux cluster of about 100 processors and the group has access to National Super Computer facilities.

Other experimental facilities used in these programs include those at the Center for Integrated Electronics, the Focus Center for Interconnects, the Center for Advanced Interconnect Systems Technologies, the electron microprobe and electron microscope facilities, accelerators at the University at Albany, the National Synchrotron Light Source at Brookhaven National Laboratory, and the Stanford Synchrotron Radiation Laboratory.

### **Educational Research and Development in Physics**

Rensselaer's physics education group pioneered the "studio" approach to physics instruction. The defining characteristics of studio physics classes are integrated lecture/laboratory form, a reduction in lecture time, a technology-enhanced learning environment, collaborative group work, and a high level of faculty-student interaction. The studio physics environment employs activities, computer tools, and multimedia materials that allow students to participate in their own learning and to construct their own scientific knowledge. Allowing students to learn directly from their interactions with the physical world through "hands-on" activities is a high priority. Students may participate in programs of the educational development group to fulfill thesis requirements for the M.S. degree.

### **Particle Physics**

The structure of matter smaller than the atomic nucleus remains one of nature's puzzles. Studies of unusual states of matter, exotic particles, provide unique insights into the fundamental properties of hadrons.

Experiments are underway at Cornell Electron Storage Ring (CESR) and the Thomas Jefferson National Accelerator Facility (JLAB). These experiments examine the properties of the proton and its excited states, and identify gluonic mesons. The instruments for this work are designed and constructed at Rensselaer and other collaborating institutions. A new detector is under design for the GlueX project at JLAB.

### **Optical Physics**

Research in optical physics is directed toward developing new optical materials and devices. A wide range of experimental techniques is used to achieve optical characterization of materials such as nanocrystalline metal and semiconductor particles in glass or in organic materials. Among them are optical absorption, luminescence, Brillouin scattering, Raman scattering, and photomodulation spectroscopies. Experimental measurements use high pressure, low temperature, and high magnetic fields to gain further understanding of the optical properties of novel materials.

Research in optical interconnects focuses on developing and testing polymer and inorganic optical waveguides to address interconnect problems that will arise as computer chips get faster.

Ultrafast photonics and optoelectronics involve the generation and detection of picosecond and femtosecond electromagnetic pulses. Of particular interest are time-resolved experiments on THz pulses. THz spectroscopy opens up novel opportunities in material characterization and information technology. A current project applies THz pulses for biophotonic imaging. Other projects deal with switching semiconductor devices at THz frequencies.

## **Faculty\***

### **Professors**

**Adams, G.S.**—Ph.D. (Indiana University); experimental particle physics; photo reactions, hadron structure, exotic hadrons.

**Casabella, P.A.**—Ph.D. (Brown University); physics education.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

**Hayes, T.M.**—Ph.D. (Harvard University); condensed matter physics.

**Jackson, S.A.**—Ph.D. (Massachusetts Institute of Technology); theoretical physics (Joint appointment with Engineering).

**Lin, S.-Y.**—Ph.D. (Princeton University); theory, fabrication, and experimental assessment of photonic crystal structures.

**Lu, T.-M.**—Ph.D. (University of Wisconsin); thin films and interfaces.

**Napolitano, J.J.**—Ph.D. (Stanford University); experimental nuclear and particle physics; scientific computation.

**Persans, R.D.**—Ph.D. (University of Chicago); spectroscopy of semiconductors; thin films; optical materials.

**Roberge, W.G.**—Ph.D. (Harvard University); theoretical astrophysics.

**Schowalter, L.J.**—Ph.D. (University of Illinois); material physics.

**Schubert, E.F.**—Ph.D. (University of Stuttgart); physics of semiconductor devices. (Joint appointment with ECSE).

**Schroeder, J.**—Ph.D. (Catholic University of America); optical properties of solids at high pressure.

**Shur, M.S.**—Dr.Sc. (Ioffe Institute); semiconductor physics, ballistic transmission, terahertz radiation (Joint appointment with ECSE).

**Sperber, D.**—Ph.D. (Princeton University); theoretical nuclear physics.

**Stoler, P.**—Ph.D. (Rutgers University); particle and nuclear physics; structure of hadrons.

**Wang, G.C.**—Ph.D. (University of Wisconsin); physics of surfaces, interfaces, and nanostructures.

**Whittet, D.C.B.**—Ph.D. (St. Andrews University); astrophysics; observational astronomy; interstellar dust; origins of life.

**Zhang, X.-C.**—Ph.D. (Brown University); ultrafast optics, photonic, optoelectronic and terahertz science and technology (Joint appointment with ECSE).

#### **Associate Professor**

**Newberg, H.J.**—Ph.D. (University of California, Berkeley); astrophysics.

**Wetzel, C.M.**—Ph.D. (Technical University, Munich); III-V nitride semiconductor physics and technology

#### **Assistant Professors**

**Korniss, G.**—Ph.D. (Virginia Polytechnic Institute); theoretical and computational physics.

**Nayak, S.**—Ph.D. (Jawaharlal Nehru University); theoretical physics and first principle calculations.

**Wilke, I.**—Ph.D. (Swiss Federal Institute of Technology); ultrafast optics, photonic, optoelectronic and terahertz science and technology.

#### **Institute Professor**

**Giaever, I.**—Ph.D. (Rensselaer Polytechnic Institute); biological physics.

#### **Clinical Professor**

**Washington, M.A.**—Ph.D. (New York University); photonics.

#### **Clinical Associate Professor**

**Bedrosian, G.**—Ph.D. (California Institute of Technology, Pasadena); educational physics; electro-magnetic analysis.

**McIntyre, C.R.**—Ph.D. (Massachusetts Institute of Technology); semiconductor materials.

#### **Adjunct Professors**

**Dwyer, S.**—Ph.D. (Rensselaer Polytechnic Institute); surface physics, tribology, physics education.

**Hauger, S.**—Ph.D. (Duke University); educational physics.

**Hudspeth, Q.**—Ph.D. (University of Florida); physics education, thin film electronic transport, physics of surfaces.

**Taiuti, M.**—Ph.D. (Dottore di Ricerca in Fisica); nuclear and particle physics.

**Weygand, D.**—Ph.D. (Syracuse University); nuclear and particle physics.

### Research Professors

**Lee, S.**—Ph.D. (University of Michigan); condensed matter.

**Slack, G.**—Ph.D. (Cornell University); electronic materials and thermoelectrics.

### Research Associate Professor

**Lu, J.**—Ph.D. (Technical University of Munich); electronic materials.

**Xu, J.**—Ph.D. (Institute of Physics, China); ultrafast optics, terahertz science and technology.

### Research Assistant Professors

**Cummings, J.**—Ph.D. (Rice University); experimental nuclear and particle physics.

**Kersting, R.**—Ph.D. (University of Aachen); optical physics and terahertz radiation.

**Liu, X.-Y.**—Ph.D. (University of Illinois, Urbana-Champaign); atomistic modeling of materials.

**Senkevich, J.**—Ph.D. (Rensselaer Polytechnic Institute); physics and chemistry of surfaces and interfaces, self-assembled chemistry and ultrathin films.

### Visiting Scientists

**Cummings, K.**—Ph.D. (University of Albany); educational physics.

**Edelstein, W.**—Ph.D. (Harvard University); magnetic resonance imaging basic sciences and applications.

**Kubarovsky, V.**—Ph.D. (Institute for High Energy Physics, Russia); experimental nuclear physics.

**Wagner, D.J.**—Ph.D. (Vanderbilt University); educational physics.

## Undergraduate Programs

Undergraduate students begin with core curriculum courses that teach basic scientific principles and develop skills in problem solving, scientific thinking, and clear oral and written expression. Students also choose from a broad range of advanced courses in the Department of Physics, Applied Physics, and Astronomy and in other science and engineering departments depending upon their individual career goals.

### Baccalaureate Programs

Rensselaer offers two undergraduate programs in physics, one leading to the B.S. in Physics and the other to the B.S. in Applied Physics. Students in the applied physics program must declare a concentration in a specific technological area, in which they take at least four elective courses.

### Physics Curriculum

#### First Year

Fall	Credit hours	Spring	Credit hours
MATH-1010	Calculus I.....4	MATH-1020	Calculus II.....4
CHEM-1100	Chemistry I.....4	BIOL-1010	Intro. To Biology.....4
PHYS-1100	Physics I.....4	PHYS-1200	Physics II.....4
	Hum. or Soc. Sci. <sup>2</sup> .....4		Hum. or Soc. Sci. <sup>2</sup> .....4

#### Second Year

Fall	Credit hours	Spring	Credit hours
PHYS-2100	Intro. to Theoretical Phys. ....4	PHYS-2350	Experimental Physics.....4
MATH-2010	Multivariate Calculus and Matrix Algebra.....4	MATH-2400	Intro. to Differential Eqns. ....4
CSCI-1100	Computer Science I.....4		Elective.....4
	Elective <sup>3</sup> .....4		Hum. or Soc. Sci. <sup>2</sup> .....4

<sup>1</sup> CHEM-1300 may be substituted for CHEM-1100 Chemistry 1

<sup>2</sup> Humanities and Social Sciences courses shall total 24 and meet distribution requirements in the catalog.

<sup>3</sup> Students with little or no electronics experience should take ENGR-1310, a one-credit laboratory course in addition to this four-credit elective.

**Third Year****Fall**

	<b>Credit hours</b>
PHYS-2330 Intermediate Mechanics .....	4
PHYS-2510 Intro. to Quantum .....	4
MATH-4600 Advanced Calculus.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

**Spring**

	<b>Credit hours</b>
PHYS-4210 Electromagnetic Theory .....	4
PHYS-4100 Intro. to Quantum Mechanics .....	4
PHYS-4420 Thermodynamics and Statistical Mechanics .....	4
Elective.....	4

**Fourth Year****Fall**

	<b>Credit hours</b>
PHYS-4370 Research Part.....	4
Elective.....	4
Elective.....	4
Hum. or Soc.Sci. <sup>2</sup> .....	4

**Spring**

	<b>Credit hours</b>
Elective .....	4
Elective .....	4
Hum. or Soc. Sci. <sup>2</sup> .....	4

**Applied Physics Curriculum****First Year****Fall**

	<b>Credit hours</b>
MATH-1010 Calculus I.....	4
CHEM-1100 Chemistry I <sup>1</sup> .....	4
PHYS-1100 Physics I.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	4

**Spring**

	<b>Credit hours</b>
MATH-1020 Calculus II .....	4
BIOL-1010 Intro. To Biology .....	4
PHYS-1200 Physics II.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

**Second Year****Fall**

	<b>Credit hours</b>
PHYS-2100 Intro. to Theoretical Phys. ....	4
MATH-2010 Multivariate Calculus and Matrix Algebra .....	4
CSCI-1100 Computer Science I.....	4
Elective <sup>3</sup> .....	4

**Spring**

	<b>Credit hours</b>
PHYS-2350 Experimental Physics .....	4
MATH-2400 Intro. to Differential Eqns. ....	4
Elective.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

**Third Year****Fall**

	<b>Credit hours</b>
PHYS-2330 Intermediate Mechanics .....	4
PHYS-2510 Quantum Phys. ....	4
MATH-4600 Advanced Calculus.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

**Spring**

	<b>Credit hours</b>
PHYS-4210 Electromagnetic Theory .....	4
Technical Elective <sup>4</sup> .....	4
PHYS-4420 Thermodynamics and Statistical Mechanics .....	4
Elective .....	4

**Fourth Year****Fall**

	<b>Credit hours</b>
Technical Elective <sup>4</sup> .....	4
Technical Elective <sup>4</sup> .....	4
PHYS-4370 Research Part.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

**Spring**

	<b>Credit hours</b>
Technical Elective <sup>4</sup> .....	4
Elective.....	4
Hum. or Soc. Sci. <sup>2</sup> .....	3-4

<sup>2</sup> Humanities and Social Sciences courses shall total 24 and meet distribution requirements in the catalog.<sup>3</sup> Students with little or no electronics experience should take ENGR-1310, a one-credit laboratory course in addition to this four-credit elective.<sup>4</sup> Technical Electives are to be selected with the aid of an adviser in order to create a concentration in an appropriate applied physics field.

### Concentrations

The applied physics program requires a concentration of four technical courses that focuses on a specific technological area. Possible concentrations include, but are not limited to optical physics, microelectronics, semiconductor physics, optoelectronics, geophysics, biophysics, computation applied physics, and environmental physics. Two such concentrations are illustrated below:

**Optical Physics**—A concentration in optical physics might include four courses from the following list:

PHYS-2620	Fundamentals of Optics	PHYS-4640	Optical Communications and
PHYS-4630	Lasers and Optical Systems		Integrated Optics
PHYS-4720	Solid-State Physics	PHYS-2370	Research Participation

**Microelectronics**—A concentration in microelectronics might include courses from the following list:

ECSE-2050	Analog Electronics and Circuits	MTLE-4160	Semiconducting Materials <sup>7</sup>
EPOW-4080	Semiconductor Power Electronics	PHYS-2370	Research Participation
ECSE-4220	VLSI Design	PHYS-4720	Solid-State Physics
ECSE-2210	Microelectronics Technology		
ECSE-4250	Integrated Circuit Processes and Design <sup>7</sup>		

### Electives

Physics or applied physics majors planning to continue on to graduate studies in these areas should take some combination of advanced physics courses to prepare for these studies. These courses should be chosen from the following undergraduate- and graduate-level courses:

PHYS-4720	Solid-State Physics	PHYS-6510	Quantum Mechanics I
PHYS-4630	Lasers and Optical Systems	PHYS-6520	Quantum Mechanics II
PHYS-4620	Particles and Nuclei	PHYS-6310	Advanced Mechanics
ASTR-4220	Astrophysics	PHYS-6110	Methods in Theoretical Physics
ASTR-4240	Gravitation and Cosmology		

Students planning on graduate work in astronomy or astrophysics are urged to choose electives from the above list, as well as include the following:

ASTR-2050	Intro. to Astr. and Astrophysics	ASTR-4220	Astrophysics
ASTR-4120	Observational Astronomy	ASTR-4240	Gravitation and Cosmology

### Minor Programs

The Department of Physics, Applied Physics, and Astronomy offers the following minors:

#### Physics

Students not majoring in physics may minor in this subject by taking at least 16 credit hours of physics courses (coded PHYS) at the 2000 level or higher.

#### Astronomy

To complete an astronomy minor, a student should take PHYS-2510, ASTR-2050, and two of the following courses: ASTR-4120, ASTR- 4510, or ASTR-4960.

#### Astrophysics

This minor is available to students majoring in physics and planning on graduate study in astronomy or astrophysics. To complete this minor, a student should take PHYS-2510, ASTR-4220, at least one four-credit research project in astrophysics, and at least three semesters of the one-credit ASTR-4900.

<sup>7</sup> Students cannot receive credit for ECSE-4250 and MTLE-4160

### Astrobiology

This multidisciplinary minor is open to students majoring in physics or in other disciplines. To complete this minor, a student must take a minimum of 16 credits of course work in this field. These courses must include four credits each of ASTR-4510 and ISCI- 4500, and two semesters of the one-credit ISCI-4510. Two additional courses outside the major field of study must also be selected from the following:

ENVE-2110	Intro. to Environmental Engineering	CHEM-2250	Organic Chemistry I
BIOL-4320	Geomicrobiology	CHEM-4810	Chemistry of the Environment
BIOL-4440	Microbial Ecology	ERTH-4070	Sedimentology
BIOL-4620	Molecular Biology	ERTH-4540	Organic Geochemistry
BIOL-4760	Molecular Biochemistry I	ASTR-2050	Intro. to Astr. and Astrophysics
BCBP-4810	Biological Spectroscopy		
BCBP-4860	Protein and Nucleic Acid Structure		

The requirement that two selected courses must be outside the major is reduced to one in the case of a double major, provided that both majors are in the primary relevant areas of study (i.e., biology, chemistry, geology, and physics).

### Dual Major Programs

Students may form a dual major in physics and any other degree program within the School of Science. In these cases, the program will satisfy the requirements of both degrees. In addition, a dual major in physics and philosophy is available by satisfying the physics requirements and pursuing 10 philosophy courses.

### Accelerated Programs

Students may generally select, in their junior year, to follow a five-year B.S.-M.S. program. These students receive the B.S. in physics and the M.S. in either physics or another science or engineering discipline.

## Graduate Programs

Graduate students develop flexible individual programs of study and research in one or more of the available research areas. The department offers both the M.S. and Ph.D. degrees in physics.

### Master's Programs

Completion of the M.S. requires 30 credits of graduate work, including a minimum of 21 credits in course work. Course work should meet the needs of the individual student, but must include PHYS-6510 and two of the following four courses: PHYS-6520, PHYS-6310, PHYS-6110, and PHYS-6410. The master's degree also requires some credits of research, which may culminate in a formally presented thesis (six to nine credits) or a research project (three credits). Some teaching experience is required for the degree.

### Doctoral Programs

Ninety credits beyond the bachelor's degree or 60 credits beyond the M.S. are required, including credits for original research culminating in a formally presented thesis. A manuscript on the thesis research should be prepared for publication.

Admission to the Ph.D. program is granted only upon passing a written qualifying examination at the beginning of the third semester of Rensselaer graduate work. The advanced undergraduate-level exam is given in two parts: 1) Mechanics and Electrodynamics and 2) Quantum Mechanics, Thermodynamics, and Introduction to Statistical Mechanics. The examination is given twice annually in August and January.

Doctoral requirements do not state a minimum number of course credits. However, students must take the basic core of six courses including PHYS-6310, PHYS-6510 and PHYS-6520, PHYS-6590, PHYS-6110, and PHYS-6410. Students are expected to obtain a grade of at least B in each of these

courses. In addition to the above sequence of core courses, there are the following doctoral course requirement: 1) one graduate 6000-level course in the area of research specialization; 2) three courses related to the student's educational needs as authorized by the student's research adviser. Note: PHYS-6530 is strongly recommended for all students. (All theory students should take this course). There are special requirements for students specializing in astrophysics and biophysics.

Once students have chosen a Ph.D. project and assembled a committee, they will present a brief written thesis proposal to the committee and orally defend it. In the oral exam, members of the committee question students specifically on the planned research and more generally on the physics related to that research. This candidacy exam is normally taken at the end of the third year.

Some teaching experience is also required for the Ph.D. degree.

## Course Descriptions

Courses directly related to all Physics, Applied Physics, and Astronomy curricula are described in the Course Description section of this catalog under the department codes PHYS or ASTR.

# Computer Science at Hartford

**Chair:** (vacant)

Program presently under revision. Please access the department website at: <http://www.rh.edu/does/index.html> for revised program.

## Master of Science in Computer Science

Applicants are assumed to have knowledge of computer concepts and programming in a high-level language (e.g., C, Pascal). To receive the Master of Science degree in Computer Science, students must earn a minimum of 30 credit hours in computer science or engineering courses and satisfy the following requirements:

### Plan of Study

Each student completes a Plan of Study in consultation with his or her adviser. This plan will include required immigration courses (if any), two core courses, elective courses, and program completion. At least two of the elective courses should pertain to a specific area, which reflects the student's professional or academic interest.

### Immigration Courses

Depending on academic background and professional experience, some students may be required to begin their studies with one or more prerequisite "immigration" course(s) beyond the standard 30 credit hours. The immigration courses are:

CISH-4961 Introduction to Computer Programming

CISH-4010 Discrete Mathematics and Computer Theory

CISH-4020 Object Structures

CISH-4030 Structured Computer Architecture

Students with two or more immigration courses as prerequisites may be admitted conditionally. Since these are the equivalent of undergraduate courses, students are expected to achieve a grade of "B" or better in each course. Achievement below this level is cause for reexamination of admission. In addition, these immigration courses will not enter into the calculation of a student's GPA for graduation.

### **Core Courses**

Each plan of study will contain the following two courses:

CSCI-4210 Operating Systems

CSCI-6050 Computability and Complexity

### **Elective Courses**

To provide some breadth to the Plan of Study, each student will take one course from each of the following three groups:

- Hardware systems (e.g., networking, computer architecture)
- Software systems (e.g., software engineering, object oriented design)
- Applications (e.g., database management, software engineering management)

With the exception of the immigration courses, all courses with the designation CISH or CSCI and most designated ECSE may be used as electives for the degree.

### **Advanced Courses**

At least 18 credit hours must be at the “advanced” level. All courses with suffix numbers 6000–6990 fall into this category. These courses may include special topics courses which are offered under CISH, CSCI-6960, or ECSE-6960.

After completing course work in a particular area, students may elect to complete a six credit master’s project (CISH-6980 or CSCI-6980) or thesis (CISH-6990 or CSCI-6990) in that area.

### **Program Completion**

Students will complete their program of study via one of two paths:

#### ***Applied Path***

CISH-6960 Research Methods

CISH-6900 Computer Science Seminar

#### ***Theory Path***

A Theory Course

Master’s Thesis/Project

#### ***For More Information***

Information concerning the computer science programs at Rensselaer at Hartford may be obtained by contacting James C. McKim, Jr. at (860) 548-2458, (800) 290-7637 x 2458, or e-mail: [jcm@rh.edu](mailto:jcm@rh.edu), or visit [www.rh.edu/does/](http://www.rh.edu/does/).

### **Computer Science Graduate Certificate Programs**

The Computer Science Graduate Certificate Programs are designed with a selective focus and require that a student successfully complete four graduate courses (12 credit hours of which nine must be in residence), with an average grade of “B” or better, in a specific area of computer science. Credits earned in Graduate Certificates may be subsequently applied toward a Master of Science degree as electives with the adviser’s approval. Additional information can be obtained from the appropriate program coordinator listed for the six Graduate Certificates on next page.

**Bioinformatics**

BICOL-6960 Bioinformatics I

BICOL-6960 Bioinformatics II

CSCI-4380 Database Systems

Approved Elective

Program coordinator: Susan Smith, e-mail: [salers2@rpi.edu](mailto:salers2@rpi.edu)

**Computer Network Communications**

ECSE-4670 Computer Communication Networks

*Select any three of the following courses:*

CISH-6210 Computer Network Analysis and Design

CISH-6220 LANs, MANs, and Internetworking

CISH-6230 Network Management

CISH-6960 Cryptography and Network Security

ECSE-6660 Broadband Networks

Program coordinator: Roger H. Brown, (860) 548-2462, (800) 290-7637 x 2462, or e-mail: [rhb@rh.edu](mailto:rhb@rh.edu)

**Database Systems**

CSCI-4380 Database Systems

CSCI-6460 Advanced Database Management Topics

CISH-6110 Object Oriented Database Systems

CISH-6120 Distributed Database Systems *or*

CSCI-6470 Database Systems for Engineering Applications

Program coordinator: Timothy O. Martyn, (860) 548-2460, (800) 290-7637 x 2460, or e-mail: [martyn@rh.edu](mailto:martyn@rh.edu)

**Graphical User Interface**

COMM-6420 Foundations of Human/Computer Interaction

CISH-6320 GUI Building

CISH-6010 Object Oriented Programming and Design

Approved Elective

Program coordinator: James C. McKim, (860) 548-2458, (800)290-7637 x 2458, or e-mail: [jcm@rh.edu](mailto:jcm@rh.edu)

**Information Systems**

ECSE-4670 Computer Communication Networks

CSCI-4380 Database Systems

COMM-6420 Foundations of Human/Computer Interaction

CISH-4020 Object Structures *or*

ECSE-6770 Software Engineering I *or*

CISH-6010 Object Oriented Programming and Design

Program coordinator: Timothy J. Hartley, (860) 548-7928, (800) 290-7637 x 7928, or e-mail: [hartley@rh.edu](mailto:hartley@rh.edu)

**Software Engineering**

*Required*

ECSE-6770 Software Engineering I

CISH-6050 Software Engineering Management

*Electives (Select any two of the following)*

CISH-6010 Object Oriented Programming and Design

CISH-6510 Web Application Design and Development

CISH-6320 GUI Building

ECSE-6780 Software Engineering II

## Interdisciplinary Programs and Research

Rensselaer's commitment to providing opportunities for interdisciplinary education is especially apparent within the School of Science. After all, the successful pursuit of almost any Institute field of study requires a strong background in one or more of the sciences. Furthermore, the various scientific disciplines overlap in many ways, just an example of which are the mathematics-based fields of chemistry and physics. The School of Science offers an impressive array of unique programs that cross not only scientific disciplines, but also disciplines within other Institute Schools.

The special interdisciplinary opportunities administered by the School of Science allow students to develop a breadth and depth of knowledge in multiple disciplines, and include both degree and research programs. By nature, these programs are highly flexible and often involve working in teams with faculty and students representing multiple disciplines.

Additional interdisciplinary programs available at Rensselaer are outlined within the catalog section of the associated Institute school or division.

### Applied Science

The School of Science offers a Master of Science in Applied Science, which is a professional degree with no thesis requirement that prepares graduates who have traditional discipline-oriented backgrounds to function more effectively in industrial, governmental, or other interdisciplinary occupations. Its intention is to help working professionals upgrade their technical expertise and cross boundaries among disciplines. In addition to extensive science offerings, students may take applicable courses in other schools such as Management, Engineering, or Humanities and Social Sciences.

Students entering the Master of Science in Applied Science program are subject to Rensselaer's general admission requirements. All programs require 30 credit hours for completion of the degree. At least half of those courses must be at the 6000 level. Within these 30 hours, a number of concentration options are also available. At least 15 hours must be in courses within the School of Science, and include some 6000 level courses.

Some concentration examples include: analytical and environmental chemistry, applied groundwater science, biochemistry/biophysics, bioinformatics, chemistry and entrepreneurship, database management systems, microelectronics manufacturing, optimization and statistics, parallel and scientific computation, photonics, polymer science and engineering, and software engineering. In addition, further combinations of courses leading to the Master of Science in Applied Science are developed as additional needs for interdisciplinary education are identified.

A typical Master of Science in Applied Science curriculum consists of:

- Two to four core courses that establish the basis for advanced study in an area of specialization
- Two to four specialization courses that are fundamental to an area of specialization
- Two to six elective courses that allow students to focus in a particular area within their specialization and gain skills intersecting their technical field with other disciplines.

## Biochemistry and Biophysics

**Director, Undergraduate Degree Program:** Joyce J. Diwan

**Director, Graduate Degree Program:** Jane F. Koretz

Biochemistry and biophysics are closely related fields. Biochemistry focuses on the interconversion of compounds in the many complex reactions of life, on the mechanisms whereby enzymes catalyze and regulate these reactions, and the function and structure of the molecular components of living organisms. Biophysics is principally concerned with processes of energy conversion, information transmission, and the structure and properties of materials in biological systems, as explored with methods of physics. Biochemical and biophysical research is advancing the frontiers of research in the basic life sciences and making possible advances in more applied fields such as medicine and agriculture. For example, in the pharmaceutical industry, elucidating mechanisms of drug action and devising new ways of dealing with diseases has increasingly depended on application of knowledge and techniques of biochemistry and biophysics.

Rensselaer's biochemistry and biophysics undergraduate curriculum includes thorough grounding in mathematics, chemistry, and physics, along with modern biochemistry, biophysics, and molecular-level biology. Advanced biochemistry and biophysics courses, many of which are jointly taught by biology and chemistry faculty, impart knowledge and training in cutting-edge research approaches. Students following this curriculum are thus exceptionally well prepared for graduate school and to become desirable prospective employees in various sectors of the biotechnology industry. The curriculum also provides an excellent background for students planning careers in medicine. While rigorous, the undergraduate curriculum offers sufficient flexibility and course choices to allow students to tailor their education to particular career paths. Most students pursue undergraduate research in faculty laboratories. Many seek industrial experience through Rensselaer's Cooperative Education Program, and the high degree of flexibility facilitates fitting a co-op experience into the degree program.

The master's degree program primarily prepares students for jobs in biotechnology, pharmaceuticals, and other related industry sectors. It is also well suited to students wishing to upgrade their skills while employed in industry. The program may also be attractive to students wishing to obtain an M.S. degree before proceeding to professional study in medicine, veterinary science, dentistry, etc. Those with a B.S. degree in a field not closely related to modern biological science who wish to enter into a doctoral program at Rensselaer or elsewhere may also benefit from the program.

### Research Innovations and Initiatives

Biophysical research at Rensselaer includes the study of areas as diverse as focusing processes of the eye, electrical impedance assays of cell motility, photosynthesis, cellular bioengineering, biofluid mechanics, and electric current computed tomography. A variety of approaches, including molecular modeling, spectroscopic probes, de novo design and chemical synthesis of unnatural proteins, and molecular biology are being used to study protein structure. Biochemical research includes the application of chromatography to large-scale purification of biological macromolecules, biosensors, prebiotic chemistry, biochemical signaling, bioanalytical chemistry, and the catalysis and mechanisms of protein folding.

### Faculty

The science and engineering faculty members of the Center for Biophysics listed below provide a variety of research opportunities for undergraduate and graduate students enrolled in the Biochemistry and Biophysics degree programs. Faculty members from the Biology and Chemistry Departments who are involved in the teaching of biochemistry and biophysics courses are designated with an asterisk (\*).

**Biology:** B. Barquera, C. Bystroff,\* J. Diwan,\* J.F. Koretz,\* R.E. Palazzo, R.H. Parsons, H.Roy,\* J.C. Salerno\*

**Biomedical Engineering:** R. Bizios, N. DePaola, J.C. Newell

**Chemistry:** Y.A. Akpalu, C.M. Breneman, C.T. Choma,\* W. Colon,\* J.P. Ferris, G.M. Korenowski, R.J. Linhardt, J. Stenken\*

**Mathematical Sciences:** M.H. Holmes, D. Isaacson

**Chemical Engineering:** G. Belfort, S.M. Cramer, J.S. Dordick

**School of Science:** I. Giaever

## Undergraduate Program

### Biochemistry and Biophysics Curriculum

#### First Year

Fall		Credit hours	Spring		Credit hours
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CHEM-1100	Chemistry I.....	4	CHEM-1200	Chemistry II .....	4
BIOL-1010	Intro. To Biology .....	4		Elective .....	4
BIOL-1020	Intro. To Biology Lab .....	1		Hum. or Soc. Sci. <sup>1</sup> .....	4
	Hum. or Soc. Sci. <sup>1</sup> .....	4			

#### Second Year

Fall		Credit hours	Spring		Credit hours
CHEM-2250	Organic Chemistry I .....	4	CHEM-2260	Organic Chemistry II .....	4
PHYS-1100	Physics I .....	4	PHYS-1200	Physics II .....	4
	Quantitative Option .....	4	BIOL-4620	Molecular Biology <sup>2</sup> .....	4
	Hum. or Soc. Sci. <sup>1</sup> .....	4		Hum. or Soc. Sci. <sup>1</sup> .....	4

#### Third Year

Fall		Credit hours	Spring		Credit hours
BCBP-4760	Molecular Biochemistry I.....	4	BCBP-4770	Molecular Biochemistry II .....	4
	Laboratory Option .....	4		Elective .....	4
CHEM-2440	Physical Chem. for Life Sci. <sup>3</sup> .....	4		Elective .....	4
	Hum. or Soc. Sci. <sup>1</sup> .....	4		Hum. or Soc. Sci. <sup>1</sup> .....	4

#### Fourth Year

Fall		Credit hours	Spring		Credit hours
	Molec. Biophysics Module .....	4		Molec. Biophysics Module .....	4
BCBP-4990	Senior Research Thesis.....	3		Elective .....	4
	Elective.....	4		Elective.....	4
	Elective .....	4		Elective .....	4

#### Molecular Biophysics Modules (Choose 2)

BCBP-4810	Biological Spectroscopy	BCBP-4860	Protein and Nucleic Acid Structure
BCBP-4210	Biophysical Methods	BCBP-4790	Protein Chemistry
BCBP-4310	Genetic Engineering	BCBP-4870	Crystallographic Analysis of Protein Structure
BCBP-4780	Protein Folding		

<sup>1</sup> Humanites and Social Science (H&SS) courses should minimally add up to 24 credits.

<sup>2</sup> Molecular Biology may be taken in the spring of the second year.

<sup>3</sup> Students may substitute CHEM-4450 and CHEM-4460.

**Quantitative Option (Choose 1)**

CSCI-1100	Computer Science I	MATH-2400	Intro. to Differential Equations
CSCI-1010	Intro. to Computer Programming	MATH-4720	Mathematics in Medicine and Biology
MATH-2010	Multivariable Calculus and Matrix Algebra		

**Laboratory Option (Choose 1)**

BCBP-4710	Biochemistry Laboratory	BIOL-4720	Molecular Biology Lab.
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**Recommended Electives**

MATH-2010	Multivariable Calculus and Matrix Algebra	BCBP-2940	Readings in Biochemistry and Biophysics
MATH-2400	Intro. to Different Equations	BCBP-2990	Research Thesis
MATH-4720	Mathematics in Medicine and Biology	BCBP-4210	Biophysical Methods
CSCI-1100	Computer Science I	BCBP-4310	Genetic Engineering
BIOL-2310	Microbiology	BCBP-4710	Biochemistry Laboratory
BIOL-2500	Genetics and Evolution	BCBP-4780	Protein Folding
BIOL-4260	Cell Biology	BCBP-4790	Protein Chemistry
BIOL-4420	Introductory Immunology	BCBP-4810	Biological Spectroscopy
BIOL-4510	Molecular Genetics	BCBP-4860	Protein and Nucleic Acid Structure
BIOL-4540	Bioinformatics I	BCBP-4870	Crystallographic Analysis of Protein Structure
BIOL-4550	Bioinformatics II	CHEM-2150	Equilibrium Chemistry and Quantitative Analysis
BIOL-4720	Molecular Biology Laboratory	CHEM-4300	Medicinal Chemistry
BIOL-4740	Cell and Developmental Biology Laboratory	CHEM-4310	Bioorganic Mechanisms
BIOL-4270	Human Physiology I	CHEM-4330	Drug Discovery
BIOL-4280	Human Physiology II	CHEM-4520	Chemical Information
BCBP-2900	Research in Biochemistry and Biophysics	CHEM-4620	Introduction to Polymer Chemistry
BCBP-2930	Out of Class Exp. in Biochemistry and Biophysics	CHEM-4640	Polymer Science Laboratory
		CHEM-4810	Chemistry of the Environment
		PHYS-2510	Quantum Physics
		DSES-4140	Statistical Analysis

Depending on immediate and long-range goals, students whose plans include one or more of the following career paths are advised to consider including the courses listed below among their module, option, or free elective choices. Students should consult their advisers when selecting courses from these lists.

**Graduate School—Biochemistry**

CSCI-1100	Computer Science I	BCBP-2990	Research Thesis
BIOL-2500	Genetics and Evolution	BCBP-4710	Biochemistry Laboratory
BIOL-4260	Cell Biology	BCBP-4780	Protein Folding
BIOL-4510	Molecular Genetics	BCBP-4790	Protein Chemistry
BIOL-4720	Molecular Biology Laboratory	BCBP-4860	Protein and Nucleic Acid Structures
BCBP-2900	Research in Biochem./Biophys.	CHEM-4310	Bioorganic Mechanisms

**Graduate School—Biophysics**

MATH-2010	Multivariable Calc. and Matrix Algebra	BCBP-2990	Research Thesis
		BCBP-4210	Biophysical Methods
MATH-2400	Intro. to Differential Equations	BCBP-4810	Biological Spectroscopy
MATH-4720	Math in Medicine and Biology	BCBP-4870	Crystallographic Analysis of Protein Structure
CSCI-1100	Computer Science I		
BCBP-2900	Research in Biochemistry/Biophysics	PHYS-2510	Quantum Physics

**Biotechnology Industry—Research**

CSCI-1100	Computer Science I	BCBP-2990	Research Thesis
BIOL-2310	Microbiology	BCBP-4310	Genetic Engineering
BIOL-2500	Genetics and Evolution	CHEM-4300	Medicinal Chemistry
BIOL-4540	Bioinformatics I	CHEM-4330	Drug Discovery
BIOL-4720	Molecular Biology Laboratory	CHEM-4620	Intro. to Polymer Chemistry
BCBP-2900	Research in Biochem./Biophys.	CHME-4430	Intro. Biochemical Engineering

**Biotechnology Industry—Management/Law**

ECON-1200	Intro. Economics	BCBP-4310	Genetic Engineering
ECON-2010	Managerial Economics	CHEM-4810	Chemistry of the Environment
CSCI-1100	Computer Science I	MGMT-1100	Intro. Management
BIOL-2310	Microbiology	DSES-4140	Statistical Analysis
BIOL-4310	Industrial Microbiology		Other courses of economics and management

**Medical/Dental School**

BIOL-2500	Genetics and Evolution	BIOL-4420	Introductory Immunology
BIOL-4270	Human Physiology I	BIOL-4260	Cell Biology
BIOL-4280	Human Physiology II	CHEM-4300	Medicinal Chemistry
BIOL-2310	Microbiology		Other courses in biology
BIOL-2410	Embryology		

**Bioinformation**

MATH-2010	Multivariable Calc. and Matrix Algebra	BIOL-4540	Bioinformatics I
		BIOL-4550	Bioinformatics II
CSCI-1100	Computer Science I	BCBP-4210	Biophysical Methods
CSCI-1200	Computer Science II	BCBP-4310	Genetic Engineering
CSCI-2300	Data Structures and Algorithms	BCBP-4860	Protein and Nucleic Acid Structure
BIOL-4510	Molecular Genetics		

**Minor Programs**

Students majoring in chemistry, biology, bioinformatics, or chemical engineering may obtain a minor in either biochemistry or biophysics by completing the courses listed below. Since different essential courses are included in the requirements of each major, the minor requirements vary for different majors.

**Biochemistry Minor for Chemistry Majors**

Students must complete BCBP-4760, BCBP-4770, and two of the following: BCBP-4710, BIOL-4260, BIOL-4620, BCBP-4860, BCBP-4310, BCBP-4780, BCBP-4790, CHEM-4310.

**Biophysics Minor for Chemistry Majors**

Students must complete BCBP-4760, BCBP-4770, and two of the following: MATH-2400, MATH-4720, BIOL-4270, BCBP-4210, BCBP-4810, BCBP-4870, PHYS-2510.

**Biochemistry Minor for Biology and Bioinformatics Majors**

Students must complete BCBP-4770, CHEM-2440, and two of the following: BCBP-4710, BIOL-4260, BCBP-4860, BCBP-4780, BCBP-4790, BCBP-4310, CHEM-4310.

**Biophysics Minor for Biology and Bioinformatics Majors**

Students must complete BCBP-4770, CHEM-2440, and two of the following: MATH-2400, MATH-4720, BIOL-4270, BCBP-4210, BCBP-4810, BCBP-4870, PHYS-2510.

**Biochemistry Minor for Chemical Engineering Majors**

Students must complete BIOL-1010, BCBP-4760, BCBP-4770, and one of the following: BCBP-4710, BIOL-4260, BIOL-4620, BCBP-4790, BCBP-4780, BCBP-4860, BCBP-4310, CHEM-4310.

**Biophysics Minor for Chemical Engineering Majors**

Students must complete BIOL-1010, BCBP-4760, BCBP-4770, and one of the following: MATH-4720, BIOL-4270, BCBP-4210, BCBP-4810, BCBP-4870.

**Graduate Programs**

Both the Master of Science and Master of Science in Applied Science degrees are available within the Biochemistry and Biophysics program. Each requires a total of 30 credit hours.

For the Master of Science degree in Biochemistry and Biophysics, 15 credits must be in courses at the 6000–6999 level. In addition, six to nine credits must be in research. Students must either have had in their undergraduate study or must include in their M.S. Plan of Study three of the molecular biophysics module courses listed above in the undergraduate curriculum, or their graduate equivalents. A thesis based on original work is required.

The Master of Science in Applied Science degree program features the possibility of combining master's level cooperative education participation or equivalent industrial experience, with course work for the degree in biochemistry and biophysics.

**Course Descriptions**

Courses of interest to Biochemistry and Biophysics students are described in the Course Description section of this catalog under the codes BIOL, BCBP, and CHEM. Course selections should be discussed with the student's adviser.

**Bioinformatics and Molecular Biology**

**Director, Undergraduate and Graduate Degree Programs:** John C. Salerno

**Program Home Page:** [http://www.rpi.edu/dept/science/www/Ugrad\\_options/Bioinformatics](http://www.rpi.edu/dept/science/www/Ugrad_options/Bioinformatics)

Revolutions in biotechnology and information technology are changing the world. Advances in molecular genetics, coupled with improved capability in robotics, computer science, and other technologies, have made mass sequencing of genetic material a part of the scientific landscape. Previously, growing sequence databases had been compiled one gene at a time by individual research laboratories. This cottage industry approach is still part of the effort, but numerous genome-sequencing projects have produced the entire sequences of viruses, bacteria, and increasingly complex eukaryotic organisms. The complete human genome with its  $10^9$  base pairs is now complete.

The enormous treasure trove of information that the sequence databases and their smaller structural counterparts represent is a priceless resource. Applications include the identification of targets for drug discovery, the study of structural and functional relationships, and work on molecular evolution. Timely advances in computer science have made the storage, organization, and utilization of these very large data collections possible.

Bioinformatics approaches incorporate expertise from the biological sciences, computer science, and mathematics. Allied computational approaches using chemical and physical methods are also of widespread interest. Rensselaer's bioinformatics and molecular biology undergraduate curriculum includes training in mathematics, chemistry, and physics. At the program's core are courses in the theory and practice of bioinformatics that deal with topics such as database design and search algorithms, sequence alignment, sequence analysis, and molecular modeling. The core includes a molecular biology sequence and training in drug discovery.

The curriculum is extremely flexible, allowing for dual majors with several other disciplines including computer science. Advanced courses are available through the biology program and the biochemistry and biophysics program, including a strong set of advanced laboratory courses. Through appropriate elective selection, students planning careers as molecular biologists with a computational background or as fully trained computer scientists with a knowledge of biological sciences can adapt the program to their needs.

There are extensive opportunities to pursue undergraduate research in faculty laboratories. The bioinformatics and molecular biology program also serves as an excellent premedical curriculum.

### **Research Innovations and Initiatives**

Bioinformatics research at Rensselaer includes the design and application of algorithms for sequence database searching, sequence alignment, and sequence analysis, molecular modeling, and allied areas in computational chemistry and simulation of biological processes. Closely related research in molecular genetics and biochemistry provides concrete applications for graduate and undergraduate students. A diverse group of agencies including NIH, NSF, the American Diabetes Association, and NASA fund this work. Research projects range from drug discovery, enzymology, signal transduction, protein structure, and protein folding to studies on environmental adaptations of microorganisms.

### **Faculty**

**Biology:** C. Bystroff, D. Crone, J. Diwan, J.F. Koretz, J.C. Salerno, S.M.E. Smith

**Chemistry:** C.M. Breneman, W. Colon, M. Wentland

**Computer and Information Science at Hartford:** T. O. Martyn

**Computer Science:** B.K. Szymanski, M.Zaki

**Decision Sciences and Engineering Systems:** M.J. Embrechts

**Mathematical Sciences:** M. Zuker

### **Undergraduate Programs**

#### **Bioinformatics and Molecular Biology Undergraduate Curriculum**

This degree program is designed to prepare students for admission to graduate or professional school. The philosophy behind it is to leave as many options as possible to the student. This flexibility is essential for those students who have specific interests and goals other than those spelled out in more traditional curricula.

**First Year****Fall**

	<b>Credit hours</b>
MATH-1010	Calculus I .....4
CHEM-1100	Chem. I .....4
BIOL-1010	Intro. to Biology. ....4
BIOL-1020	Intro. to Biology. Lab.....1
	Hum. or Soc. Sci. Elective .....4

**Spring**

	<b>Credit hours</b>
MATH-1020	Calculus II .....4
CHEM-1200	Chem. II .....4
BIOL-2120	Intro. Cell and Molec. Biol.....4
	Hum. or Soc. Sci. Elective .....4

**Second Year****Fall**

	<b>Credit hours</b>
	Hum. or Soc. Sci. Elect. ....4
CHEM-2250	Organic Chem. I .....4
PHYS-1100	Physics I.....4
CSCI-1100	Comp. Sci I.....4

**Spring**

	<b>Credit hours</b>
CSCI-1200	Comp. Sci II.....4
CHEM- 2260	Organic Chem. II.....4
PHYS-1200	Physics II.....4
BIOL-4620	Molec. Biology .....4

**Third Year****Fall**

	<b>Credit hours</b>
	Hum. or Soc. Sci. Elect. ....4
CHEM-4330	Drug Discovery.....3
CHEM-4340	Drug Discovery Lab .....1
BIOL-4760	Molec. Biochem. I.....4
MATP-4600	Prob. Theory & Aps. ....4

**Spring**

	<b>Credit hours</b>
	Hum. or Soc. Sci. Elective .....4
	Hum. or Soc. Sci. Elective .....4
	Elective .....4
BIOL-4770	Molec. Biochem. II .....4

**Fourth Year****Fall**

	<b>Credit hours</b>
BIOL-4720	Molecular Biol lab.....4
BIOL-4540	Bioinformatics I .....4
	Elective.....4
	Elective.....4

**Spring**

	<b>Credit hours</b>
BIOL-463	Molecular Biol. II.....4
BIOL-455	Bioinformatics II .....4
	Elective.....4
	Culminating Exp.*.....3

This curriculum requires a minimum of 128 credit hours.

**Elective Recommendations****Biochemistry**

BCBP-4310	Genetic Engineering	BCBP-2830	Out of Class Exp. in Biochemistry and Biophysics
BCBP-4810	Biological Spectroscopy	BCBP-2940	Readings in Biochemistry and Biophysics
BCBP-4210	Biophysical Methods	BCBP-2990	Research Thesis
BCBP-4860	Protein and Nucleic Acid Structure	BCBP-4210	Biophysical Methods
BCBP-4710	Biochemistry Laboratory		
BCBP-2900	Research in Biochemistry and Biophysics		

**Biology**

BIOL-1010	Introduction to Biology	BIOL-4420	Introductory Immunology
BIOL-2310	Microbiology	BIOL-4510	Molecular Genetics
BIOL-2500	Genetics and Evolution	BIOL-4740	Cell and Developmental Biology Laboratory
BIOL-4270	Human Physiology I		
BIOL-4280	Human Physiology II		

\*Chosen from one of the following courses: BIOL-4070 or BIOL-4990.

**Chemistry**

CHEM-2440	Physical Chemistry for Life Sciences	CHEM-4520	Chemical Information
CHEM-4300	Medicinal Chemistry	CHEM-4620	Introduction to Polymer Chemistry
CHEM-4310	Bioorganic Mechanisms	CHEM-4640	Polymer Science Laboratory
CHEM-4450	Macroscopic Physical Chemistry	CHEM-4810	Chemistry of the Environment
CHEM-4460	Microscopic Physical Chemistry		

**Computer Science**

CSCI-1100	Computer Science <sup>3</sup>	CSCI-4020	Computer Algorithms
CSCI-1200	Computer Science II	CSCI-4260	Graph Theory
CSCI-2200	Programming in C++	CSCI-4380	Database Systems
CSCI-2300	Data Structures and Algorithms		

**Mathematics**

MATH-2010	Multivariable Calculus and Matrix Algebra
MATH-2400	Differential Equations
MATH-4720	Mathematics in Medicine and Biology

**Other**

DSES-4140	Statistical Analysis
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**Graduate Program**

The primary goal of the of the master's degree program in this field is to educate students for jobs in biotechnology, pharmaceuticals, and related industry sectors. The professional Master of Science in Applied Science program with a concentration in bioinformatics is also available to those wishing to upgrade their skills while employed in industry. The Master of Science in biology with a concentration in bioinformatics may attract those desiring an M.S. degree before proceeding to professional study in medicine or an allied health field. It may also be useful to students with a B.S. degree in biological sciences who wish to prepare for eventual entry in to a doctoral program at Rensselaer or elsewhere. It is possible to enter the doctoral program in biology with a concentration in bioinformatics.

**Center for Inverse Problems (IPRPI)**

**Director:** Joyce R. McLaughlin

**Center Home Page:** [www.iprpi.rpi.edu](http://www.iprpi.rpi.edu)

IPRPI Center research programs emphasize cross disciplinary inverse problems the solution of which have a significant impact on society, advance scientific understanding and contribute to the research education of young people who will join the scientific and engineering enterprise. The research focus of inverse problems is to find objects and/ or their material or biological properties that cannot be directly measured. For these problems, application areas include geophysics and geotechnical work including earthquake dynamics, medical imaging that targets medical diagnosis, radar imaging including enhancing home security, and a broad set of problems in solid mechanics and electromagnetics. Applied mathematics and computing play a central role. This is a vast scientific area, in which Rensselaer has a significant, high quality, well established science and engineering base.

Among those problems addressed at Rensselaer, are some at the most basic scientific level, for example finding properties of the earth's substructure from seismic measurements, or defining new experiments where the data yield new human tissue properties. Others are focused on direct applications, for example establishing the origin of contaminants measured in ground water, finding sediment properties of the

<sup>3</sup> Required if lacking computer science skills.

seabed, locating objects concealed by vegetation cover, locating mines in the sea environment, finding malignant tumors in biological tissue, locating sources of heart malfunction, or finding temperature distributions in inaccessible regions. In all cases it is either not possible, as in determining the earth's substructure properties, or not desirable, as in locating tumors in tissue, to make direct measurements. In all cases, solution of these problems results in improved quality and safer lives.

Scientific challenges include modeling of the physical problem, creation of new mathematics for analysis of the model, identification of appropriate (often large) and/ or rich data sets, scientific computing and visualization, and experimental verification. Some approaches are based on effective use of a mathematical model in order to make optimal use of the data; other approaches involve model-blind "data mining" methods. Since inverse problems are concerned with the processing of data and extraction of relevant information, the field is a part of Information Technology.

Rensselaer's goal in creating this center is to create a synergistic group of researchers with complementary talents and related interests whose combined expertise can successfully solve an even wider group of important problems. Funding includes significant opportunity for postdoctoral fellows and graduate students who work in team environments to advance problem solutions.

### **Affiliated Faculty**

**Mathematical Sciences:** J. McLaughlin, M. Cheney, D. Isaacson

**Earth and Environmental Sciences:** S. Roecker, R. McCaffrey, C. Williams

**Mechanical, Aerospace and Nuclear Engineering:** A. Maniatty

**Civil Engineering:** M. Zeghal

## **Center for Pervasive Computing and Networking**

**Director:** Boleslaw K. Szymanski, Computer Science

**Associate Directors:** Shivkumar Kalyanaraman, Electrical, Computer and System Engineering, and Bulent Yener, Computer Science

**Program Home Page:** <http://www.rpi.edu/cpcn>

A multidisciplinary group of researchers from the Schools of Engineering and Science has come together in Rensselaer's Center for Pervasive Computing and Networking to collaborate on projects that contribute to the goal of pervasive computing. This vision foresees a world in the not-distant future in which computer systems are embedded in everything: from personal digital assistants to implanted biological devices, to bridge-monitoring systems, and to teams of robots sent into a collapsed building to locate survivors. Untethered - wireless - communication is constant and, in many cases, so automated that human intervention is unneeded. Wireless, broadband community systems inexpensively bring people together for virtual town meetings, video doctor-patient conferences, and on-line business transactions. Computers in automobiles share information on congestion, quickly computing alternate routes. The promises are immense, but the challenges are formidable. Some of the major research areas currently pursued by the researcher in the Center are listed below.

## Research Innovations and Initiatives

### Grids and Worldwide Computing

As workstations and desktop computers gain power and increasing numbers are connected to the Internet 24 hours a day, a movement has arisen to create both formal and ad hoc networks in which users combine their computing power, utilizing idle time on machines ranging from individual desktops and PCs to clusters of PCs to supercomputers to form parallel processors capable of tackling very large problems. To achieve these goals, advances are needed in many areas, including programming and protocols for parallel processing, tracking and accessing widely distributed pieces of data, and routing messages over a constantly changing and sometimes unreliable network. Although grid computing has made a lot of progress in recent years through projects such as Globus, the focus in Rensselaer's Center is on more dynamic and autonomous environments in which task allocation, migration, and fault tolerance are supported automatically.

### Cybersecurity

Without serious attention to security issues, the world of pervasive computing could turn rapidly from dream to nightmare, as on-line criminals and terrorists steal private information, destructively attack individual computers and entire networks, and send damaged and dangerous programs to unprotected systems. Center researchers are investigating use of data mining systems, finite state finite automata augmented with probabilities, bioinformatics techniques, normally used to match DNA sequences, and recursive data mining to detect variations from the user's normal behavior. They are also exploring the use of generic code-carrying proofs as a secure and memory-stingy method of sending programming code. Another group is working on security for an ad hoc wireless system and identifying security gaps and designing protection against specific attacks in the Border Gateway Protocol.

### Networking

Center researchers have developed very efficient methods to run simulations to detect problems on computer networks and then to apply traffic management techniques to solve the problems. Their goals are to reduce congestion, automate many management tasks, and improve quality of service. They use these simulations to optimize very complex systems. They are developing BANANAS, an Internet architectural framework, that gives messages more flexibility in the routes they choose, and working on overlay systems that can deliver very reliable broadband services to groups of users. Another team developed Genesis (The General Network Simulation Integration System), which divides a large network or even the entire Internet into domains and runs a simulation of each over a given time interval on a separate processor. The processors then exchange information and run new simulations for the time interval until they converge on a solution.

### Wireless Networks

Unlike cell phone systems, in which messages travel by way of fixed towers, devices in ad hoc wireless systems communicate directly with each other. They pass messages from node to node as needed, even as some devices move around and others unpredictably come on- or off-line, creating a constant need to find new routes for messages. Rensselaer researchers are working on all levels of the technology to make such networks efficient and reliable. The new approaches include using microelectronics techniques to create a multi-hop optical wireless system and using radio frequency (RF) and optical techniques to build an inexpensive and easily accessible community network around the Rensselaer campus. Centers teams are also working on distributed networks of sensors and actuators, developing methods through which groups of cameras can exchange information and work together, and developing techniques for distributed groups of robots to communicate and cooperate.

## Center for Terahertz Research

**Director:** Xi-Cheng Zhang

**Center Home Page:** [www.rpi.edu/terahertz](http://www.rpi.edu/terahertz)

The faculty members of the Center for Terahertz Research are among the world's first scientists to exploit the unique advantages of terahertz (THz) radiation. Using the relatively unexplored terahertz portion of the electromagnetic spectrum, they are creating innovative imaging and sensing technologies that hold enormous potential in biomedical imaging, genetics diagnostics, microelectronics and the chemical and biological materials identification fields that support homeland defense initiatives.

The promise of terahertz wave radiation, known as "T-rays," is being realized through ongoing research at the THz Center's state-of-the-art laboratories: Dr. Xi-Cheng Zhang's THz Optics lab, Dr. Michael Shur's THz Electronics lab, the THz Quantum Optics Lab, and Dr. Ingrid Wilke's THz lab and Dr. Gwo-Ching Wang's Studio lab. Together, these researchers are overcoming significant challenges posed by the fundamental physics that underlie this large and historically inaccessible portion of the electromagnetic spectrum.

Rensselaer's THz research team has become the established leader in the development and application of terahertz technology. Their breakthroughs in microscopy, imaging, and development of electro-optic THz emitters and detectors have opened the door to tremendous opportunities for THz radiation throughout major industries.

Research at the center is currently focused on the generation and detection of free-space THz beams using ultra-fast optics and electro-optic crystals. A primary goal is to develop and refine the instrumentation finding higher dynamic ranges, achieving faster data acquisition, and increasing sensitivities to enable the detection of monomolecular layers that will move THz technology beyond its current niche applications to support wider use in biomedicine. During the last several years, scientists and engineers from more than 75 universities, companies, and clinics have visited the labs, and Rensselaer's THz team has helped scientists from 18 countries learn how to use THz sensors.

Rensselaer's terahertz research group has received more than \$14 million in grants from the National Science Foundation, Army Research Office, Army Research Laboratory, Air Force Office of Scientific Research, Department of Energy, Defense Advanced Research Projects Agency, W.M. Keck Foundation, Research Corporation, IMRA America Incorporated, Molecular OptoElectronic Corporation, 3-D Digital Corp., Zomega Technology Corporation, NASA, and Lockheed Martin.

The center's labs are equipped with the most advanced photonic and opto-electronic instrumentation for generating, measuring and recording picosecond and femtosecond terahertz radiation waves. Rensselaer's Center for Terahertz Research stands at the forefront of terahertz technology, a science still in its infancy yet expected to become one of the most promising research areas for transformational imaging in the 21st century.

### Affiliated Faculty

**Michael Shur**, Patricia W. and C. Sheldon Roberts Professor, Professor of ECSE & Physics, Director, Center for Broadband Data Transport Science and Technology

**Ingrid Wilke**, Assistant Professor of Physics

**Gwo-Ching Wang**, Professor and Chair of Physics

## Environmental Science

**Director:** Teofilo Abrajano, Jr.

**Program Home Page:** <http://www.rpi.edu/dept/envsci>

Environmental issues continue to be prominent in the lives of everyone. Essentially no place on the planet has escaped perturbation resulting from activities of an ever-growing human population. The challenge is to maintain those attributes of the Earth that make it habitable while at the same time providing for human needs. Science will play an absolutely critical role in enabling technological civilizations to move toward sustainable interactions with the natural world.

While effective environmental scientists must be rigorously educated in one area of science, they must have a perspective far broader than any single science discipline affords. In fact, cognizance of considerations beyond just the sciences is also required. Rensselaer's environmental science degree addresses these challenges with a multifaceted program.

The Environmental Seminar considers topical environmental issues from numerous perspectives. Through it, students receive a broad overview of environmental challenges in preparation both for their major and for leadership roles in environmental science.

A guided selection of courses in the Humanities and Social Sciences broadens perspective and understanding of the human approach to and interactions with the natural world. Two courses, IENV-4500 and IENV-4700, taken in the final two years of study, enable the student to grasp the broadly varied, interdisciplinary dimensions of the natural environment and its human dimension. The requirement for an intensive environmental experience is an overt acknowledgement that environmental science is a discipline concerned with the natural world.

The science core of 38 credit hours gives each student a common core of 10 courses that introduces important approaches for understanding the natural world. The student-elected concentration in one of the traditional scientific disciplines gives depth in one area of science. With judicious use of the 28 credit hours of electives, a student can prepare to pursue a number of career options including graduate study in the concentration discipline.

### Research Innovations and Initiatives

The School of Science offers numerous opportunities for advanced study. Some examples include the impact of acid rain on the Adirondacks, characterization of subsurface microorganisms with the potential for bioremediation, PCB and other contaminant analysis in the Hudson River, studies of aquatic biota in Lake George, and nitrogen cycling in local ecosystems. Students are encouraged to seek research opportunities in environmental science as described in each of the traditional scientific disciplines.

### Faculty Committee

R.F. Bopp, C.W. Boylen, S.J. Breyman, J.M. Gowdy, G.M. Korenowski, P.D. Persans, W.L. Siegmann.

### Undergraduate Program

#### Environmental Science Curriculum

This curriculum leads to a B.S. in environmental science. A typical four-year program is illustrated below. However, the order in which students take courses within the first two years is flexible.

**First Year****Fall**

MATH-1010	Calculus I.....	4
BIOL-1010	Introduction to Biology .....	4
CHEM-1100	Chemistry I .....	4
	Hum. or Soc. Sci. Elective <sup>4</sup> .....	4

**Credit hours****Spring**

MATH-1020	Calculus II <sup>5</sup> .....	4
CHEM-1200	Chemistry II .....	4
ERTH-1200	Geology II .....	4
	Hum. or Soc. Sci. Elective .....	4

**Credit hours****Second Year****Fall**

CHEM-2250	Organic Chemistry I .....	4
ERTH-2210	Field Methods .....	2
PHYS-1100	Physics I .....	4
IENV-1920	Environmental Seminar.....	2
	Hum. or Soc. Sci. Elective .....	4

**Credit hours****Spring**

BIOL-2120	Intro. to Cell and Molecular Biology ..	4
	Concentration and Elective <sup>6</sup> .....	8
	Hum. or Soc. Sci. Elective .....	4

**Credit hours****Third Year<sup>7</sup>****Fall**

IENV-4500	Global Environmental Change .....	4
	Concentration and Elective .....	12

**Credit hours****Spring**

ERTH-4180	Environmental Geology .....	4
	Concentration and Elective .....	8
	Hum. or Soc. Sci. Elective .....	4

**Credit hours****Fourth Year****Fall**

IENV-4700	One Mile of the Hudson River I <sup>8</sup> .....	4
	Concentration and Elective .....	12

**Credit hours****Spring**

	Concentration and Elective .....	16
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**Credit hours****Concentrations**

The environmental science degree program requires one concentration. Concentration options and the associated courses are shown below.

**Biology**

(all of the following)

BIOL-2310	Microbiology
BIOL-2500	Genetics and Evolution
BIOL-4620	Molecular Biology
BIOL-4760	Molecular Biochemistry I
CHEM-2260	Organic Chemistry II

(one of the following)

BIOL-4320	Geomicrobiology
BIOL-4700	Freshwater Ecology Laboratory
BIOL-4850	Principles of Ecology

**Chemistry**

(all of the following)

CHEM-2030	Inorganic Chemistry I
CHEM-2150	Equilibrium Chemistry and Quantitative Analysis
CHEM-4450	Macroscopic Physical Chemistry
CHEM-4810	Chemistry of the Environment

(one of the following)

CHEM-2260	Organic Chemistry II
CHEM-4460	Microscopic Physical Chemistry

(one of the following)

CHEM-2950	Undergraduate Research (3 credits)
CHEM-4xxx	Chemistry Elective
CHEM-4990	Senior Thesis

<sup>4</sup> Hum. and Soc. Sci. courses should be selected in consultation with the adviser and the Environmental Science Faculty Committee. Examples of environmentally relevant options include: ECON-4230, ECON-4250, IHSS-2100, PHIL-4300, STSS-1110, STSS-2300, STSS-4540 and STSS-4320.

<sup>5</sup> With permission of the director of Environmental Sciences, a student may elect another Math course (Course numbers MATH-xxxx, MATP-xxxx, or courses cross-listed with these numbers).

<sup>6</sup> Each student is required to elect one of the concentrations listed below.

<sup>7</sup> Each student is required to engage in an activity that qualifies as an intensive environmental experience as described below.

<sup>8</sup> This course is offered every other year in the fall term of odd-numbered years and therefore is a junior year course for some students

**Computer Science—students may choose from two options:****Option A (Computer Science)**

(all of the following)

- CSCI-1100 Computer Science I
  - CSCI-1200 Computer Science II
  - CSCI-2300 Data Structures and Algorithms
  - CSCI-2400 Models of Computation
  - CSCI-2500 Computer Organization
- One course from the series CSCI-4xxx

**Option B (Scientific Computation)**

(all of the following)

- MATH-2010 Multivariable Calculus and Matrix Algebra
- MATH-2400 Introduction to Differential Equations
- CSCI-1100 Computer Science I
- CSCI-1200 Computer Science II
- CSCI-2300 Data Structures and Algorithms
- CSCI-4800 Numerical Computing

**Geology**

(Six of the following courses, four of which must be at the 4000 level)

- ERTH-2100 Introduction to Geophysics
- ERTH-2140 Introduction to Geochemistry
- ERTH-2330 Earth Materials
- ERTH-2610 Oceanography

- ERTH-2120 Structural Geology
- ERTH-4710 Groundwater Hydrology
- ERTH-4540 Organic Geochemistry
- ERTH-4070 Sedimentology
- ERTH-4190 Environmental Measurements
- ERTH-4690 Aqueous Geochemistry

**Mathematics**

(both of the following)

- MATH-2010 Multivariable Calculus and Matrix Algebra
- MATH-2400 Introduction to Differential Equations

(one of the following)

- MATH-4200 Mathematical Analysis I
- MATH-4600 Advanced Calculus

(one of the following sequences)

- MATH-4700 Foundation of Applied Mathematics
- MATP-4700 Mathematical Methods of Operations Research

(two of the following)

- MATH-4210 Mathematical Analysis II
- MATH-4300 Introduction to Complex Variables: Theory and Applications
- MATH-4400 Introduction to Dynamical Systems and Chaos
- MATH-4500 Methods of Partial Differential Equations of Mathematical Physics
- MATH-4800 Numerical Computing
- MATH-4820 Introduction to Numerical Computing for Differential Equations
- MATP-4600 Probability Theory and Applications
- MATP-4620 Mathematical Statistics

**Physics**

(all of the following)

- MATH-2400 Introduction to Differential Equations
- PHYS-1200 Physics II
- PHYS-2100 Introduction to Theoretical Physics

- PHYS-2330 Intermediate Mechanics I
- PHYS-2510 Quantum Physics I
- PHYS-4210 Electromagnetic Theory

## Minor Programs

Sustainable stewardship of the environment is the single most important challenge facing the world, and this minor is ideal for students wishing to develop a multidisciplinary background in environmental science. The program of study requires a minimum of four courses of which three are required. These required courses include: BIOL-4850, CHEM-4810, and EARTH-4180. A minimum of one additional course must be selected from the list below. At the discretion of the adviser and the environmental science program director, the student may take an alternative not on the list, or complete a four-credit research project. At least three of the four courses required for the minor must be at the 4000 level.

ENVE-4310	Applied Hydrology and Hydraulics	BIOL-4700	Fresh Water Ecology Laboratory
MANE-4700	Solar Devices and Renewable Energy	BIOL-4870	Environmental Toxicology
BIOL-4310	Industrial Microbiology	ERTH-4710	Groundwater Hydrology
BIOL-4320	Geomicrobiology	ERTH-4690	Aqueous Geochemistry
BIOL-4440	Microbial Ecology	ERTH-4180	Environmental Geology
ERTH-4690	Aqueous Geochemistry	ERTH-4540	Organic Geochemistry
ERTH-4500	Global Environmental change		

Students interested in developing a broad, multidisciplinary background in energy to complement their more focused major program may also consider another minor option—the Interschool Minor in Energy. See Interdisciplinary Programs and Research in the Humanities and Social Sciences section of this catalog for details on this program.

## Special Opportunities in Environmental Science

### Environmental Studies Program

Building on the unusual strength and breadth of Rensselaer's synthesis of engineering, science, and the humanities and social sciences, the Environmental Studies Program offers students a unique educational opportunity to develop a truly multidisciplinary approach to environmental studies.

Students who enter Rensselaer in the Environmental Studies Program will take a broad range of basic courses in their first two years. They then choose one of five majors: economics (with an ecological economics focus), environmental engineering, environmental science (with a concentration in a specific area of science), hydrogeology, or science, technology, and society (with an environmental focus). To complement their major programs, students may earn a wide variety of minors. All the majors in the program offer their own environmental minors, and the Schools of Architecture and Management offer special environmental courses as well. Rather than becoming narrow specialists, students participating in the Environmental Studies Program will receive a multidisciplinary education that prepares them to address a variety of environmental problems.

See Interdisciplinary Programs and Research in the Humanities and Social Sciences section of this catalog for a complete description of this program.

### Intensive Environmental Experience

In consultation with the adviser and with the approval of the director of the Environmental Science Program, students must select and engage in an intensive activity related to the environment. They may do so either directly (as in "natural world" experience) or indirectly through temporary employment (e.g., as a co-op or intern) or through participation in an environmental research monitoring or assessment program. The environmental experience, envisioned typically as a summer activity occurring after the sophomore or junior year, must last at least a month and, in some cases, may be associated with earning academic credit. To successfully fulfill this requirement, students must document the experience and obtain approval for it from the Environmental Science Faculty Committee.

## Interdisciplinary Science

**Chair:** Samuel C. Wait, Jr.

The Interdisciplinary Science curriculum provides an education in the sciences for undergraduate students whose interests range outside the traditional disciplines and career paths. It is suitable for students wishing to combine sciences in innovative ways or to combine science with more humanistic studies such as management, law, education, communication, public service, economics, policy-making, or community affairs. Students who are undecided among the sciences, have particular special interests, or seek nontraditional career paths may follow the Interdisciplinary Science curriculum while becoming familiar with their options.

The introductory courses recommended are the same as those for departmental science majors. However, the deep undergraduate concentration in a single science area that is characteristic of departmental majors is replaced by a broader coverage of science areas and a greater choice of courses, including nonscience courses. Students vary their programs to emphasize preparation for their own particular professional objectives.

This curriculum is suited especially for students who wish to:

- prepare for work in interdisciplinary areas of science such as material science or climatology
- combine a strong foundation in science with studies in arts, philosophy, psychology, management, economics, or public affairs
- develop a broader and more interdisciplinary education in the health-related science areas
- prepare to teach science at the secondary school or junior college level
- do graduate work in the history or philosophy of science or are interested in science as part of American culture.

A bachelor's program in interdisciplinary science is excellent preparation for an MBA or a degree in a field such as law or communications. Combinations such as these prepare students for many effective roles in today's community.

### Undergraduate Program

The core course requirements of the Interdisciplinary Science curriculum are 20 science courses, each carrying three or more credits, chosen from offerings in the fields of astronomy, biology, biochemistry and biophysics, chemistry, computer science, environmental sciences, geology, mathematical sciences (course codes MATH and MATP) and physics. Each curriculum must include courses in at least six science disciplines. For this purpose, course codes MATH and MATP are a single discipline as are course codes ASTR and PHYS. In order to ensure depth and breadth, the curriculum must consist of at least eight courses in one discipline and four courses in each of two other disciplines. The remaining four courses are to be chosen from at least three other disciplines. The eight-course concentration must include two or more courses at the 4000 level. Other Institute-wide requirements for graduation such as the humanities and social sciences core requirements must also be met.

The student's specific objectives will determine the balance of the curriculum to yield a total of 124 credits needed for graduation.

This curriculum leads to the Bachelor of Science in Interdisciplinary Science.

**First Year****Fall**

	<b>Credit hours</b>
MATH-1010	Calculus I.....4
CHEM-1100	Chemistry I <sup>6</sup> .....4
PHYS-1100	Physics I <sup>6</sup> .....4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Spring**

	<b>Credit hours</b>
MATH-1020	Calculus II.....4
CHEM-1200	Chemistry II <sup>6</sup> .....4
PHYS-1200	Physics II <sup>6</sup> .....4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Second Year****Fall**

	<b>Credit hours</b>
BIOL-1010	Intro. To Biology <sup>6</sup> .....4
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Spring**

	<b>Credit hours</b>
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Third Year****Fall**

	<b>Credit hours</b>
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Spring**

	<b>Credit hours</b>
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Science Option <sup>1,2</sup> .....3-4
	Hum. or Soc. Sci. <sup>4</sup> .....4

**Fourth Year****Fall**

	<b>Credit hours</b>
	Science Option <sup>1,2</sup> .....3-4
	Culminating Experience <sup>5</sup> .....3-4
	Elective.....3-4
	Elective.....3-4

**Spring**

	<b>Credit hours</b>
	Science Option <sup>1,2</sup> .....3-4
	Elective.....3-4
	Elective.....3-4
	Elective.....3-4

<sup>1</sup> Science Options are chosen from among the offerings of the departments of Biology, Chemistry, Computer Science, Earth and Environmental Sciences, Mathematics and Physics. EARTH-1030 and EARTH-1040, Natural Science I and II do not satisfy the Science Options. MATH and MATP are a single discipline. ASTR and PHYS are a single discipline. BIOL and BCBP are a single discipline.

<sup>2</sup> Science Option: All six science options must be fulfilled. (i). Eight courses from a single discipline; (ii) Four courses from a second discipline; (iii). Four courses from a third discipline; and (iv) One course from each of the three disciplines not represented in (i), (ii) or (iii). Two or more of the courses in the eight course sequence must be at the 4000 level.

<sup>4</sup> Humanities and Social Sciences courses shall total 24 and meet distribution requirements in the catalog.

<sup>5</sup> All students must successfully complete at least one culminating experience carrying three or more credits. Some examples are Thesis Research, Project, Software Development and Critical Assessment of Literature.

<sup>6</sup> The sequencing of courses may be rearranged to meet student's needs as long as prerequisites are met, i.e. Biology may be moved to the first, third, or fourth year if desired.

## Multidisciplinary Science

Traditionally, graduate degrees have focused on a single subject matter such as chemistry, physics, or mathematics. However, current and expected future trends in the working environment show that jobs will increasingly bridge more than one area of specialization. Biochemistry, for example, which is of major importance in today's society, now spans two or three disciplines. Practitioners must have a thorough knowledge of several areas of chemistry and biology. The same is true of bioinformatics, a new multidisciplinary field that depends on expertise in biology and computational sciences. These are just two in a growing number of fields that cross specialization. Rensselaer's M.S. and Ph.D. in Multidisciplinary Science meet the need of graduates who anticipate careers in such occupations.

Rensselaer strongly emphasizes interdisciplinary research programs that bridge disciplines within the School of Science and between the School of Science and the School of Engineering. The George M. Low Center for Industrial Innovation was specifically constructed to house research centers such as the Center for Integrated Electronics, the Center for Composite Materials and Structures, the Center for Automation Technologies, the Center for Multiphase Research, and the Scientific Computation Research Center.

Students within multidisciplinary graduate programs are under the tutelage of faculty from more than one discipline. This highly knowledgeable faculty will determine which courses the student needs, develop appropriate examinations, and supervise research activities. The dean of science appoints the doctoral committee and supervises the student's overall progress.

Students interested in pursuing such multidisciplinary graduate programs must follow Rensselaer's standard graduate admission guidelines and must seek approval from faculty representing all disciplines related to their individual programs.

Prior to admission to the program, the student must demonstrate that there has been previous contact with a faculty member at Rensselaer concerning the proposed multidisciplinary research, that financial aid is available and, with the help of the faculty member who is to be the principal research adviser, the student should prepare a preliminary Plan of Study and a preliminary research proposal that clearly indicates why this research is suited for the multidisciplinary program instead of a department program.

## The Darrin Fresh Water Institute

**Director:** Sandra A. Nierzwicki-Bauer

**Associate Directors:** Richard F. Bopp, Charles W. Boylen

The Margaret A. and David M. Darrin '40 Fresh Water Institute, with research facilities both on the main campus and at the field station on Lake George, provides opportunities for Rensselaer undergraduate and graduate students, faculty, and visiting scientists to study a number of ecosystems and conduct basic and applied research on environmental problems. The research field station, located at Bolton Landing, N.Y., includes a renovated, year-round Adirondack lodge (which houses a multi-computing facility and provides housing for students studying at the Institute during the academic year), several small cottages, a boathouse, and a 7,500-square-foot teaching and research facility.

Computer-simulation models integrate field studies with laboratory experiments. Studies of ecosystem function and the influence of human activities on specific environmental systems help prevent or minimize adverse environmental impacts. The Lake George ecosystem has been under intensive study for the past 30 years and will continue to be one focal point for the Institute's research activities. Other areas of research concentration include the Hudson River ecosystem, the effects of acid rain on the Adirondacks, the effects of land use on watersheds, studies and controls of exotic species (e.g. Eurasian Milfoil and Zebra Mussels), and the effects of environmental pollutants on both terrestrial and aquatic systems.

The Institute fosters a multidisciplinary team approach in both education and research with participants from the various disciplines within the School of Science, as well as other environmental programs across the Rensselaer campus. Other university laboratories and field stations also join in cooperative studies.

The Darrin Fresh Water Institute also has facilities on campus with the W.M. Keck Foundation Water Quality Laboratory. This laboratory is equipped with state-of-the-art instrumentation to conduct sophisticated studies of water quality and the fate of pollutants. Analytical equipment to examine the chemistry and microscopy equipment to study interactions between organisms and substrates are components of this interdisciplinary research laboratory, which is located in the Materials Research Center.

Additionally, on-campus facilities include the iEAR/Darrin Fresh Water Institute Environmental Multimedia Studio. Environment-related multimedia resources are produced in this studio. Such projects include the production and cablecasting of the Darrin Fresh Water Institute summer lecture series and the production of the DFWI home page, which includes a "virtual tour" of research facilities at the Bolton Landing field station. Visit the site at <http://www.rpi.edu/dept/dfwi/>.

The Darrin Fresh Water Institute is an integral part of Rensselaer's environmental initiative. Summer courses involving both classroom instruction and intensive field studies are held at the Lake George site. Student participation in research activities at the Institute is encouraged through the participation with individual faculty and student internships available each summer.

## New York Center for Studies on the Origins of Life

**Director:** James P. Ferris, Department of Chemistry

**Associate Directors:** Douglas C.B. Whittet, Department of Physics, Applied Physics, and Astronomy, and John W. Delano, Department of Earth and Atmospheric Sciences, and Department of Chemistry University at Albany, SUNY

**Assistant Director:** Ann Marie Strack

**Program Home Page:** <http://www.origins.rpi.edu>

The New York Center for Studies on the Origins of Life involves faculty, postdoctorals, graduate students, and undergraduate students from Rensselaer Polytechnic Institute, the State University of New York at Albany, and the College of Saint Rose in education and research programs seeking to understand how life originated and evolved. Some of the major research areas are listed below.

### Research Innovations and Initiatives

#### Sources of Organics on the Primitive Earth

Two major hypotheses for the origins of organics on the early Earth are being evaluated in the proposed research. First is the idea that the organic precursors to life were initially formed in the interstellar medium and, after processing during the formation of the solar system, were delivered to the Earth's surface. The second hypothesis is that a reducing atmosphere formed by volcanic outgassing from a reduced mantle on the primitive Earth was the source of the organic precursors for life.

#### Interstellar Sources

The organics present in the interstellar medium are investigated by ground-based and orbiting observatories in the two–25 microns wavelength range of the infrared by Douglas C.B. Whittet. These measurements have been made on the Infrared Space Observatory and on ground-based observatories in Hawaii and Chile. The high resolving power of these telescopes allows the detection of infrared frequencies characteristic of functional groups in organic molecules.

### **Shock Processing of Prebiotic Materials**

Organic molecules formed in the interstellar medium are brought to the solar nebula in the icy coatings on dust grains. Wayne Roberge is simulating the processing of ices by the accretion shock where infalling dust enters the solar nebula, by shocks inside the solar nebula, and by external wind shocks where the bipolar outflow strikes infalling material. We find that nebular and accretion shocks can anneal the ices, greatly altering the ices' capacity to retain volatile organics. The efficiency of annealing depends strongly on heliocentric distance, with important consequences for the relative volatile content of Jupiter family versus Kuiper Belt comets.

### **Reactions During Planet Formation**

An important stage of organics processing is in the planetesimals created in the early stages of the planets, moons, asteroids, and comets. When radioactive decay heated these bodies, the frozen water in them liquefied. The reaction with water and the radiation from radioactive elements further altered the organics. Meteorites are fragments from asteroids which, together with comets, are believed to have brought these organics with them when they impacted the primitive Earth. These organics are believed to be the major source of starting materials for the origins of life. Michael J. Gaffey is using infrared spectroscopic measurements to investigate the structures of the organics on the outer belt asteroids.

### **The Oxidation State of the Earth's Crust and Mantle**

John W. Delano has determined the original oxidation state of ancient volcanic rocks up to 3.96 billion years ago using the geochemistries of Cr and V. The results of that investigation were published in late 2001 and indicate that high-temperature volcanic gases were not a likely source of chemically reduced gases at any time during the last 3.96 billion years. Work is proceeding in an effort to determine the Earth's oxidation state of high-temperature volcanic gases prior to 3.96 billion years ago to see if they might have served as a source of gas species useful for the formation of prebiotic molecules.

### **Atmospheres of Titan and Jupiter**

James P. Ferris is investigating through laboratory experiments the photochemical processes in the atmospheres of Titan and Jupiter. Using a flow chemical reactor where it is possible to irradiate the low-mixing ratios of atmospheric organics, the photochemical transformations in proposed primitive atmospheres are being investigated. With a flow reactor, it is possible to obtain sufficient amounts of reactants for their identification and quantification by nuclear magnetic resonance (NMR) and mass spectrometry.

### **The RNA World**

Ribonucleic acid (RNA) was the most important biopolymer for the first life on Earth. The emphasis in this research is the prebiotic synthesis of RNA and the search for evidence of the RNA world in the introns of primitive life on Earth today.

### **Thioacids as Phosphorylating Reagents**

William J. Hagan is investigating the thermal and photochemical formation of thioacids, which represent precursors of high-energy phosphate donors that might have promoted the phosphorylation of sugars, such as ribose. The latter is a possible step in the conversion of nucleosides to nucleotides, the building blocks of RNA.

### Prebiotic RNA Synthesis

James P. Ferris is investigating the mineral-catalyzed formation of RNA from activated mononucleotides. The research will center on the origin of the RNA world, where RNA or RNA-like molecules have been proposed to be the most important biopolymers in the first life on Earth.

### Search for Catalytic RNA Sequences

The third research emphasis is Sandra A. Nierzwicki-Bauer's search for evidence of the postulated RNA world in the extant life on the Earth today. If RNA was the basis for the first life on Earth, vestiges of the sequences of ancient catalytic RNA in the RNA sequences of slow-growing, deep subsurface microorganisms may be found. The presence of the nucleotide sequence of the Group I intron, which catalyzes the splicing of RNA, is the object of the search in the introns of the subsurface bacteria.

### The Impact History of the Primitive Earth

John W. Delano is determining the timing of large impact events on the Moon, and by analogy on the Earth, and the implications for the sustainability of life on the early Earth. Impact-produced glasses from three Apollo landing sites are being chemically and isotopically analyzed individually to determine the ages of impact events on the Moon. This dating makes it possible to determine whether the impact flux was simple (e.g., monotonic decrease through time) or complex (e.g., late cataclysm).

### Minor Programs

The Biology, Biochemistry and Biophysics, Chemistry, Earth and Environmental Sciences, and Physics Departments participate in a multidisciplinary minor in Astrobiology for students majoring in these or other disciplines. Students must take a minimum of 16 credits of course work in this field. These courses include ASTR-4510, and ISCI-4500, four credits each, and two semesters of the one-credit course ISCI-4510. A further two courses outside the major field of study are also required, selected from the following:

ENVE-2110	Introduction to Environmental Engineering	ERTH-4070	Sedimentology
BCBP-4860	Protein and Nucleic Acid Structure	BIOL-4620	Molecular Biology
CHEM-2250	Organic Chemistry I	ERTH-4540	Organic Geochemistry
BIOL-4320	Geomicrobiology	BIOL-4760	Molecular Biochemistry I
CHEM-4810	Chemistry of the Environment	BCBP-4810	Biological Spectroscopy
BIOL-4440	Microbial Ecology	ASTR-2050	Introduction to Astronomy and Astrophysics

For a double major, the requirement that the two selected courses must be outside the major field of study is reduced to one provided both majors are in the primary relevant areas of study (i.e. biology, chemistry, geology, and physics).

### Affiliated Faculty

**Earth and Environmental Sciences:** J. Abrajano, M.J. Gaffey, A. Sharma, B. Watson

**Natural Sciences, the College of Saint Rose:** W.J. Hagan

**Biology:** S.A. Nierzwicki-Bauer

**Physics, Applied Physics, and Astronomy:** W. Roberge

## New York State Center for Polymer Synthesis

**Director:** Brian Benicewicz, Department of Chemistry

**Center Home Page:** <http://www.rpi.edu/polymers>

Dedicated in 1998, the New York State Center for Polymer Synthesis provides bridges for companies to work with Rensselaer faculty and students in designing, producing, and testing novel polymers than can change the way people live and work. Many high-technology industries remain materials limited, meaning that significant improvements in technology could be made if new, structurally tailored polymers with specific, predictable properties were prepared. Often, the creation of new polymers spawns entirely new industries. Thus, the center is committed to working with companies on their polymer-related problems. An extensive foundation in polymer science and special expertise in polymer synthesis has made the center highly successful in these endeavors.

To facilitate its research projects, the center houses advanced technology for the discovery, scale-up, processing, and evaluation of unique polymers. The Center's focus is threefold: groundbreaking research, corporate and government partnerships, and undergraduate and graduate research.

Current research under way at the center includes work on protein design and synthesis, studies of protein folding and its effect on diseases, using enzymes for polymer synthesis, block copolymers, inorganic polymers, controlled free radical polymerizations, preparing polymer membranes for fuel cells, and creating polymer nanocomposites. Award-winning research that involves turning waste cellulose from paper mills into the raw materials that go into new plastics has also been conducted at the center. In addition, it is also the site of world-renowned and pioneering work on photo-initiated polymerizations and their applications in photoresists and adhesive curing.

### Affiliated Faculty

**Chemical Engineering:** G. Belfort, S. Cramer, J. Dordick, S. Garde, R. Kane, S. Kumar, B. Nauman

**Chemistry:** Y. Akpalu, T. Apple, B. Benicewicz, C. Choma, W. Colon, J. Crivello, L.V. Interrante, S. Krause, J. Moore, C. Ryu

**Materials Science and Engineering:** P.M. Ajayan, C. Chung, R. Ozisik, L. Schadler, S. Sternstein