The Division of Science

In the Division of Science, programs in graduate study leading to the degree of doctor of philosophy are offered in the fields of biological sciences, biochemistry, chemistry, mathematics, and physics. Programs leading to the degree of master of science are also available in these departments.

In its programs of research and instruction, the Division of Science proposes: (1) to educate ethically grounded scientists of disciplined intelligence who can participate fruitfully in the affairs of human society; (2) to conduct research dedicated to the discovery and integration of truth and to train additional scientists with comparable skills and ideals; and (3) to interpret the principles and discoveries of science, with their implications and significance, by lectures, research, articles, and books.

Graduate students in the Division of Science are encouraged to cross departmental lines of instruction and to participate in interdisciplinary programs to broaden their outlook and promote the integration of the sciences in areas of overlap.

Biological Sciences

Chair:

Charles F. Kulpa Jr.

Director of Graduate Studies:

Gary A. Lamberti

Telephone: (574) 631-6552
Fax: (574) 631-7413
Location: 107 Galvin Life Sciences Center
E-mail: biosadm@nd.edu
Web: http://www.science.nd.edu/biology

The Program of Studies

The graduate program in biological sciences is designed to provide students with depth of knowledge and insight into their particular areas of interest and a broad background in the whole area of biology. Special efforts are made to place the students' areas of interest into proper perspective with the other areas of biology and with cognate sciences. The goal is to train the students to be professional biologists in every good sense of the word "professional."

To achieve this goal, all students are encouraged to take appropriate courses in other departments as well as in biological sciences. Formally structured interdisciplinary programs are available in biochemistry and biophysics (see program description in this *Bulletin*), and with the Department of Civil Engineering and Geological Sciences and the Department of Chemical and Biomolecular Engineering.

The Department of Biological Sciences is housed in the Galvin Life Sciences Center. The facilities are excellent for most types of laboratory research in biology. They include controlled environment rooms, photographic facilities and an optical facility (scanning and high-resolution transmission electron microscopes, plus confocal imaging system), radioisotope rooms with specialized equipment, ultracentrifuges, centralized automated sequencing and imaging systems, sterile transfer rooms, computing equipment, and facilities for behavioral and electrophysiological research. The recently completed Hank Center for Environmental Science adds more than 20,000 square feet of state-of-the-art research space for aquatic ecology and environmental biology that includes greenhouses, wet laboratories, a field sample processing room, and a fully equipped shop.

In addition, the Freimann Life Science Center provides a modern animal care facility for research and teaching. Two lakes on campus, several nearby natural areas, and the University's 7,500-acre Environmental Research Center (UNDERC) in northern Wisconsin and the upper peninsula of Michigan offer a wide variety of habitats for ecological, limnological, and entomological field studies.

A specialized teaching and research library is housed in the Life Sciences Center as a branch of the campus library. The department maintains and operates a PC-based Local Area Network (LAN) and a Macintosh LAN. The LANs are connected to University-wide networks. The department's Greene-Nieuwland Herbarium contains about 250,000 specimens. The Radiation Laboratory, a University institute for high-energy radiation studies, and the Center for Environmental Science and Technology also provide facilities and specialized instrumentation for biological research. In addition, the University maintains a Bioscience Core Facility to provide basic biochemical support for cellular and molecular biology. The University publishes the journal *The American Midland Naturalist.*

Because there are many opportunities for fruitful research in areas that tend to bridge gaps between subdisciplines of biology or between biology and other disciplines, the areas of concentration are not rigidly defined. Special programs exist in aquatic ecology, evolution and environmental biology, cellular and molecular biology, developmental biology, microbiology, parasitology, physiology, and vector biology, but even within each of these programs there is considerable flexibility in the choice of courses. Students are expected to plan, with their advisory committee, a program of courses and research appropriate to their individual needs.

In addition to the University-wide requirements of the Graduate School, applicants for admission to graduate studies in this department should be adequately prepared in general biology, physics, organic chemistry, mathematics through calculus, and one or more areas of the life sciences. Course deficiencies in these certain areas and prerequisites for advanced graduate courses may be made up at Notre Dame.

The master's degree is a 24-credit-hour program requiring the satisfactory completion of a minimum of 15 credit hours of course work, passing a research proposal review, and completing a suitable master's thesis. A student must include nine of the 24 credit hours in thesis research.

For the degree of doctor of philosophy, the student is expected to complete a 54-credit-hour requirement. This is composed of at least 24 credit hours of course work and the remainder as dissertation research. The student must pass a comprehensive examination consisting of both an oral and a written examination, write and officially have approved a dissertation on research conducted under the direction of an adviser and committee, and pass a defense of the dissertation.

Students in the doctoral degree program must also fulfill a one-year teaching requirement that usually involves assisting in the instruction of undergraduate or graduate laboratory courses. This requirement may be automatically fulfilled if the student has a graduate assistantship for financial aid.

Incoming graduate students may be assigned an interim faculty adviser by the director of graduate studies. These assignments are made with consideration of the specific academic interests of the student. It is the responsibility of the interim adviser to guide the student's program until a research adviser is selected. By the end of the first semester of the second year of residence the Ph.D. student must have chosen a faculty member as a research adviser and have begun a research program. The master's student should choose an adviser by the end of the first year of residence. The student, in consultation with his or her adviser, selects an advisory committee. The members of this committee will contribute guidance, expertise, and stimulation to the student in his or her graduate program and will serve as the examining committee for the candidacy examinations and for the final defense.

Financial Assistance

Students are offered financial assistance on a competitive basis, with consideration given to grades, GRE examination scores, recommendations, and other factors. The University offers three types of support to full-time graduate students: fellowships, graduate and research assistantships, and tuition scholarships. Students may receive one type of support or a combination of types. A number of fellowships for women and minorities are available. To be considered, Biological Sciences requires that all application materials must be received by the Graduate Admissions Office by January 15.

Most graduate students in Biological Sciences are awarded full-tuition scholarships and are supported as teaching or research assistants (TAs or RAs). A student supported by a teaching assistantship typically works 10 to 12 hours per week. Typical duties include teaching in an undergraduate laboratory section, setting up the laboratory, and grading papers. The student also takes classes and is expected to carry on thesis research. TA appointments are for nine months and are generally supplemented with a two- or three-month summer stipend from individual faculty research grants and/or departmental funds. A student supported by a research assistantship registers for some classes and carries out thesis research under a faculty research adviser. RA support comes from government, industrial, or private grant funds. RA appointments are generally for 12 months.

Course Descriptions

Each course listing includes:

- Course number
- Title
- (Lecture hours per week—laboratory or tutorial hours per week—credits per semester)
- Instructor
- Course description
- (Semester normally offered)

504. Developmental Genetics
(3-3-4) Staff
Prerequisite: An introductory genetics (BIOS 250 or BIOS 303) or equivalent. Selected topics in developmental genetics dealing with mechanisms of gene action. Consideration of the role of genes in the embryology, morphology, physiology, and behavior of organisms. (On demand)

508. Population Genetics
(3-0-3) Hollocher
*Prerequisite: I*ntroductory genetics (BIOS 250 or BIOS 303) or equivalent. This course will describe and mathematically analyze the processes responsible for genetic change within populations. (On demand)

511. Protozoology
(3-3-4) Staff
Prerequisite: A parasitology course (BIOS 415) or equivalent, or consent of instructor. Emphasis on developmental biology and evolutionary trends, analysis of mechanisms involved in host-parasite relations and disease, and epidemiology of parasitic protozoa. (On demand)

514. Field Parasitology
(2-1-3) Adams
Prerequisites: BIOS 241, 250 and 415, 415L or equivalent, and consent of instructor. This is a course using current and classical methods of identification of parasites in natural populations. Field collection will be done during fall break at UNDERC for subsequent molecular and morphological laboratory analysis. Special attention will be given to applying modern approaches to studying the common symbiotic relationships of fish, amphibians, and mollusks at UNDERC. The UNDERC participation is mandatory to take this course. (On demand)

515. Vector Genetics
(3-0-3) Besansky and Severson
Prerequisite: A course in genetics (BIOS 250 or 303) or equivalent, and consent of instructor. The principles of genetics as they apply to arthropod vectors of disease agents. (On demand)

516. Physiological Chemistry of Animal Parasites
(2-3-3) Staff
Prerequisites: Biochemistry (CHEM 420 or equivalent) and consent of instructor. Biochemistry and comparative biochemistry of animal parasites. Emphasis on intermediary metabolism, enzymology, antiparasitic agents, and host-parasite relationships. (On demand)

518. Cell Variation and Growth
(3-3-4) Staff
Prerequisite: Cell biology (BIOS 241 or 341) or equivalent. A comparison of developmental processes, e.g., growth and differentiation in single-cell and metazoan animals at the cell and cell organelle levels of organization. Systems analyzed are embryonic, regenerative, normal, and neoplastic. Laboratory: tissue culture, organ culture, cell reaggregation, microscopy, bright-field cytochemistry, phase; fluorescence. (On demand)

520. Arbovirology
(2-0-2) Grimstad
Prerequisite: Consent of instructor. A study of the methods and mechanisms of transmission of viruses by arthropod vectors and of the life histories of the vectors as they pertain to viral transmission. (On demand)

520L. Arbovirology Laboratory
(0-3-1) Grimstad
Prerequisite: BIOS 520 or Concurrent. Laboratory studies on arthropod-borne viruses. (On demand)

524. Ichthyology
(3-3-4) Staff
Prerequisite: Consent of instructor. The evolution, taxonomic classification, anatomy, physiology, aquaculture, and zoogeography of fishes, with an examination of the life history of selected species. (On demand)

524L. Ichthyology Laboratory
(0-3-1) Staff
Corequisite: BIOS 524 and consent of instructor. An examination of fish species reflecting lecture topics. (On demand)

525. Community Ecology
(3-0-3) Lodge
Prerequisite: General Ecology (BIOS 312) or equivalent, and consent of instructor. Community ecology concepts, historical development, philosophical, and methodological approaches. Emphasis is on competition, predation, temporal, and spatial variability, exotic species, and food webs. (On demand)

527. Stream Ecology
(3-3-4) Lamberti and Tank
Prerequisite: General ecology (BIOS 312) or equivalent, and consent of instructor. This course explores the interaction of biological, chemical, and physical features of streams and rivers. Quantitative analysis of stream biota and periodic physical features is conducted during field laboratory sessions. Human impacts on flowing waters are explored, along with current theory of stream ecology. (On demand)

528. Environmental Microbiology
(2-0-2) Kulpa
Prerequisite: Consent of instructor. A characterization of the roles of microbes in natural and manmade environments; their interrelations with each other, with higher organisms, and with human affairs. (On demand)

529. Theoretical Population Ecology
(3-0-3) Belovsky
Prerequisite: Consent of instructor An in-depth discussion of issues in population ecology from the analytical and theoretical points of view. (On demand)

530. Immunobiology of Infectious Disease
(3-0-3) Staff
Prerequisite: BIOS 462, 415, 435, or consent of instructor. This course provides a critical overview of various infectious organisms and how they interact with their host. Examples will include intracellular and extracellular pathogens, generation of toxins, molecular mechanisms of invasion, and immune activation and protection. Students will be expected to give oral presentations based on critical review of primary literature as well as written reports. (On demand)

531. Molecular Biology I
(3-0-3) Huber
Prerequisite: BIOS 156, 202, CHEM 224, 248 or equivalent, or consent of instructor. The first of a two-semester sequence that will provide an introduction to molecular biology, molecular genetics, and nucleic acid biochemistry. Lecture topics include physical chemistry of nucleic acids, bacterial genetics, principles of cloning, DNA replication and recombination, prokaryotic and eukaryotic transcription, and RNA processing and translation. Listed also as CHEM 531. (Fall)

532. Molecular Biology II
(3-0-3) O'Tousa
Prerequisite: BIOS 531 The second semester of the sequence. Lecture topics include: transposable elements, yeast genetics, gene families, molecular aspects of development, animal viruses, and computer-assisted analysis of nucleic acids and proteins. Listed also as CHEM 532. (Spring)

533. Proteins and Nucleic Acids
(3-0-3) Staff
The structure, stability, and interactions of proteins and nucleic acids will be discussed. The chemical rules by which these biological macromolecules operate will be examined. (On demand)

535. Comparative Endocrinology
(3-0-3) Boyd
Prerequisite: Consent of instructor. A systematic comparative analysis of chemical mediation in biological systems with special emphasis on vertebrate species. A study of the structure and function of endocrine tissues, the biochemistry of hormones and their effects on the physiology and behavior of organisms. (On demand)

536. Advanced Virology
(3-0-3) Fraser
Prerequisite: Consent of instructor. Current molecular aspects of virology including diagnosis, prevention, therapy, and genetic manipulation. (On demand)

538. Neurobiology
(3-0-3) Staff
Prerequisite: Consent of instructor. Morphology and function of the different nervous systems found in animals. The role of receptors and effectors shall be discussed. Special attention will be given to questions of neuronal control of behavior patterns. (On demand)

539. Advanced Cell Biology I
(3-0-3) Staff
Prerequisite: Consent of instructor. An upper-level course directed at graduate students and advanced undergraduates with previous background in cell and molecular biology. The course focuses on the molecular basis and regulation of cell structure and function, covering key topics that include membrane structure, function, and transport, cellular energetics, organelle biogenesis, protein trafficking, vesicular transport, signaling, and cytoskeletal function. (On demand)

540. Advanced Cell Biology II
(3-0-3) Staff
Prerequisite: Consent of instructor. A continuation and expansion of topics presented in Advanced Cell Biology I. (On demand)

543. Ethics and Science
(3-0-3) Shrader-Freschette
Prerequisite: Consent of instructor. Use of four ethical theories and five classical logical/analytical criteria to ethically evaluate case studies in contemporary science. Problems analyzed via contemporary science include practical issues of plagiarism, attribution, peer reviewing, data sharing, data ownership, collaborative science, scientific misconduct, paternalism, whistleblowing, conflicts of interest, secrecy in science, and advocacy in science. Methodological issues to be dealt with include scientists misrepresenting their opinions with confirmed science, cooking and trimming their data, failure to attend to the purposes for which their research may be used or misused, and scientists' use of evaluative presuppositions, questionable inferences and default rules, question-begging validation and benchmarking, and misleading statistics. (On demand)

554. Biological Research Applications of Computers
(3-2-4) Hellenthal
Prerequisite: Consent of instructor. Data processing techniques that have direct application to biological research and teaching. Emphasis is on the use of computers for the solution of specific biological data handling and analysis of problems. (On demand)

556. Histology
(3-3-4) Staff
Prerequisite: Consent of instructor. An in-depth examination of the normal structure of vertebrate animal tissues and cells. Histological techniques (fixation, embedding, staining) will be taught in the laboratory. (On demand)

558. Biological Electron Microscopy
(3-3-4) Staff
Prerequisite: Consent of instructor. Characteristics and biological applications of transmission and scanning electron microscopy. Current methods in ultrastructural preparation and analysis. (On demand)

560. Environmental Physiology and Biochemistry
(3-0-3) Duman
Prerequisite: Consent of instructor. A course concentrating on physiological and biochemical adaptations that enable organisms to exist under extremes of such environmental variables as temperature, oxygen concentration, osmotic concentration, pressure, water availability, pH, etc. (Fall: on demand)

561. Advanced Aquatic Ecology
(3-3-4) Lamberti and Lodge
Prerequisite: An ecology course and consent of instructor. Population interactions, community analysis, biogeochemical cycles, and ecosystem structure and functioning in streams, lakes, and oceans. (On demand)

562. Aquatic Insects
(3-3-4) Hellenthal
Prerequisite: A course in entomology, invertebrate zoology, or ecology and consent of instructor. The taxonomy and ecology of insects having aquatic stages in their life cycles. (Spring: on demand)

563. Wetland Ecology
(3-0-3) Staff
Prerequisites: BIOS 312, 312L, or equivalent and consent of instructor. Cycling of nutrients and carbon, plant communities, hydrology, successional development, and management in wetland ecosystems will be explored. Several Saturday field trips are mandatory. (On demand)

564. Behavioral Ecology
(3-0-3) Lodge
Prerequisite: An ecology course and consent of instructor. Emphasis is placed on the behavioral components of species interactions and their importance in natural selection and population regulation. Topics include adaptations and natural selection, group and kin selection, sociality and cooperations, sexuality and mating systems, predator and prey behavior, behavior of competitors, territoriality, coevolutionary arms races, signals, thermoregulation, and habitat selection. (On demand)

568. Introduction to UNDERC
(1-0-1) Belovsky
Open only to students previously accepted into the UNDERC program. (Spring)

569. Practicum in Aquatic Biology
(V-V-6) Staff
Practical training in aquatic and environmental biology through lecture and field experience at the University's environmental research facility located in northern Wisconsin and the upper peninsula of Michigan. Course includes an independent research project. (Summer)

570. Topics in Cell Biology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include bioisotopes or chemistry of cell organelles. (On demand)

571. Topics in Physiology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include invertebrate and vertebrate physiology. (On demand)

571A. Physiology Practicum
(V-V-V) Staff
Subject matter changes depending on students' needs. (On demand)

572. Topics in Botany
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include plant taxonomy or biology of lower plants. (On demand)

573. Topics in Ecology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include systems analysis in ecology or biogeography. (On demand)

574. Topics in Evolutionary and Systematic Biology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include numerical taxonomy and population genetics. (On demand)

575. Topics in Developmental Biology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective subjects include developmental physiology, determination and differentiation, extracellular matrix, and invertebrate development. (On demand)

576. Topics in Biocomputing
(V-V-1) Staff
Prerequisite: Consent of instructor. A specific area concerning the use of computers in biology will be covered each time the course is given. Lectures, demonstrations, and laboratory are variable, depending upon the subject treated. (On demand)

577. Topics in Genetics/Molecular Biology
(V-V-V) Staff
Prerequisites: Consent of instructor. Selected topics in molecular biology as reflected by the current literature. (On demand)

578. Scientific Writing
(3-0-3) Boyd
Prerequisite: Consent of instructor. Students are instructed in the skills needed to write publication-quality manuscripts. (On demand)

579. Topics in Parasitology and Vector Biology
(V-V-V) Staff
Prerequisite: Consent of instructor. Subject matter changes depending on students' needs. Prospective topics include specific diseases (e.g., Malaria, dengue), molecular genetics of vectors, bioinformatics, and others. (On demand).

580. Seminars
(1-0-1) Staff
Advanced level, current topics in the areas listed below. An introductory course in the area or consent of the instructor is usually required.

A. Ecology
B. Developmental Biology
C. Physiology/Neurobiology/Behavior
D. Genetics/Molecular Biology
E. Parasitology/Vector Biology
F. Cell Biology/Microbiology

599. Thesis Direction
(V-V-V) Staff
Research and direction for resident master's students. (Every semester)

600. Nonresident Thesis Research
(0-0-1) Lamberti
Students away from campus register for one credit hour each semester during regular academic year only. (Every semester)

611. Experimental Parasitology
(3-3-4) Adams
Prerequisite: Consent of instructor. A seminar and laboratory on current methods used in parasitological research. Protozoan, helminth, and arthropod parasites will be considered. (On demand)

622. Advanced Immunology
(3-0-3) Staff
Prerequisites: Principles of microbiology, immunology, biochemistry, or consent of instructor. A course concerned with the immunochemistry of antigens, antibodies, and their interaction. Antibody biosynthesis and the cellular aspects of the immune response are also considered. (On demand)

663, 664, 665. Methods in Cellular and Molecular Biology
(V-V-V) Staff
Prerequisite: Consent of instructor. Laboratory instruction in biochemical, molecular biological, and immunological techniques. The course is divided into three nine-week sections: protein purification and modification, gene cloning and expression, and immunochemistry and cellular immunology. Students will learn a wide range of methodologies intended to prepare them for research. (On demand)

671. Special Problems I
(V-V-V) Staff
Special topics in the field of interest of individual graduate students. (Every semester)

680. BBMG Seminar
(V-V-V) Staff
Special seminar series for MBP participants.

699. Research and Dissertation
(V-V-V) Staff
Research and dissertation for resident doctoral students. (Every semester)

700. Nonresident Dissertation Research
(0-0-1) Lamberti
Students away from campus register for one credit hour each semester during regular academic year only. (Every semester)

Other graduate courses taught on an irregular basis:

501. Advanced Molecular Genetics
502. Genetics of Lower Eukaryotes
503. Advanced Microbial Physiology
506. Cytogenetics
509. Plant Anatomy
510. Experimental Parasitology
512. Helminthology
517. Biological Microtechniques
523. Practicum in Environmental Biology
526. Invertebrate Pathology
534. Plant Physiology
537. Microbial Genetics
541. Physical Chemistry for Biologists
565. Nutrition
590. Seminar in Microbial Genetics
672. Special Problems II
681. Special Problems in Microbiology

Faculty

John H. Adams, *Associate Professor.* B.A., Hendrix College, 1978; M.Sc., Univ. of Illinois, 1982; Ph.D., ibid., 1986. (1991)

Gary E. Belovsky, *the Gillen Director of UNDERC and Professor.* B.B.A., Univ. of Notre Dame, 1972; M.F.S., Yale Univ., 1972; Ph.D., Harvard Univ., 1977. (2001)

Harvey A. Bender, *Professor.* B.A., Western Reserve Univ., 1954; M.S., Northwestern Univ., 1957; Ph.D., ibid., 1959. (1960)

Nora J. Besansky, *Professor.* B.S., Oberlin College, 1982; M.S., M.Phil., Yale Univ., 1987; Ph.D., ibid., 1990. (1997)

Sunny K. Boyd, *Associate Professor*. A.B., Princeton Univ., 1981; M.S., Oregon State Univ., 1984; Ph.D., ibid., 1987. (1987)

Frank H. Collins, *the George and Winifred Clark Professor of Biological Sciences*. A.B., Johns Hopkins Univ., 1966; M.A., Univ. of East Anglia, 1973; M.S., Univ. of California, Davis, 1980; Ph.D., ibid., 1981. (1997)

Crislyn D'Souza-Schorey, *the Walther Cancer Institute Assistant Professor.* B.Sc., Univ. of Bombay, India, 1986; M.Sc., ibid., 1988; Ph.D., Univ. of Texas, San Antonio, 1992. (1998)

John G. Duman, *the Martin J. Gillen Professor of Biological Sciences.* B.S., Pennsylvania State Univ., 1968; Ph.D., Univ. of California, San Diego (Scripps Institute of Oceanography), 1974. (1974)

Jeffrey Feder, *Associate Professor.* B.A., Pomona College, 1980; Ph.D., Michigan State Univ., 1989. (1993)

Michael T. Ferdig, *Assistant Professor.* B.S., Univ. of Nebraska, Lincoln, 1987; M.S., ibid., 1990; Ph.D., Univ. of Wisconsin, Madison, 1997. (2001)

Malcolm J. Fraser Jr., *Professor.* B.S., Wheeling College, 1975; M.S., Ohio State Univ., 1979; Ph.D., ibid., 1981. (1983)

Paul R. Grimstad, *Assistant Chair and Associate Professor.* B.A., Concordia College, 1967; M.S., Univ. of Wisconsin, 1972; Ph.D., ibid., 1973. (1976)

Kristin M. Hager, *Assistant Professor.* B.Sc., Univ. of Illinois, 1989; Ph.D., Univ. of Alabama, Birmingham, 1996. (2000)

Ronald A. Hellenthal, *Assistant Chair and Professor*. A.A., Los Angeles Valley College, 1965; B.A., California State Univ., Northridge, 1967; Ph.D., Univ. of Minnesota, 1977. (1977)

Jessica J. Hellmann, *Assistant Professor*. B.S., Univ. of Michigan, 1996; Ph.D. Stanford Univ., 2000. (2003)

Edward H. Hinchcliffe, *Assistant Professor.* B.Sc., Univ. of Dayton, 1989; Ph.D., Univ. of Minnesota, 1995. (2001)

Hope Hollocher, *the Clare Boothe Luce Associate Professor.* B.A., Univ. of Pennsylvania, 1982; Ph.D., Washington Univ., St. Louis, 1991. (2000)

David R. Hyde, *the Navari Family Director of the Center for Zebrafish Research and Professor.* B.S., Michigan State Univ., 1980; Ph.D., Pennsylvania State Univ., 1985. (1988)

Alan L. Johnson, *Professor.* B.A., Univ. of Vermont, 1972; M.S., ibid., 1975; Ph.D., Cornell Univ., 1979. (1993)

Charles F. Kulpa Jr., *Chair and Professor.* B.S., Univ. of Michigan, 1966; M.S., ibid., 1968; Ph.D., ibid., 1970. (1972)

Gary A. Lamberti, *Director of Graduate Studies, Assistant Chair, and Professor*. B.S., Univ. of California, Berkeley, 1975; Ph.D., Univ. of California, Berkeley, 1983. (1989)

Lei Li, *Associate Professor.* B.S., Shandong Univ., China, 1985; Ph.D., Georgia State Univ., 1995. (2003)

David M. Lodge, *Professor and Fellow of the Joan B. Kroc Institute for International Peace Studies.* B.S., Univ. of the South, 1979; D.Phil., Oxford Univ., England, 1982. (1985)

Mary Ann McDowell, *Assistant Professor.* B.S., Univ. of Nebraska, Lincoln, 1988; M.S., ibid., 1990; Ph.D., Univ. of Wisconsin, Madison, 1995. (2001)

Rev. James J. McGrath, C.S.C., *Assistant Chair and Associate Professor.* A.B., Univ. of Notre Dame, 1955; M.A., Univ. of California, 1963; Ph.D., ibid., 1966. (1965)

Kenneth R. Olson, *Adjunct Professor.* B.S., Univ. of Wisconsin, LaCrosse, 1969; M.S., Michigan State Univ., 1970; Ph.D., ibid., 1972. (1975)

Joseph E. O'Tousa, *Professor.* B.S., Univ. of California, Irvine, 1976; Ph.D., Univ. of Washington, Seattle, 1980. (1985)

Jeanne Romero-Severson, *Associate Professor.* B.S., Univ. of Wisconsin, Madison, 1974; M.S., ibid., 1975; Ph.D., ibid., 1984. (2003)

Jeffrey S. Schorey, *Assistant Professor.* B.Sc., Southeast Missouri State Univ., 1985; Ph.D., Univ. of Texas Health Science Center, San Antonio, 1992. (1998)

David W. Severson, *Professor.* A.A., Rochester Community College, 1970; B.A. Winona State Univ., 1975; M.Sc., Univ. of Wisconsin, LaCrosse, 1978; Ph.D., Univ. of Wisconsin, Madison, 1983. (1997)

Neil F. Shay, *Associate Professor.* B.S., Univ. Massachusetts, Amherst, 1976; M.A.T., ibid., 1979; Ph.D., Univ. Florida, 1990. (2000)

Jennifer L. Tank, *the Galla Assistant Professor.* B.S., Michigan State Univ., 1988; M.S., Virginia Polytechnic Institute and State Univ., 1992; Ph.D., ibid., 1996. (2000)

Martin P. Tenniswood, *the Coleman Professor of Life Sciences.* B.Sc., Trent Univ., Ontario, 1973; Ph.D., Queen's Univ., Kingston, 1979. (1998)

Kevin T. Vaughan, *Associate Professor.* B.A., Hamilton College, 1984; M.S., State Univ. New York, Buffalo, 1986; Ph.D., Cornell Medical College, 1992. (1998)

JoEllen J. Welsh, *Professor*. B.A., Rutgers Univ., 1975; Ph.D., Cornell Univ., 1980. (1998)

Chemistry and Biochemistry

Chair:

Marvin J. Miller

Director of Graduate Studies:

Richard E. Taylor

Telephone: (574) 631-7058
Fax: (574) 631-6652
Location: 251 Nieuwland Science Hall
E-mail: taylor.61@nd.edu
Web: http://www.science.nd.edu/chemistry

The Program of Studies

The graduate programs in chemistry and biochemistry at Notre Dame are directed toward the master's and Ph.D. degrees. Applications are taken from students seeking a degree in either chemistry or biochemistry.

The Ph.D. program is designed to prepare the student for a career in research or college-level teaching in chemistry, biochemistry, and related fields. Advanced courses in several areas of chemistry and biochemistry are available (see list below) along with regular seminars and special topics courses. Students usually begin active research during the spring semester of their first year. Admission to candidacy for the doctoral degree occurs after completion of written and oral examinations in the area of specialization.

The department considers teaching an integral part of the education of a graduate student. Teaching performance, therefore, is considered as part of the semiannual graduate student evaluations. A minimum of one year of teaching experience is required of all advanced degree-seeking students.

Both the Ph.D. and master's degrees require a dissertation based upon experimental and/or theoretical research. The department participates in interdisciplinary programs involving the Departments of Biological Sciences, Physics, and Engineering. These programs include the Keck Transgene Center, the Walther Cancer Research Center, the Radiation Laboratory, the Center for Environmental Science and Technology, and the Center for Nano Science and Technology. A student normally selects his or her area of research and thesis adviser by the end of the first semester.

The Department of Chemistry and Biochemistry has excellent facilities for research, including most modern instruments for investigations in the major areas of chemistry and biochemistry. In addition to equipment found in the research laboratories of individual faculty members, department facilities include the Lizzadro Magnetic Resonance Research Center, the Molecular Structure and Mass Spectrometry Facilities, and the Surface Science Laboratory.

The latter is maintained jointly by the Department of Chemistry and Biochemistry and the Department of Electrical Engineering. In addition to holdings in Hesburgh Library, all the major chemical, biochemical, and biophysical specialty journals are available in the Chemistry-Physics Research Library located in Nieuwland Science Hall. Other relevant holdings are found in the Life Sciences Library located in Galvin Life Sciences Center. The Radiation Research Laboratory, which is operated by the U.S. Department of Energy, is one of the world's leading research centers in radiation chemistry and draws scientists from all over the world to the Notre Dame campus. The laboratory has a staff of approximately 20 research scientists, two of whom have joint appointments in the Department of Chemistry and Biochemistry (see Radiation Laboratory in this *Bulletin*).

Currently, there are over 140 graduate students and approximately 45 postdoctoral investigators in the department. Visiting scientists from the United States and foreign countries are often in residence.

Course Descriptions

Each course listing includes:

- Course number
- Title
- (Lecture hours per week—laboratory or tutorial hours per week—credits per semester)
- Instructor
- Course description
- (Semester normally offered)

420. Principles of Biochemistry
(3-0-3) Staff
A general treatment of the various areas of modern biochemistry; including protein structure and function, bioenergetics, molecular basis of genetic and developmental processes, cellular mechanisms and intermediary metabolism. (Fall and spring)

443. Inorganic Chemistry
(3-0-3) Sevov
Group Theory, Molecular Orbital Theory, structure, and spectroscopy are used as vehicles for the introduction of molecules from inorganic, organometallic, solid state, and organic chemistry. (Fall)

521. Fundamentals of Biochemistry
(3-0-3) Nowak
The chemical properties of biological molecules such as amino acids, proteins, nucleotides, carbohydrates, lipids, and enzymes. Physical and chemical principles are utilized to understand biological processes. (Fall)

522. Intermediary Metabolism
(3-0-3) Staff
Prerequisite: CHEM 521. A study of the chemical reactions characteristic of living systems: mechanisms, regulation, and energetics of metabolism. (Spring)

531. Molecular Biology I
(3-0-3) Huber
The first of a two-semester sequence that provides an introduction to molecular biology, molecular genetics, and nucleic acid biochemistry. Topics include: physical chemistry of nucleic acids, bacterial genetics, principles of cloning, DNA replication and recombination, prokaryotic and eukaryotic transcription, and RNA processing and translation. Listed also as BIOS 531. (Fall)

532. Molecular Biology II
(3-0-3) Staff
The second semester of the sequence. Lecture topics include: yeast genetics and molecular biology; retroviruses and transposable elements; transgenic mice; and special topics covering cell cycle regulation, oncogenes, development in *Drosophila*, signal transduction, and cloning of human disease genes. (Spring)

535. Medicinal Chemistry
(3-0-3) Staff
Prerequisite: CHEM 224 or equivalent. The chemical, biological, and medical aspects of medicinal agents. The course will include CNS depressants, CNS stimulants, benzodiazepines, cardiovascular agents, analgesics, cascades (arachidonic acid, renin, peptides) antibiotics, cancer, transmitters, teratogens, metabolism, drug design, cholesterol, anti-inflammatory agents, antiulcer agents, Alzheimer's and Parkinson's diseases. (Every other fall)

599. Thesis Direction
(V-V-V) Staff
Research and reading for master's students.

601, 602. Seminar in Chemistry
(V-0-0) (V-0-0) Staff
Prerequisite: Registration as graduate student in chemistry. Lectures by invited speakers.

603. Research Perspectives in Chemistry and Biochemistry
(2-0-2) Staff
Lectures by the faculty of the Department of Chemistry and Biochemistry.

604. Effective Scientific Presentations
(2-0-2) Staff
Students are instructed in the skills needed to give research quality scientific presentations.

610. Organometallic Chemistry
(3-0-3) Brown
Structure and reactions of organometallic compounds and applications to synthetic and catalytic reactions. (Every other fall)

611, 612. Seminar in Inorganic Chemistry
(1-0-1) (1-0-1) Staff
Lectures on the topic of inorganic chemistry.

614. Advanced Inorganic Chemistry
(3-0-3) Inorganic Faculty
A course in modern inorganic chemistry, incorporating the chemistry of clusters, organometallic chemistry, bioinorganic chemistry and photochemistry. Emphasis is placed on a molecular orbital approach to topics in main group and transition metal chemistry. Aspects of solid-state chemistry are also included.

615. Inorganic Mechanisms
(3-0-3) Brown, Fehlner
A general treatment of the mechanisms of inorganic reactions, including an examination of the sources of mechanistic data. (Every other fall)

616. Solid State and Cluster Chemistry
(3-0-3) Sevov, Fehlner
A survey of synthesis, structure (geometric and electronic), spectroscopic, dynamic properties, and reactivity of solid state and molecular cluster compounds of the main group and transition metal elements. (Spring)

617, 618. Special Topics in Inorganic Chemistry
(V-0-V) (V-0-V) Staff
Recent offerings have included: Advanced Laboratory Techniques in Inorganic Chemistry; MOs in Organometallics x-ray Crystallography.

620. Bioinorganic Chemistry
(3-0-3) Scheidt
The role of metals in biological systems. (Every other spring)

621, 622. Seminar in Biochemistry
(1-0-1) (1-0-1) Staff
Lectures on the topic of biochemistry.

623. Enzyme Chemistry
(3-0-3) Nowak
Prerequisite: CHEM 522. Physical and chemical properties and mechanism of action of enzymes and their role in metabolic processes. (Every other spring)

624. Advanced Biochemical Techniques
(2-6-4) Staff
Prerequisite: Permission of instructor. Advanced laboratory in biochemical techniques with emphasis on protein purification, enzyme kinetics, carbohydrate analysis, and DNA cloning and sequencing. (Spring)

626. NMR Spectroscopy in Chemistry and Biochemistry
(3-0-3) Serianni
A survey of modern NMR methods used to determine molecular structure and conformation, study chemical and biochemical reactivity, and probe metabolic processes in biological systems. 1D, 2D, and 3D spectroscopy and MRI/MRS are treated. (Every other year)

627, 628. Special Topics in Biochemistry
(V-0-V) (V-0-V) Staff
Prerequisite: Permission of instructor. Recent offerings have included: Glycoconjugates; Spectroscopy in Biochemistry; Chemistry and Biology of RNA.

631, 632. Advanced Organic Chemistry I, II
(3-0-3) (3-0-3) Wiest, Miller
The theoretical basis of organic reaction mechanisms and a detailed study of the preparation and reactions of organic functional groups. (Fall and spring)

634. Structure Elucidation
(3-0-3) Staff
The interpretation of data from NMR, IR, MS, UV, and x-ray methods with an emphasis on the practical as opposed to the theoretical point of view. (Spring)

635, 636. Seminar in Organic Chemistry
(1-0-1) (1-0-1) Staff
Lectures on the topic of organic chemistry.

637, 638. Special Topics in Organic Chemistry
(V-0-0) (V-0-0) Staff
Recent offerings have included: Advanced Physical Organic Chemistry; Computers in Chemistry; Enzymes in Organic Synthesis; Chemical Basis of Gene Expression.

639. Synthetic Organic Chemistry
(3-0-3) Taylor
Prerequisite: CHEM 632. A systematic and critical study of the synthetic methods of modern organic chemistry including the development of multistage syntheses and organometallic reagents. (Fall)

641. Statistical Mechanics I
(3-0-3) Gezelter
Foundations of statistical mechanics; canonical, microcanonical, and grand canonical ensembles; thermodynamic properties of chemical substances in terms of partition functions; chemical equilibrium; thermal radiation; quantum statistics; and chemical kinetics and the approach to equilibrium. (Spring)

642. Chemical Kinetics
(3-0-3) Jacobs
Rates and mechanisms of chemical reactions in the condensed phase; formalisms, theory. (Fall)

643, 644. Seminar in Physical Chemistry
(1-0-1) (1-0-1) Staff
Lectures on the topic of physical chemistry.

645, 646. Seminar in Radiation Chemistry
(1-0-1) (1-0-1) Staff
A continuing informal discussion of areas in radiation chemistry currently active either at Notre Dame or elsewhere.

647, 648. Special Topics in Physical Chemistry
(V-0-V) (V-0-V) Staff
Current topics of modern theoretical and experimental physical chemistry. A recent offering is: Computer Simulation of Organic and Biological Molecules.

649. Quantum Mechanics
(3-0-3) Gezelter
A chemically oriented survey of quantum mechanics at an intermediate level; wave packets, commutator relations, angular momentum, central field problems, harmonic oscillators, and approximation methods. Some relevant mathematical concepts are developed: matrix algebra orthogonal functions. (Every other fall)

650, 651. Computational Chemistry I, II
(3-0-3) (3-0-3) Gezelter, Wiest
An overview of the fundamental theory, methodology, and applications of computational chemistry. Topics include simulation techniques such as molecular dynamics and Monte Carlo as well as a wide range of quantum chemistry methods. Applications center on organic molecules and biological systems such as proteins and DNA. Hands-on computer experience is an integral part of these courses. (Fall and spring)

652. Molecular Spectroscopy
(3-0-3) Hartland
Prerequisite: CHEM 649 or permission of instructor. A study of the interaction of light with matter, at the single- and multi-photon level. Topics include group theory, molecular vibrational analysis, nonseparability of electronic, vibrational, and rotational motion, angular momenta coupling, and time-independent and time-dependent perturbation theory. (Every other year)

653. Surface Chemistry
(3-0-3) Kandel, Jacobs, Lieberman
The chemistry and physics of surfaces and interfaces. Topics include scanning probe microscopy, atomic force microscopy, near-field scanning optical microscopy, image analysis and surface templating.

655. Chemical Reaction Dynamics
(3-0-3) Jacobs
Prerequisite: CHEM 649 or permission of instructor. An overview of experiments and theories that examine the detailed mechanisms by which atoms and molecules react. Topics include potential energy surfaces, impact parameters, energy consumption and disposal, classical trajectory simulations, and quantum scattering methods. (Every other year)

680. Seminar in Biochemistry, Biophysics and Molecular Biology
(1-0-1) Staff
Lectures on the topics of biochemistry, biophysics, and molecular biology.

697. Directed Readings
(V-V-V) Staff
Reading and research on specialized topics that are immediately relevant to the student's interests and not routinely covered in the regular curriculum.

699. Research and Dissertation
(V-V-V) Staff
Research and dissertation for resident doctoral students.

699Z. Visiting Student Research
(V-V-V) Staff
Research for visiting students.

700. Nonresident Dissertation Research
(0-0-1) Staff
Required of nonresident graduate students who are completing their dissertations in absentia and who wish to retain their degree status.

Faculty

Brian Baker, *Assistant Professor.* B.S., New Mexico State Univ., 1992; Ph.D., Univ. of Iowa, 1997. (2001)

J. Eli Barkai, *Assistant Professor.* B.S., Tel-Aviv University, 1991; M.S., ibid., 1994; Ph.D., ibid., 1998. (2002)

Subhash Chandra Basu, *Professor.* B.S., Calcutta Univ., 1958; M.S., ibid., 1960; Ph.D., Univ. of Michigan, 1966; D.Sc., Univ. of Calcutta, 1976. (1970)

Seth N. Brown, *Associate Professor.* B.S., Massachusetts Institute of Technology, 1988; Ph.D., Univ. of Washington, 1994. (1996)

Francis J. Castellino, *Dean Emeritus of Science, the Kleiderer-Pezold Professor of Biochemistry, and Director of the Keck Center for Transgene Research.* B.S., Univ. of Scranton, 1964; M.S., Univ. of Iowa, 1966; Ph.D., ibid., 1968. (1970)

Patricia Clark, *the Clare Booth Luce Assistant Professor.* B.S., Georgia Institute of Technology, 1991; Ph.D., Univ. of Texas, 1997. (2001)

Xavier Creary, *the Charles L. Huisking Sr. Professor of Chemistry.* B.S., Seton Hall Univ., 1968; Ph.D., Ohio State Univ., 1973. (1974)

Thomas P. Fehlner, *Associate Chair, and the Grace-Rupley Professor of Chemistry.* B.S., Siena College, 1959; M.A., Johns Hopkins Univ., 1961; Ph.D., ibid., 1963. (1964)

J. Daniel Gezelter, *Assistant Professor.* B.S., Duke Univ., 1989; CPS, Univ. of Cambridge 1990; Ph.D., Univ. of California at Berkeley, 1995 (1999)

Holly V. Goodson, *Assistant Professor.* A.B., Princeton Univ., 1988; Ph.D., Stanford Univ., 1995 (2000)

Gregory V. Hartland, *Associate Chair and Professor.* B.S., Univ. of Melbourne, 1985; Ph.D., Univ. of California, Los Angeles, 1991. (1994)

Paul Helquist, *Professor.* B.A., Univ. of Minnesota, 1969; M.S., Cornell Univ., 1971; Ph.D., ibid., 1972. (1984)

Kenneth W. Henderson, *Associate Professor.* First Class Honours in Chemistry, Univ. of Strathclyde (U.K.),1990; Ph.D., ibid., 1993. (2002)

Paul W. Huber, *Associate Professor.* B.S., Boston College, 1973; Ph.D., Purdue Univ., 1978. (1985)

Dennis C. Jacobs, *Professor and Fellow of the Center for Social Concerns.* B.S., Univ. of California, Irvine, 1981; B.S., ibid., 1982; Ph.D., Stanford Univ., 1988. (1988)

S. Alex Kandel, *Assistant Professor.* B.S., Yale Univ., 1993; Ph.D., Stanford Univ., 1999. (2001)

Viktor Krchnak, *Research Professor.* Ph.D., Institute of Organic Chemistry, Prague, 1974. (2003)

M. Kenneth Kuno, *Assistant Professor.* B.A., Washington University - St. Louis, 1993; Ph.D., MIT, 1998. (2003)

A. Graham Lappin, *Professor.* B.Sc., Univ. of Glasgow, 1972; Ph.D., ibid., 1975. (1982)

Marya Lieberman, *Associate Professor.* B.S., Massachusetts Institute of Technology, 1989; Ph.D., Univ. of Washington, 1994. (1996)

Joseph P. Marino, *the William K. Warren Foundation Dean of the College of Science, and Professor of Chemistry.* B.S., Pennsylvania State Univ., 1963; Ph.D., Harvard 1967. (2002)

Dan Meisel, *Professor.* B.S., Hebrew Univ. in Jerusalem, 1967; Ph. D., ibid., 1974. (1998)

Marvin J. Miller, *Chair and the George and Winifred Clark Professor of Chemistry.* B.S., North Dakota State Univ., 1971; M.S., Cornell Univ., 1974; Ph.D., ibid., 1976. (1977)

Shahriar Mobashery, *the Navari Professor of Chemistry and Biochemistry.* B.S, University of Southern California, 1981; Ph.D., University of Chicago, 1985. (2003)

Thomas L. Nowak, *Professor.* B.S., Case Institute of Technology, 1964; Ph.D., Univ. of Kansas, 1969. (1972)

Nicholas F. Paoni, *Research Professor.* B.S., Univ. of California-Davis, 1972; Ph.D., Univ. of Notre Dame, 1977. (2002)

Victoria A. Ploplis, *Research Professor and Associate Director of the Keck Center for Transgene Research.* B.A., The Dominican Univ., 1975; Ph. D., Univ. of Notre Dame, 1981. (1998)

Mary Prorok, *Research Associate Professor.* B.S., State Univ. of New York at Buffalo, 1982; Ph.D., ibid., 1991. (1998)

Elliot D. Rosen, *Research Associate Professor.* B.A., Columbia College, 1969; Ph.D., Univ. of Iowa, 1980. (1984)

W. Robert Scheidt, *the William K. Warren Professor of Chemistry and Biochemistry.* B.S., Univ. of Missouri, 1964; M.S., Univ. of Michigan, 1966; Ph.D., ibid., 1968. (1970)

Anthony S. Serianni, *Professor.* B.S., Albright College, 1975; Ph.D., Michigan State Univ., 1980. (1982)

Slavi C. Sevov, *Professor and Director of Graduate Recruitment.* B.S., Univ of Sofia, 1983; M.Sc., ibid., 1985; Ph.D., Iowa State Univ., 1993. (1995)

Bradley D. Smith, *Professor.* B.S., Univ. of Melbourne, 1982; Ph.D., Pennsylvania State Univ., 1988. (1991)

Richard E. Taylor, *Professor.* B.S., State Univ. of New York, Oswego, 1987; Ph.D., Rensselaer Polytechnic Institute, 1992. (1995)

Igor N. Veretennikov, *Research Assistant Professor.* M.S., Moscow Institute of Physics and Technology, 1989; Ph.D., University of Notre Dame, 1997. (2003)

Rev. Joseph Walter, C.S.C., *Chair of Preprofessional Studies and Associate Professor.* B.S., Duquesne Univ., 1951; Ph.D., Univ. of Pittsburgh, 1955. (1961)

Olaf Guenter Wiest, *Associate Professor.* Vordiplom, Univ. of Bonn, 1987; M.S., ibid., 1991; Ph.D., ibid., 1993. (1995)

Mathematics

Chair:

William G. Dwyer

Director of Graduate Studies:

Julia Knight

Telephone: (574) 631-7245
Fax: (574) 631-6579
Location: 255 Hurley Hall
E-mail: math@nd.edu
Web: http://www.science.nd.edu/math

The Program of Studies

The purpose of the doctoral program in mathematics is to assist students in developing into educated, creative, and articulate mathematicians. The program consists of basic courses in the fundamentals of algebra, analysis, geometry, logic, topology and ; more advanced topics and seminars; and approximately two to three years of thesis work in close association with a member of the faculty. Limited enrollment and the presence of active groups of strong mathematicians provide excellent opportunities for research in algebra, complex analysis, partial differential equations, logic, algebraic geometry, differential geometry, topology, and applied mathematics. Most students complete the program within five years; some finish in four years; a few in three.

Students are supported by fellowships and teaching assistantships. Students' teaching responsibilities are integrated into their professional development as mathematicians.

First-year students have no teaching duties and usually devote themselves full time to courses. The written candidacy examinations are taken by the beginning of the second year. The oral candidacy examination is taken during the second year. A reading knowledge of one approved language, in addition to English, is required. Ideally, the language requirement is completed by the end of the year. For more about these, see the Doctoral Regulations on the website.

The Department of Mathematics has its own building with good computer facilities and a comprehensive research library of nearly 35,000 volumes that subscribes to 275 current journals. Graduate students are provided with comfortable office space and are assured a stimulating and challenging intellectual experience.

Areas of Research

Applied Mathematics

The Department of Mathematics has about half-a-dozen faculty members actively involved in a variety of areas of mathematics and its applications to physics, engineering, biology, and problems arising from industry. The research disciplines they are pursuing, often in conjunction with members of other departments at Notre Dame, include the following: numerical analysis of PDE and of polynomial systems, nonlinear dynamical systems and partial differential equations, control theory, mathematical biology, optimization theory, interior point algorithms, coding theory, and cryptography.

Applied PDE. Partial differential equations arise from various applications in the real world; the important role of mathematical analysis and numerical study is to provide qualitative and quantitative information about the system being considered. The objectives are: to study the existence, uniqueness, convergence, and asymptotic behaviors of the solution; to establish mathematical theory about the model; to study the special properties of the solution.

There are many exciting examples of such problems where faculty at Notre Dame are involved.

(1) Free boundary problems (a PDE problem where the domain is moving) appear in material with solid and liquid states, in cell growth problems from biology, in semiconductor manufacturing through film growth.

(2) Homogenization problems. Many systems from engineering and industry have two or more different scales which are treated through Homogenization technique, an important technique which is very useful for obtaining important features of the system.

(3) Blowup problems. In many reaction diffusion systems with nonlinear source terms, finite time blowup may occur. Understanding the exact behavior of the blowup will be very helpful in understanding the system.

Coding and Cryptography. In collaboration with several faculty in the electrical engineering department we investigate the algebraic properties of block codes and convolutional codes. Coding theory is concerned with the storage and transmission of information and the ability to recover the information as completely as possible even if some of the data are lost. A good example is the genetic code stored in a DNA molecule or the ISBN used by book publishers. Coding theory is widely applied in data communication and mathematically it is interconnected with algebraic geometry on the algebraic side and with information theory on the analytic side. For about three years, one to two faculty members and several graduate students have been working on the construction of new one-way trapdoor functions to be used in the next generation of public key cryptography.

Computation and Numerics. One on-going project, being carried on with mathematicians and engineers at other institutions, is the development of the new area of numerical algebraic geometry. This area is to algebraic geometry what numerical linear algebra is to linear algebra. Its goal is the development of efficient numerical algorithms to solve systems of polynomials in several variables. This amounts to the development of numerical techniques to manipulate algebraic varieties. The approach taken is to numerically model the classical notion of generic points by random points on irreducible components of the solution set. Classical interpolation techniques combined with homotopy continuation techniques are used to numerically do what elimination theory does in computer algebra programs. One recent success is the development of numerical techniques to decompose a complex algebraic variety into its irreducible components. In particular, this gave the first homotopy algorithm to find the exact set of isolated solutions of a system of polynomials: previous homotopy algorithms find a finite set of solutions containing the isolated solutions, but often also containing solutions from positive dimensional components.

Another project, involving mathematicians, engineers, and scientists from Notre Dame and elsewhere, is the development of numerical and analytical techniques for the solution of free boundary and boundary value problems. Such problems arise in fluid mechanics (free surface fluid flows), biology (tumor and blood vessel growth), and electromagnetics and acoustics (direct and inverse scattering of radiation from complicated geometries), to name just a few. The techniques currently being investigated are geometric perturbation theory (the “small parameter” is the deformation of the free or complicated boundary from a canonical geometry) coupled with analytic continuation techniques (e.g., Pade approximation). This area of research involves rigorous mathematical analysis for the justification of the proposed perturbation series coupled with numerical implementation of these algorithms and large-scale computational simulations to gain new insight into the underlying physical models.

Mathematical Biology. Several members of the department are participating in an interdisciplinary biocomplexity program at Notre Dame which is supported by NSF. Biocomplexity is the study of the unique complex structures and behaviors that arise from the interaction of biological entities (molecules, cells, or organisms). While physical and chemical processes give rise to a great variety of spatial and temporal structures, the complexity of even the simplest biological phenomena is infinitely richer.

The biocomplexity group, which consists of researchers from the physics, mathematics, and computer science and engineering departments, studies multicellular aggregates, such as embryonic and mature tissues, which often share the properties of “excitable media” and “soft matter,” familiar to modern condensed matter physics and dynamical systems theory. Changes in tissue shape and form during development and repair, skeletal formation, gastrulation, segmentation, are well suited to analysis by physical and mathematical concepts, particularly in conjunction with modern knowledge of cells’ adhesive forces and the molecular composition and rheology of cytoplasm and extracellular matrix.

Optimization. Optimization is an interdisciplinary area of applied mathematics. Recently there have been breakthrough developments in the area of interior-point algorithms of optimization which enabled researchers to solve important large scale problems in electrical engineering, mechanical engineering, portfolio allocation, protein folding, and many other areas. Most of the departments in the University have faculty who use optimization as an important tool for solving problems.

Algebraic Geometry and Commutative Algebra

The roots of algebraic geometry and commutative algebra are to be found in the 19th-century study of algebraic equations in relation to the geometry of their solutions. Such a line of investigation goes back at least to Descartes and the idea of coordinatizing the plane. Commutative algebra and algebraic geometry study the solutions of those equations by forming an algebraic object, called a ring, given by polynomial functions on the set of solutions. While commutative algebra deals with the algebraic structure of such a ring, algebraic geometry focuses on the geometry of solution sets. Such sets include parabolas, spheres, Euclidean space, projective spaces, and a vast array of beautiful and intricate concrete curves, surfaces, and higher dimensional sets. For example, to study the set of solutions of the parabola y=x^2-3x +1 in C^2, we construct the ring C[x,y]/(y - x^2 + 3x - 1) where C represents the complex numbers. This ring represents polynomial functions on the parabola. In the same way we study the solution set of a system of any number of polynomial equations by relating the algebraic structure of its ring of polynomial functions to the geometry of the set.

In the Department of Mathematics research is conducted in many parts of this subject, including adjunction theory, Castelnuovo theory, curve theory, various aspects of the projective classification of varieties, the study of group actions, liaison theory, minimal free resolutions, Rees algebras, and the numerical analysis of polynomial systems. There is also activity in nearby areas dealing with coding theory, cryptology and nonlinear partial differential equations. (See the section on interdisciplinary mathematics.)

The main areas of focus in research on algebraic geometry and commutative algebra include:

Theory of Infinitesimals. This study involves using polynomials to construct the “simplest possible” geometric object obeying certain restraints; for example, a surface containing certain points and having specified tangents and curvatures. This has immediate application to the study of infinitesimal interpolation in science overall, as well as to the analysis of singularities and deformations in algebraic geometry.

Commutative Noetherian Rings. Properties of ideals in a commutative Noetherian ring R are studied; more precisely, with invariants associated to an ideal as well as to structures of various algebras associated to an ideal as the Blowup algebras. These are algebraic constructions that are related to an essential step in the process of desingularization, the blowup of a variety along a subvariety. For example, a curve that has a singular point (such as the solution set of~y^2=x^3 in the plane) may be “treated” by blowing up the point (in this case the origin).

Liaison Theory. This deals with the idea that when the em union of two solution sets is especially nice, then a good deal of information about one may be gleaned from information about the other. Several aspects of liaison theory (also called linkage theory) are studied in our department. It is an old theory, but developments of the last five years or so have reestablished it as an exciting area.

Minimal Free Resolutions. The minimal free resolution of an ideal describes all the generators of the ideal, all the relations among the generators, the relations among the relations, etc. Current interest includes finding the minimal free resolutions for ideals of generic forms and ideals of fat points.

Differential Geometry

The striking feature of modern differential geometry is its breadth, touching so much of mathematics and theoretical physics. It uses a wide array of techniques from areas as diverse as differential equations, real and complex analysis, topology, Lie groups, and dynamical systems. Activity at Notre Dame covers the following areas at the forefront of current research:

Submanifold Geometry. The geometry of a space is often reflected in its distinguished classes of submanifolds. Our research in this area includes minimal submanifolds, surfaces of constant mean curvature, isoparametric submanifolds, and volume minimizing cycles. Such submanifolds are themselves of physical interests (membranes, soap films, soap bubbles, and supersymmetric cycles). Umbilic points of immersed surfaces have also been extensively studied. This theory has connections to compressible plane fluid flow and general relativity.

Global Differential Geometry. One of the most important areas of differential geometry is the study of how curvature influences the topological and analytic structures of Riemannian or Kähler manifolds. Our research in this area includes results on the Euler number of Kähler manifolds, complex surfaces of positive bi-sectional curvature, A-genus and metric of positive scalar curvature, Witten genus and metric of positive Ricci curvature, spectrum of the Laplace operator, connections between manifolds of negative curvature, dynamical systems and ergodic theory, closed geodesics and marked length spectrum, harmonic functions on non-compact spaces with Gromov's hyperbolicity, splitting theorems, isoperimetric inequalities, minimal volume and CR-structures on spaces with non-positive curvature.

Partial Differential Equations and Riemannian Geometry. Many geometric problems are equivalent to problems in the theory of partial differential equations. Indeed, some properties of partial differential equations are best interpreted in a geometric way. Prescribing the curvature of surfaces in three-dimensional space, the isometric imbedding problem, variational problems in Riemannian geometry such as the Yamabe problem—all of these are geometric questions which involve a deep understanding of nonlinear partial differential equations.

Gromov-Witten Invariants and Quantum Cohomology. String theory has been a great source of inspiration for many exciting new developments in mathematics, one of which is the theory of Gromov-Witten invariants and quantum cohomology. It has profound applications in symplectic geometry, algebraic geometry, and integrable systems. Our research here has been focused on the generating function of Gromov-Witten invariants and its relation with the Virasoro algebra.

Algebra—Lie Theory

The notion of a Lie group had its origins in the study of the "continuous symmetries" of differential equations. Lie theory has subsequently become an enormously rich and beautiful theory with fundamental applications in mathematics (e.g., group theory, differential equations, topology, harmonic analysis, differential geometry), physics, and chemistry.

The algebra group at Notre Dame studies the representation theory, structure and geometry of semisimple Lie groups and Lie algebras, Kac-Moody Lie algebras and groups, finite and algebraic groups, and quantum groups, using a variety of algebraic, geometric and combinatorial methods. Our research involves the detailed study of specific representations (e.g., constructing and parametrizing representations, determining their dimensions, tensor products, extensions, etc), the study of spaces with Lie group actions and their connections to representations, and the study of global properties of representation categories.

Detailed Study of Representations. The character table of a finite group provides a rich collection of invariants of the group; classically, the "characters" correspond to ordinary (complex) representations. Of course, modular representations provide even more invariants. Some aspects of the classification of finite simple groups relied on the availability of precise information about the nature of representations for the finite Lie type groups. A finite Lie type group is closely related to the group of rational points of a simple algebraic group over a field of positive characteristic. We study mainly the "rational" representation theory of these algebraic groups; one may typically obtain from such study information on the modular representations of the corresponding finite Lie type groups.

Representation Theory and Geometry. One can often study representations of a group by constructing the group as the symmetries of a geometrical object and considering some class of functions on the object. For example, the rotation group in three variables may be regarded as the symmetry group of the two-dimensional sphere, and the representations of the rotation group arise from decomposing functions on the sphere according to the action of the Laplace operator. In more sophisticated settings, representations are associated to geometric objects with singularities, and it is a subtle and interesting question to understand the relation between the singularities and the corresponding representations.

One can also study the reverse problem and use representation theory to study geometrical problems, including classical 19th-century intersection theory. In particular, a certain kind of geometric structure called a Poisson structure yields a new approach to intersection theory problems. The Poisson structure is closely related to quantum groups.

Global Structure of Lie Representation Categories. There are many important relationships which have emerged in recent years between categories of finite or infinite-dimensional representations of algebraic groups, affine Lie algebras, and quantum groups. In all these theories, an important role is played by the Weyl group, which is a crystallographic Coxeter group. We have initiated the study of certain representation theories naturally associated to (possibly non-crystallographic) Coxeter groups and begun to study, for crystallographic Coxeter groups, the relationships of such categories with categories of representation-theoretic or geometric interest in Lie theory. We have also begun to study certain very similar representation categories which are less directly related to classical Lie theory.

Partial Differential Equations

Partial differential equations is a many-faceted subject. Our understanding of the fundamental processes of the natural world is based largely on partial differential equations. Examples are the vibrations of solids, the flow of fluids, the diffusion of chemicals, the spread of heat, the interactions of photons and electrons, and the radiation of electromagnetic waves. Today partial differential equations have developed into a vast subject that interacts with many other branches of mathematics such as complex analysis, differential geometry, harmonic analysis, probability, and mathematical physics.

The Laplace equation and its solutions, the harmonic functions, form a link between partial differential equations and complex analysis, since analytic functions are the solutions to the Cauchy-Riemann equations. Boundary behavior of analytic functions on a domain is studied through the Neumann problem, which is a boundary value problem for an elliptic (Laplace-like) operator. Furthermore, nonelliptic equations appear as natural objects in the study of manifolds that are boundaries of domains. These equations are similar to the degenerate elliptic equations arising in sub-Riemannian geometry and diffusion processes. Solvability and regularity of solutions to such equations form an active direction of research. The methods involved include subelliptic estimates and microlocal analysis.

Another direction of research is devoted to nonlinear elliptic partial differential equations with emphasis on second order equations. Differential geometry provides a rich source of such equations. Examples are the minimal surface equation and the Monge-Ampere equation. One important property studied by researchers in this field is the regularity of solutions, in particular the impact of regularity of coefficients and boundary values on that of solutions. An active area is the study of properties of geometric objects associated to solutions, e.g., level sets of solutions. Studies are focused on the geometric structure of these sets, and methods are from geometric measure theory.

Yet another direction involves the study of nonlinear evolution equations arising in mathematical physics such as the Euler equations of hydrodynamics or various infinite dimensional analogues of completely integrable Hamiltonian systems like the Korteweg-de Vries equation. A large amount of work is devoted to the study of the corresponding Cauchy problem for such equations. Recent developments in the area involve the use of harmonic analysis techniques to establish existence and uniqueness of solutions under low regularity initial data.

In fact, there is a very close connection between partial differential equations and harmonic analysis, starting with Fourier series and the heat equation and continuing with fundamental solutions, the construction of inverses to elliptic equations and pseudo-differential equations, the solution to wave equations and Fourier integral operators, to spectral analysis, and asymptotic techniques methods. Harmonic analysis techniques form a major part of the modern theory of linear and nonlinear partial differential equations.

The research of the partial differential equations group also includes the study of free boundary problems, reaction-diffusion equations, variational inequalities, homogenization problems, and other equations arising from industrial applications.

Logic

The research in mathematical logic at Notre Dame is mainly in two broad areas: computability theory and model theory. Computability theory concerns computability and complexity, often measured by Turing degree. A set is computable if there is a program for computing its characteristic function on an ideal computer that never crashes. Set A is Turing reducible to set B if there is a program for computing the characteristic function of A on a computer equipped with a CD-ROM giving the characteristic function of B. Turing reducibility is a partial ordering on the set of subsets of the natural numbers, and the Turing degrees are the equivalence classes of the corresponding equivalence relation. A set is computably enumerable if it is the range of a computable function, or, equivalently, the domain of a partial computable function. The set E of all computably enumerable subsets of the natural numbers forms a lattice under the operations of union and intersection. Soare showed that the collection of "maximal" sets is a definable orbit in E. There is ongoing work on automorphisms and the relation between complexity and structural properties, definable in the lattice.

Well-known theorems may pose interesting problems in computability. This is true, in particular, for Ramsey's theorem, on which there is recent work. There has been quite a lot of work on computability and complexity in familiar kinds of mathematical structures—groups, linear orderings, Boolean algebras, etc. Much of this work has involved connections between definability and complexity. There has also been work on complexity of models of arithmetic. The standard model, consisting of the natural numbers with addition and multiplication, is computable; i.e., the operations are computable. Tennenbaum showed that no non-standard model can be computable. A recent result says that for any non-standard model there is an isomorphic copy of strictly lower Turing degree.

The other broad area of active work is model theory, particularly classification theory and o-minimality. In recent years, methods developed in the context of stability theory have been used to analyze structures such as pseudofinite fields, pseudo-algebraically closed fields, difference fields, and quadratic forms over finite fields. This research has yielded applications to arithmetic number theory. Model-theorists now have a good understanding of how these dependence relations fit in a general framework. Ongoing work generalizes techniques from the geometrical stability theory of superstable theories to this broader class. This research is likely to give insight into the model-theoretic properties of bilinear forms and groups definable in structures such as those mentioned above.

The standard example of an o-minimal structure is the field of real numbers. In the early 1980s, it was noticed that many properties of semi-algebraic sets (sets definable in the field of reals) can be derived from a very few axioms, essentially the axioms defining o-minimal structures. After Wilkie proved that the exponential field of real numbers is o-minimal, the subject has grown rapidly. From a model-theoretic point of view, these structures resemble strongly-minimal structures, and many tools and methods of classification theory can be adapted to o-minimal structures. This remarkable combination of tools from stability theory and methods of semi-algebraic and subanalytic geometry provides elegant and surprisingly efficient applications not only in real algebraic and real analytic geometry, but also in analytic-geometric categories (e.g., groups of Lie type) over arbitrary real closed fields.

Topology

There is a large topology group at Notre Dame, and the research of its members covers a wide area of currently active areas. For a more detailed view of our current research one can consult the departmental Web page and its information about individual faculty members.

Basic algebraic topology is one active area of research here. Research continues on various types of homotopy theory, both stable and unstable, often from an axiomatic point of view. One area of application is to the study of Lie groups by homotopy theoretic methods. Other problems in homotopy theory under active consideration are problems that elucidate the influence of topology on differential geometry. A particular interest is in questions of which manifolds support metrics, the curvature of which is positive in various senses and of how many such metrics there are.

Controlled topology is another area of active research. One direction concerns various aspects of rigidity, which loosely means describing the ways that a discrete group can act on Euclidean space. This problem is a rich source of inspiration and has lead to groundbreaking work on stratified spaces by many people, not just at Notre Dame. Work on various foundational issues in controlled topology leads to the study of stratified spaces.

Basic geometric topology is an area that overlaps some of the above. Work not previously mentioned includes work on how algebraic invariants of a manifold affect the homotopy type of its group of topological or differentiable symmetries. This leads to further problems in algebraic topology and in algebra. There is also research on the classification of various geometrically interesting manifolds.

Algebraic K-theory is an active area of research as well. Ongoing research investigates the link between algebra and topology that lies at the center of K-theory. Contributions have been made to the study of L-theory, the quadratic analogue of K-theory that figures prominently in applications of topology to the study of manifolds and stratified spaces.

Research in low-dimensional manifolds is yet another area represented at Notre Dame. Research in gauge theory is applied to the study of four dimensional manifolds as well as more traditional techniques applied to the algebraic topology of four manifolds, their topological classification, and their differentiable classification. There is also research in three manifolds and the four manifolds they bound using gauge theory, especially the invariants based on the Sieberg-Witten equations.

Course Descriptions

The following course descriptions give the number and title of each course. The basic course sequences numbered 601-610 are given every year, as is the basic course 617. Other basic courses, numbered 611, 612, 613, 614, 617, 618, 625, 633, 637, 643, and 644 are given approximately every other year. Seminars 671-686, and reading and research courses 698-700 are offered every year. Other courses, with numbers up to 666, are topics courses. Each year topics courses are offered in algebraic geometry, differential geometry, algebra, partial differential equations, complex analysis, topology, logic, and applied mathematics. The particular topics change (probably never repeating), and the instructors rotate within groups. Thus, students are exposed to a variety of topics in which various members of the faculty have interest and expertise. The list below includes the courses offered every year, plus a typical selection of topics courses. Each course listing includes:

- Course number
- Title
- (Lecture hours per week—laboratory or tutorial hours per week—credits per semester)
- Instructor
- Course description
- (Semester normally offered)

513. Coding Theory
(3-0-3) Migliore
An introductory seminar with the ultimate goal being the recent developments in algebraic coding theory involving the interconnection between algebraic curves over finite fields and Goppa codes.

597. Directed Readings
(V-V-V) Staff
Readings not covered in the curriculum which relate to the student's area of interest.

601, 602. Basic Algebra
(3-0-3) (3-0-3) Staff
Standard results in group theory and ring theory; modules, linear algebra, multilinear algebra; Galois theory; Wedderburn theory; elements of homological algebra; introduction to an advanced topic in algebra.

603, 604. Basic Real Analysis
(3-0-3) (3-0-3) Staff
Rigorous review of the calculus of several variables; measure and integration on the real line and in general measure spaces; Haar measure; Banach spaces; Fourier series.

605, 606. Basic Complex Analysis
(3-0-3) (3-0-3) Staff
Analytic functions; Cauchy's theorem; Taylor and Laurent series; singularities, residue theory; complex manifolds; analytic continuation; conformal mappings; entire functions; meromorphic functions.

607, 608. Basic Topology
(3-0-3) (3-0-3) Staff
Topological spaces and metric spaces; the fundamental group and covering spaces; homology theory; basic theorems in algebraic topology.

609, 610. Basic Modern Logic
(3-0-3) (3-0-3) Staff
Propositional calculus and predicate logic, completeness, compactness, omitting types theorems, results on countable models; recursive and recursively enumerable sets, Turing degrees, the Friedberg-Muchnik theorem, minimal degrees; axioms of ZFC, ordinals and cardinals, constructible sets.

611. Nonlinear Dynamical Systems
(3-0-3) Staff
This class reviews the linear and nonlinear dynamical systems, such as Duffing's, Van der Pol's and Lorentz equations, geometry of the phase space, symplectic structures, variational methods, nonlinear Hamiltonian systems, integrable systems, quasiperiodic motion, averaging method, discrete dynamical systems, and the logistic function.

We also cover bifurcation phenomena and transition to chaos and theory of patterns. These include Hamiltonian vector fields, normal forms, stable and unstable manifolds, structural stability, Poincare maps, Liapunov exponents, power spectra, Hopf bifurcation, Smale diffeomorphism, perturbations of nonlinear systems, the geometric structure of the perturbed phase space, chaos and nonintegrability in Hamiltonian systems, KAM theory, perturbation of homoclinic orbits, Poincare-Melnikov method; for example, Arnold diffusion, symbolic dynamics, hyperbolic sets, strange attractors, numerical route to chaos. Theory of patterns include fractals, the Julia and Mandelbrot sets, lattice-based models, pattern dynamics in physics and biology, pattern inference, pattern recognition, and metric pattern theory.

612. Discrete Mathematics
(3-0-3) Staff
The course will provide an introduction into different subjects of discrete mathematics. Topics include (1) Graph Theory: Trees and graphs, Eulerian and Hamiltonian graphs; tournaments; graph coloring and Ramsey's theorem. Applications to electrical networks. (2) Enumerative Combinatorics: Inclusion-exclusion principle, Generating functions, Catalan numbers, tableaux, linear recurrences and rational generating functions, and Polya theory. (3) Partially Ordered Sets: Distributive lattices, Dilworth's theorem, Zeta polynomials, Eulerian posets. (4) Projective and combinatorial geometries, designs and matroids.

613. Optimization
(3-0-3) Staff
Vector spaces and convex sets; convex Hull; theorems of Caratheodory and Radon; Helly's Theorem; convex sets in Euclidean space; the Krein-Milman theorem in Euclidean space; extreme points of polyhedra; applications; the moment curve and the cyclic polytope; the cone of nonnegative polynomials; the cone of positive semidefinite matrices; the idea of semidefinite relaxation; semidefinite programming; cliques and the chromatic number of a graph; the Schur-Horn theorem; and the Toeplitz-Hausdorff theorem.

614. Basic PDE (Applied Analysis)
(3-0-3) Staff
Laplace equations: Green's identity, fundamental solutions, maximum principles, Green's functions, Perron's methods. Parabolic equations: Heat equations, fundamental solutions, maximum principles, finite difference and convergence, Stefan Problems. First order equations: characteristic methods, Cauchy problems; vanishing of viscosity-viscosity solutions. Real analytic solutions: Cauchy-Kowalevski theorem, Holmgren theorem.

617. Numerical Analysis
(3-0-3) Staff
The course is a solid theoretical introduction to numerical analysis. Topics covered include polynomial interpolation, least squares, numerical integration, numerical linear algebra, and an introduction to numerical solutions of ordinary and partial differential equations.

618. Numerical Methods in PDE
(3-0-3) Staff
This is part of a two-semester sequence, with Numerical Analysis I as prerequisite. Finite difference methods for time dependent equations and systems of equations.

1. Interpolation (particularly interpolation using trig functions), grid functions, and approximation of derivatives.
2. Examples of systems of particl differential equations arising in engineering and science, and the stability and convergence of their solutions.
3. High order accurate difference methods, and Fourier methods.
4. Well posed problems and general solutions for a variety of types of systems of equations with constant coefficients.
5. Stability and convergence: for constant coefficient systems, for variable coefficients.
6. Hyperbolic systems of equations with constant coefficients and then with variable coefficients in one and then several space variables, the method of lines, the finite volume method, and the Fourier method.

621, 622. Topics in Algebraic Geometry
(3-0-3) (3-0-3) Staff
This course provides an introduction to algebraic geometry. Topics from recent years include geometry of compact complex surfaces, complex adjunction theory, intersection theory of algebraic schemes.

625. Differentiable Manifolds
(3-0-3) Hind
Foundation to begin studying differentiable manifolds, forms, and vector bundles; brief introduction to Morse theory; Riemannian manifolds.

633. Nonlinear Analysis
(3-0-3) Staff
Elements of variational calculus, with application to: theory of interfaces, existence of solitons, vortices and bubbles, image segmentation,control theory. Implicit function and fixed-point theorems, with application to: Bose-Einstein condensation, existence of discrete breathers, existence of small data solutions of nonlinear Schroedinger, heat, and wave equations, economics. Gradient and Hamiltonian systems: energy conservation versus energy dissipation, stability of stationary solutions and traveling waves, stability of periodic solutions and Floquet theory.

634. Topics in Applied Partial Differential Equations
(3-0-3) Staff
Topics covered will include: differentiable manifolds, vector fields, differential forms, and tensor analysis; inverse and implicit function theorems, transversality, Sard's theorem, Morse theory, integration on manifolds, Stokes Theorem, de Rham cohomology.

637. Linear Control
(3-0-3) Staff
Introduction to linear system theory. Linear-quadratic control, H-infinity control, introduction to robust control based on matrix cube theorem, linear matrix inequalities and interior-point algorithms.

643. Probability
(3-0-3) Staff
The first part of a two-semester sequence. Topics will include: elements of measure and integration theory; basic setup of probability theory (including sample spaces, conditional probability, independence) as well as random variables, the "law of large numbers;" discrete random variables (including random walks); ontinuous random variables, the basic distributions, sums of random variables; generating functions, branching processes, basic theory of characteristic functions, central limit theorems; Markov chains (embedding, birth and death processes, Poisson processes); Monte Carlo simulations; more "laws of large numbers," including the law of the iterated logarithm, Martingales, filtered sigma algebras, and the simplest martingale convergence theorems; various stochastic processes, including Brownian motion, queues, and applications; Martingales, including stopping times and optimal stopping; and the rudiments of stochastic integration (including Ito's formula and the Black-Scholes differential equation.)

644. Stochastic Analysis
(3-0-3) Staff
Prerequisite: MATH 643. The second part of a two-semester sequence, this course is an introduction to stochastic modeling and the underlying theory, with application to models from science and engineering. Topics will include stochastic versus deterministic models; diffusion processes in physics, biology, population dynamics, and epidemiology; discrete and continuous Markov chain models, with applications; the long run behavior of Markov chains; Poisson processes, with applications; Brownian motion and related processes.; the Ornstein-Uhlenbeck Process; elements of stochastic dynamical systems; and numerical methods for stochastic processes.

647, 648. Differential Geometry
(3-0-3) Staff
This course provides an introduction to modern differential geometry. Topics include: Riemannian manifolds, connections, parallel translation, geodesics, the exponential map, the torsion and curvature, Jacobi fields, first and second variation of arc length, cut loci and conjugate locus, and elementary comparison theorem.

651, 652. Topics in Algebra
(3-0-3) (3-0-3) Staff
A sample course, given by Dyer, covered basic properties of polytopes and polyhedra with an emphasis on counting the numbers of faces using techniques from commutative algebra and representation theory.

653, 654. Topics in PDE
(3-0-3) (3-0-3) Staff
A sample course, given by Shaw, covered methods of solving partial differential equations in complex analysis. Central questions: solutions of Cauchy-Riemann equations in several variables, regularity of solutions up to the boundary, and solvability and estimates for tangential Cauchy-Riemann equations on the boundaries.

655, 656. Topics in Complex Analysis
(3-0-3) (3-0-3) Staff
A sample course, given by Stanton, covered complex manifolds. Hermitian and Kähler manifolds. Connections, curvature, Chern classes on holomorphic vector bundles, Hodge theorem. Sheaf Theory. Kodaira Embedding Theorem.

657, 658. Topics in Topology
(3-0-3) Staff
One sample course, given by Dwyer, emphasized homotopy theory. Dual purpose: to impart to the student a certain amount of basic information (fibre bundles, spectral sequences, cohomology operations, etc.) and to teach the student how to grapple with the existing and extensive advanced material in an inquiring but skeptical way.

Another sample course, given by Connolly, covered the initial solutions of the question as to when a manifold is the interior of a compact manifold with boundary (by Browder-Livesay, Levine, and Siebenman); the recasting of this theory by Quinn with its far-reaching consequences.

661, 662. Topics in Logic: Computable Structures and the Hyperarithmetical Hierarchy
(3-0-3) Staff
One sample course, given by Knight, covered results connecting definability in computable structures with bounds on complexity. The results apply to familiar kinds of mathematical structures (vector spaces, orderings, Boolean algebras). The proofs involve priority constructions, arbitrarily nested, and forcing.

Another sample course, given by Buechler, covered results connecting definability in computable structures with an overview of the model theory of classes of finite structures. 0-1 laws, Fagin's Theorem, Ehrenfeucht games and ultra-products of finite structures. Generic structures and limits of finite structures are discussed.

665. Topics in Applied Mathematics
(3-0-3) Staff
One sample course, given by Alber, covered methods of symplectic geometry; those that use interesting examples from the applications of analysis and those that serve as links between geometry and modern analysis; unexpected results in both pure and applied mathematics via the application of such methods to nonlinear Hamiltonian systems.

666. Topics in Differential Geometry
(3-0-3) Staff
This is an advanced topics course in differential geometry. The following topics were taught in previous years: geometry of submanifolds; minimal surfaces; manifolds of non-positive curvature; analysis on symmetric spaces; sympletic geometry; and complex differential geometry and spectral geometry.

669. Introduction to Ergodic Theory
(3-0-3) Staff
We present some global properties of dynamical systems where individual orbits seem very erratic. We first study the case example of hyperbolic automorphisms of the torus, then go to more general hyperbolic maps, then to maps which look like hyperbolic, but satisfy only weaker conditions.

Courses 671 through 686 are further topics courses, not restricted in area. The actual topics studied in these courses will appear on the student's transcript when possible.

671, 672. Seminar in Algebra
(V-0-V) (V-0-V) Staff
Topics vary by semester.

673, 674. Seminar in Analysis
(V-0-V) (V-0-V) Staff
Topics vary by semester.

675, 676. Seminar in Complex Analysis
(V-0-V) (V-0-V) Staff
Topics vary by semester.

677, 678. Seminar in Topology
(3-0-3) (3-0-3) Staff
Topics vary by semester.

681, 682. Seminar in Mathematical Logic
(V-0-V) (V-0-V) Staff
Topics vary by semester.

683, 684. Seminar in Number Theory
(V-0-V) (V-0-V) Staff
Topics vary by semester.

685, 686. Seminar in Geometry
(V-0-V) (V-0-V) Staff
Topics vary by semester.

Other seminars are organized and supported by groups of students and faculty who wish to discuss some particular body of mathematics.

Other Graduate Courses

697. Directed Readings
(V-0-V) Staff
Readings not covered in the curriculum which relate to the student's area of interest.

699. Research and Dissertation
(V-V-V) Staff
Research and dissertation for resident graduate students.

699S. Research Seminar
(V-V-V) Staff
Topics vary by semester.

700. Nonresident Dissertation Research
(0-0-1) Staff
Required of nonresident graduate students who are completing their dissertations in absentia and who wish to retain their degree status.

Faculty

Algebra

Katrina D. Barron, *Assistant Professor.* A.B., Univ. of Chicago, 1987; Ph.D., Rutgers Univ., 1996. (2001)

Matthew J. Dyer, *Associate Professor.* B.Sc., Sydney Univ., 1983; M.Sc., ibid., 1985; Ph.D., ibid., 1988. (1989)

Samuel Evens, *Associate Professor.* P.A. and B.A., Haverford College, 1984; Ph.D., Massachusetts Institute of Technology, 1988. (1999)

Alexander J. Hahn, *Director of the Kaneb Center for Teaching and Learning, Professor of Mathematics, and Fellow of the Nanovic Institute for European Studies.* B.S., Loyola Univ., Los Angeles, 1965; M.S., Univ. of Notre Dame, 1968; Ph.D., ibid., 1970. (1972)

Timothy O'Meara, *Provost Emeritus of the University and the Rev. Howard J. Kenna, C.S.C., Professor Emeritus of Mathematics.* B.Sc., Univ. of Capetown, 1947; M.S., ibid., 1948; Ph.D., Princeton Univ., 1953. (1962)

Richard Otter, *Professor Emeritus.* A.B., Dartmouth College, 1941; Ph.D., Indiana Univ., 1946. (1947)

Barth Pollak, *Professor Emeritus.* B.S., Illinois Institute of Technology, 1950; M.S., ibid., 1951; Ph.D., Princeton Univ., 1957. (1963)

Warren J. Wong, *Professor Emeritus.* B.S., Univ. of Otago, 1954; M.S., ibid., 1955; Ph.D., Harvard Univ., 1959. (1964)

Algebraic Geometry

Mario Borelli, *Associate Professor Emeritus.* B.S., Scuola Normale di Pisa, 1956; Ph.D., Indiana Univ., 1961. (1965)

Karen Chandler, *Assistant Professor*. B.S., Dalhousie Univ., 1987; Ph.D., Harvard Univ., 1992. (1995)

Alan Howard, *Professor Emeritus.* B.A., Rutgers Univ., 1953; Ph.D., Brown Univ., 1965. (1968)

Juan C. Migliore, *Professor.* B.A., Haverford College, 1978; Ph.D., Brown Univ., 1983. (1989)

Claudia Polini, *Associate Professor.* B.S., Universita degli Studi di Padova, 1990; Ph.D., Rutgers Univ., 1995. (2001)

Dennis M. Snow, *Professor*. B.S., Merrimack College, 1975; M.S., Univ. of Notre Dame, 1977; Ph.D., ibid., 1979. (1982)

Andrew J. Sommese, *the Vincent J. Duncan and Annamarie Micus Duncan Professor of Mathematics.* B.A., Fordham Univ., 1969; Ph.D., Princeton Univ., 1973. (1979)

Applied Mathematics

Mark S. Alber, *Professor.* M.S., Moscow Institute of Technology, 1983; Ph.D., Univ. of Pennsylvania, 1990. (1990)

Leonid Faybusovich, *Professor.* M.S., Leningrad Polytechnic Institute, 1978; Ph.D., Harvard Univ., 1991. (1991)

Michael Gekhtman, *Associate Professor.* B.S., M.S., Kiev State Univ., 1985; Ph.D., Ukrainian Academy of Science, 1990. (1999)

Brian Hall, *Associate Professor.* B.A. and B.S., Cornell Univ., 1988; Ph.D., ibid., 1993. (1999)

Bei Hu, *Professor.* B.S., East China Normal Univ., 1982; M.S., ibid., 1984; Ph.D., Univ. of Minnesota, 1990. (1990)

Cecil B. Mast, *Associate Professor Emeritus.* B.S., DePaul Univ., 1950; Ph.D., Univ. of Notre Dame, 1956. (1959)

Gerard K. Misiolek, *Associate Professor.* M.S., Warsaw Univ., 1987; Ph.D., State Univ. of New York, Stony Brook, 1992. (1993)

David P. Nicholls, *Assistant Professor.* B.S., Univ. of Illinois, Urbana, 1993; Sc.M., Brown Univ., 1995; Ph.D., ibid., 1998. (2001)

Joachim J. Rosenthal, *Professor of Mathematics and Concurrent Professor of Electrical Engineering.* Vordiplom, Univ. Basel, 1983; Diplom, ibid., 1986; Ph.D., Arizona State Univ., 1990. (1990)

Michael Sigal, *the Rev. Howard J. Kenna, C.S.C., Memorial Professor of Mathematics.* Ph.D., Tel Aviv Univ., 1976. (2003)

Andrew J. Sommese, *the Vincent J. Duncan and Annamarie Micus Duncan Professor of Mathematics*. B.A., Fordham Univ., 1969; Ph.D., Princeton Univ., 1973. (1979)

Complex Analysis

Jeffrey Diller, *Associate Professor.* B.S., Univ. of Dayton, 1988; Ph.D., Univ. of Michigan, 1993. (1998)

Wilhelm F. Stoll, *the Vincent J. Duncan and Annamarie Micus Duncan Professor Emeritus of Mathematics.* Ph.D., Univ. of Tubingen, 1953. (1960)

Pit-Mann Wong, *Professor.* B.Sc., National Taiwan Univ., 1971; Ph.D., Univ. of Notre Dame, 1976. (1980)

Differential Equations

Matthew Gursky, *Director of Undergraduate Studies and Professor.* B.S., Univ. of Michigan, 1986; Ph.D., California Institute of Technology, 1991. (2001)

Qing Han, *Associate Professor.* B.S., Beijing Univ., 1986; M.S., Courant Institute, 1991; Ph.D., ibid., 1993. (1994)

A. Alexandrou Himonas, *Associate Chair and Professor.* B.S., Patras Univ., 1976; M.S., Purdue Univ., 1982; Ph.D., ibid., 1985. (1989)

Mei-Chi Shaw, *Professor.* B.S., National Taiwan Univ., 1977; M.S., Princeton Univ., 1978; Ph.D., ibid., 1981. (1987)

Nancy K. Stanton, *Professor.* B.S., Stanford Univ., 1969; Ph.D., Massachusetts Institute of Technology, 1973. (1981)

Differential Geometry

Jianguo Cao, *Professor.* B.S., Nanjing Univ., 1982; M.S., ibid., 1985; Ph.D., Univ. of Pennsylvania, 1989. (1996)

Richard Hind, *Assistant Professor.* B.A., Cambridge Univ. U.K., 1993; Ph.D., Stanford Univ., 1997. (2000)

François Ledrappier, *the John and Margaret McAndrew Professor of Mathematics*. B.S., École Polytechnique, 1968; Ph.D., Univ. Paris, 1975. (2002)

Xiaobo Liu, *Associate Professor.* B.S., Tsinghua Univ., P.R. China, 1987; Ph.D., Univ. of Pennsylvania, 1994. (1999)

Brian Smyth, *Professor.* B.S., National Univ. of Ireland, 1961; M.S., ibid., 1962; Ph.D., Brown Univ., 1966. (1966)

Frederico J. Xavier, *Professor.* B.S., Univ. Federal De Pernambuco, 1971; M.S., ibid., 1973; Ph.D., Univ. of Rochester, 1977. (1985)

Logic

Steven A. Buechler, *Professor.* B.A., B.S., Eastern Illinois Univ., 1975; M.A., Univ. of Maryland, 1977; Ph.D., ibid., 1981. (1987)

Peter Cholak, *Professor.* B.A., Union College, 1984; M.A., Univ. of Wisconsin, 1988; Ph.D., ibid., 1991. (1994)

Abraham Goetz, *Associate Professor Emeritus.* M.S., Univ. of Wroclaw, 1949; Ph.D., ibid., 1957. (1964)

Julia F. Knight, *Director of Graduate Studies and the Charles L. Huisking Professor of Mathematics.* B.A., Utah State Univ., 1964; Ph.D., Univ. of California, Berkeley, 1972. (1977)

Sergei Starchenko, *Associate Professor.* M.S., Univ. of Novosibirsk, 1983; Ph.D., ibid., 1987. (1997)

Vladeta Vuckovic, *Associate Professor Emeritus.* M.S., Univ. of Belgrade, 1949; Ph.D., ibid., 1953. (1963)

Topology

Francis X. Connolly, *Professor.* B.S., Fordham Univ., 1961; M.S., Univ. of Rochester, 1963; Ph.D., ibid., 1965. (1971)

John E. Derwent, *Associate Professor Emeritus*. B.S., Univ. of Notre Dame, 1955; Ph.D., ibid., 1960. (1963)

William G. Dwyer, *Chair and the William J. Hank Family Professor of Mathematics.* B.A., Boston College, 1969; Ph.D., Massachusetts Institute of Technology, 1973. (1980)

Liviu Nicolaescu, *Associate Professor*. B.S., Univ. Al. I Cuza, Iasi, Romania, 1987; Ph.D., Michigan State Univ., 1994. (1998)

Stephan A. Stolz, *the Rev. John A. Zahm, C.S.C., Professor of Mathematics*. B.S., Univ. of Bielefeld, 1975; M.S., Univ. of Bonn, 1979; Ph.D., Univ. of Mainz, 1984. (1988)

Laurence R. Taylor, *Professor.* B.A., Princeton Univ., 1967; Ph.D., Univ. of California, Berkeley, 1971. (1973)

E. Bruce Williams, *Professor.* B.S., Massachusetts Institute of Technology, 1967; Ph.D., ibid., 1972. (1975)

M.D./Ph.D. Joint Degree Program

Acting Director:

John F. O'Malley

Telephone: (574) 631-5574
Fax: (574) 631-7821
Location: B-22 Haggar Hall
E-mail: scbme.1@nd.edu
Web: http://galen.sbcme.nd.edu

The Program of Studies

The University of Notre Dame and Indiana University School of Medicine offer a joint M.D./Ph.D. degree for exceptional students interested in academic medicine. This unusual partnership between a private Catholic university and a state-supported medical school was formed in 1995. The program draws on the strengths of the medical faculty and the research excellence of the graduate program faculty to train scientists who can bridge the gap between clinical medicine and basic life sciences.

The South Bend Center for Medical Education (Indiana University School of Medicine) is in the process of building a new medical education facility that will also house the Notre Dame Transgene Center.

General Requirements

To earn the joint degree, students will complete the first two years of medical school at the South Bend Center for Medical Education (SBCME), located on the Notre Dame campus, and continue at Notre Dame for three more years to pursue the University's doctoral degree through the Graduate School. The last two years of medical school then will be completed at the Indiana University School of Medicine's main campus in Indianapolis.

Program descriptions and requirements, as well as course and faculty listings for all of Notre Dame's doctoral programs, may be found elsewhere in this *Bulletin.* Students in the M.D./Ph.D. program may pursue the doctoral degree in any of these disciplines. Course and faculty listings specific to the medical training may be found below.

Admission

Admission to the program requires separate applications to the Notre Dame Graduate School and the Indiana University School of Medicine. The Graduate School will accept MCAT scores in place of the GRE scores required of all applicants. The parallel applications will be coordinated and tracked by the South Bend Center for Medical Education, which serves as the central office for the combined degree program. Representatives from Notre Dame and the I.U. School of Medicine monitor and oversee the program.

Application to the joint degree program will not jeopardize a student's application to either the Graduate School or the School of Medicine. The student may be admitted to either school independently. Students admitted into the joint degree program will receive both tuition and stipend assistance.

For information and application materials, interested students should contact the South Bend Center for Medical Education.

Course Descriptions

The following courses are central to center programs. Each course listing includes:

- Course number
- Title
- (Lecture hours per week—laboratory or tutorial hours per week—credits per semester)
- Instructor
- Course description
- (Semester normally offered)

SBCM 501. Gross Anatomy
(3-9-8) O'Malley
An intensive study of the gross structure of the human body, accomplished through maximum student participation in the dissection of the human cadaver together with formal lectures and assigned readings.

SBCM 503. Neuroscience
(3.5-3.5-5) Kingsley
An integrated course that canvasses the biophysics, biochemistry, anatomy, physiology, and pathology of the human nervous system and its vasculature.

SBCM 504. Human Physiology
(3-3.5-8) Olson
The study of the physiology of the cardiovascular, respiratory, renal, endocrine, and gastrointestinal systems. Emphasis is placed on medical aspects of human physiology. Student participation laboratories are used to demonstrate classic physiologic principles and current bioanalytic techniques.

SBCM 505. Histology/Embryology
(2.5-3.5-5) Hamlett
The study of microscopic anatomy of normal human tissues. Light microscopy receives the major emphasis, but electron microscopic structure is included in areas of special interest. Two lecture hours per week are devoted to the fundamentals of embryology.

SBCM 512. Introduction to Clinical Medicine I: Behavioral Science
(2-0-2) Macri
This course focuses on the emotional, intellectual, and social development of the human being. Every attempt is made to help medical students understand their own personalities and to begin the process of using themselves as therapeutic agents.

SBCM 556. Medical Microbiology
(3.5-5-7) Staff
A diversity of microbiology and related subtopics are studied within this course, including immunology, virology, bacteriology, parasitology, mycology, and aspects of infectious disease. While primary emphasis is on the biology and pathogenic mechanisms of individual organisms, microbe relationships are discussed extensively throughout the course.

SBCM 600. Introduction to Clinical Medicine I: The Patient-Doctor Relationship
(2-0-2) Magneson, staff
A multidepartmental interdisciplinary course designed to introduce students to medical ethics, history taking, and the patient-doctor relationship through interactions with faculty and patients in a variety of settings. In small groups facilitated by primary care and behavioral science faculty, students direct their learning toward the complexity of the context from which a patient seeks medical care. In order to achieve this, students examine normal human behavior and development throughout the life cycle. Issues addressed include preventive health care, sexuality, cultural diversity, minority health issues, religion and spirituality, family dynamics, the economics of health care, and death and dying.

SBCM 605. Medical Genetics
(2-0-2) McKee
A survey course of lectures and discussions dealing with the mechanisms and patterns of inheritance. Emphasis on human genetic disorders. Students may also participate in the Memorial Hospital Regional Genetic Counseling Clinic, where they will be introduced to genetic diagnosis, management, and counseling of patients with genetic diseases.

SBCM 651. Introduction to Medicine–II
(19-0-19) Magneson, team
A multidepartmental multidisciplinary course designed to introduce clinical medicine. Includes medical history taking and physical examination skills learned at the bedside with direct patient contact. Clinical medicine is surveyed concurrently with emphasis on pathophysiology and diagnosis. Problem-solving skills are stressed, including synthesis and interpretation of medical data.

SBCM 652. Biostatistics
(1-0-1) Kingsley
Biostatistics for medical students.

SBCM 653A. General Pathology
(3-1-4) Prahlow
The study of diseases that affect human tissues. Emphasis is placed on the principles of inflammation, necrosis, repair, growth disturbances, and hemodynamic and metabolic disorders. Students participate in laboratory exercises, which are constructed for problem case analysis.

SBCM 653B. Systemic Pathology
(8-0-8) Prahlow
The study of disease and its relationship to structural and functional abnormalities of specific organ systems. Emphasis is placed on both pathologic anatomy and clinical manifestations of disease.

SBCM 654. Pharmacology
(5-2-7) Staff
A systematic study of the mechanism of action, disposition, and fate of drugs in living systems with emphasis on drugs of medical importance.

CHEM 667M. Biological Chemistry
(5-0-5) McKee
The lecture sequence provides an analysis of current biochemical topics and an introduction to those areas of biochemistry that are especially relevant in medicine. Emphasis is placed on metabolic pathways, endocrine control, and related clinical problems.

Additional programs in biomedically related sciences appear elsewhere in the *Bulletin* in the Department of Biological Sciences (parasitology, vector biology, virology, bacteriology, and chemistry and biochemistry).

Faculty

William C. Hamlett, *Adjunct Professor (biological sciences).* B.S., Univ. of South Carolina, 1970; M.S., ibid., 1973; Ph.D. Clemson Univ., 1983. (1991)

Robert E. Kingsley, *Adjunct Associate Professor (biological sciences).* B.A., Univ. of Michigan, 1965; Ph.D., Indiana Univ., 1971. (1974)

Edward E. McKee, *Adjunct Associate Professor (chemistry and biochemistry).* B.S., Pennsylvania State Univ., 1972; Ph.D., ibid., 1977. (1991)

Kenneth R. Olson, *Adjunct Professor (biological sciences) and Concurrent Professor of Chemical and Biomolecular Engineering* . B.S., Univ. of Wisconsin, LaCrosse, 1969; M.S., Michigan State Univ., 1970; Ph.D., ibid., 1972. (1975)

John F. O'Malley, *Adjunct Associate Professor (biological sciences).* B.S., Holy Cross College, 1952; M.S., Worcester State, 1957; Ph.D., Creighton Univ., 1971. (1971)

Joseph A. Prahlow, *Adjunct Associate Professor (clinical) (biological sciences).* B.S., Valparaiso Univ., 1986; M.D., Indiana Univ. School of Medicine 1990. (2000)

The Molecular Biosciences Program

Codirectors:
David R. Hyde, *Professor of Biological Sciences*
Paul W. Huber, *Professor of Chemistry and Biochemistry*

Telephone:
(574) 631-8054 (Hyde),
(574) 631-6042 (Huber)
Location:
264 Galvin Life Sciences (Hyde),
437 Stepan Chemistry (Huber)
E-mail:
dhyde@nd.edu,
phuber@nd.edu
Web: http://www.science.nd.edu/MBP/MBP.html

Current research probing the molecular details of the biological sciences requires simultaneous application of genetic, biochemical, and molecular biological principles and expertise. The Molecular Biosciences Program (M.B.P.) provides a broad range of training opportunities for students seeking careers within this active research field. Faculty participants of the Department of Biological Sciences and the Department of Chemistry and Biochemistry administer the M.B.P. within the College of Science. Students interested in the M.B. program should apply for admission to the Department of Biological Sciences or Chemistry and Biochemistry depending on their research interests.

Research Facilities

The Department of Biological Sciences, housed in the modern Galvin Life Sciences complex, has excellent facilities for all laboratory research in molecular biology. Facilities and training opportunities are available in genetics, molecular and cell biology, and developmental biology. The Department of Chemistry and Biochemistry has training opportunities in the fields of gene expression, protein structure and enzyme kinetics. Many M.B.P. faculty have research activities within the newly established Walther Cancer Center and Keck Transgene Center.

The University maintains modern research facilities in support of the Molecular Biosciences Program. The Biosciences Core Facility maintains instrumentation for DNA, RNA, and peptide synthesis, amino acid and carbohydrate analysis, and protein and peptide sequencing. The Department of Biological Sciences houses an optics facility for confocal microscopy and scanning and transmission electron microscopy and a new flow cytometry facility equipped with a Coulter Epics XL flow cytometer and a Coulter ALTRA flow sorter. The College of Science NMR Facility contains state-of-the-art high field spectrometers that support both chemical and biological nuclear magnetic resonance research. The Mass Spectrometry Facility is equipped to analyze high mass biomolecules and determine exact masses of low and medium size molecules. The Freimann Life Science Center provides a modern animal care facility. The staff of certified veterinary technicians ensures proper care and use of laboratory research animals. Several science libraries are found on campus in Nieuwland Science Hall, the Radiation Laboratory, and the Galvin Life Sciences Building. Additional resources are available in the main campus Hesburgh Library.

Degree Requirements

Students participating in the Molecular Biosciences Program must complete the degree requirements of either the Department of Biological Sciences or the Department of Chemistry and Biochemistry. Several courses are designed for all M.B.P. students, and are usually taken during the first year of graduate school. There are additional elective courses in each department to allow for specialization within the M.B.P. Students in the Biological Sciences are required to take Molecular Biology I and II, Fundamentals of Biochemistry, and five elective courses. These are minimum requirements. The student's research adviser and committee may require additional courses based on the background and research interests of the student. In the Department of Chemistry and Biochemistry there are specific requirements depending on the focus of the study. A student in Biochemistry is required to take Fundamentals of Biochemistry,
Intermediary Metabolism, Molecular Biology I, and Advanced Biochemical Techniques. In Organic Chemistry, a student is required to take Advanced Organic Chemistry I, Advanced Organic Chemistry II, and Synthetic Organic Chemistry, with an additional nine credit hours of courses.

All M.B.P. students must pass both oral and written comprehensive examinations. Students will conduct original research and write an approved dissertation on this work. The work is conducted under the direction of an adviser participating in the M.B.P. Students in the program also must complete a one-year teaching requirement that usually involves assisting in the instruction of laboratory courses within their discipline. All students participate in the seminar activities of the program.

Course Descriptions

Both required and elective courses of the Molecular Biosciences Program are categorized according to the department offering the course. Please refer to the section on degree requirements for more information.

Biological Sciences

Developmental Genetics
Analysis of the cellular and molecular genetic mechanisms underlying animal development, with emphasis on major vertebrate and invertebrate model systems.

Immunology
An introductory course emphasizing the cells and tissues of the immune system and the nature and function of antigens and antibodies.

Molecular Biology I
Physical chemistry of nucleic acids, bacterial genetics, principles of cloning, DNA replication and recombination, prokaryotic and eukaryotic transcription, RNA processing and translation. Listed also as CHEM 531.

Molecular Biology II
Yeast genetics and molecular biology; retroviruses and transposable elements; recombinant DNA: tools and applications in Drosophila, yeast, and mice. Listed also as CHEM 532.

Advanced Cell Biology I
The basic biochemical, structural, and biophysical properties of key systems involved in membrane transport, protein trafficking, bioenergetics, cell signaling, vesicular transport, organelle biogenesis, and cytoskeletal functions.

Advanced Cell Biology II
The biochemical, structural, and biophysical properties of key systems involved in cellular adhesion, cell cycle regulation, programmed cell death (apoptosis), and the relationship to mechanisms of disease leading to carcinogenesis, aging.

Immunobiology of Infectious Diseases
Course focuses on the cellular and molecular mechanisms behind human diseases. Specifically, the design and effects of drug treatments on microbial and cellular processes and the development and implementation of vaccines.

Topics in Tumor Biology
Course examines the cell and molecular basis of tumor genesis and development in specific cancer cell types.

Chemistry and Biochemistry

Fundamentals of Biochemistry
Chemistry of carbohydrates, amino acids, proteins, nucleotides, nucleic acids, lipids, and enzymes.

Intermediary Metabolism
A study of the chemical reactions characteristic of living systems.

Molecular Biology I
Physical chemistry of nucleic acids, bacterial genetics, principles of cloning, DNA replication and recombination, prokaryotic and eukaryotic transcription, RNA processing and translation. Listed also as BIOS 531.

Molecular Biology II
Yeast genetics and molecular biology; retroviruses and transposable elements; recombinant DNA: tools and applications in Drosophila, yeast, and mice. Listed also as BIOS 532.

Enzyme Chemistry
Physical and chemical properties and mechanism of action of enzymes and their role in metabolic processes.

NMR Spectroscopy in Chemistry and Biochemistry
A survey of modern NMR methods used to determine molecular structure and conformation, study chemical and biochemical reactivity, and probe metabolic processes in biological systems.

Chemical Basis of Gene Expression
Emphasis is placed on eukaryotic gene structure, replication, transcription, and translation.

Advanced Organic Chemistry I and II
The theoretical basis of organic chemistry and a detailed study of the preparation and reactions of organic compounds.

Synthetic Organic Chemistry
A systematic and critical study of the synthetic methods of modern organic chemistry, including the development of multistage syntheses.

Teaching, Research Fellowships

Financial support is available to all students. The Molecular Biosciences Program nominates outstanding applicants for University-wide fellowships, some of which are specific for female and minority candidates. The M.B.P. also administers program-specific fellowships that support incoming and matriculating students. Research assistantships are available in many of the research laboratories, and teaching assistantships are available to all students. Teaching assistantships typically involve 10 to 12 hours of work per week teaching within an undergraduate laboratory course. All M.B.P. students are awarded full-tuition scholarships.

Application and Admission

Students interested in the Molecular Biosciences Program must apply for admission to one of the departments involved in the program, Biological Sciences or Chemistry and Biochemistry. Applicants should choose the department that best serves their training goals. Each department has different degree requirements, as described above. Usually the research adviser will be in the same department as the student, although this is not a necessity.

To apply to this program, please submit a completed Graduate School application form. On this application, you must specify to which of the host departments (Biological Sciences or Chemistry and Biochemistry) you are applying, and specify that your area of interest or specialization will be the Molecular Biosciences Program. Transcripts of all previous academic credits, three recommendation forms from undergraduate instructors aware of your qualifications, and a statement of purpose are also required.

Graduate Record Exam (GRE) General Test scores must also be submitted and your choice of one Advanced Study Examination. The GRE advanced test is required for consideration within the Department of Biological Sciences and is highly recommended for the Department of Chemistry and Biochemistry. Information about these tests can be obtained from:

GRE ETS
P.O. Box 600
Princeton, NJ 08541-6000

Faculty and Research

Biological Sciences

John H. Adams, molecular interactions of malaria merozoites with host erythrocytes and genetic/antigenic variation of Plasmodium.

Crislyn D'Souza-Schorey, Small GTPases in cell signaling and membrane trafficking.

John G. Duman, Physiological and biochemical adaptations to subzero temperatures, especially (1) structure and function of antifreeze proteins and ice nucleating proteins, and (2) studies of transgenic plants expressing insect antifreeze proteins.

Malcolm J. Fraser Jr., baculovirus molecular genetics, transposons, transgenic engineering of insects.

David R. Hyde, molecular genetics of Drosophila vision, molecular genetics of eye development and retinal degeneration in zebrafish, mechanisms of neuronal regeneration in zebrafish.

Alan L. Johnson, ovarian follicular growth, differentiation, and atresia; apoptosis.

Lei Li, molecular genetic basis of visual disorders, circadian clock and olfactory centrifugal inputs on visual sensitivity.

Joseph E. O'Tousa, maturation, structure, and function of rhodopsin, molecular genetics of retinal degeneration, control of cell death processes.

Jeffrey S. Schorey, molecular and cellular processes of mycobacterium-host cell interactions.

Neil F. Shay, molecular, cellular, and physiological aspects of nutrition and nutrient deficiencies.

Martin P. R. Tenniswood, tumor biology, apoptosis in hormone-dependent cancers.

Kevin T. Vaughan, dynactin complex, dynein-mediated organelle transport.

JoEllen J. Welsh, breast cancer, apoptotic mechanisms.

Chemistry and Biochemistry

Brian M. Baker, biophysical chemistry of macromolecular interactions, receptor-ligand interactions in immunity.

Subhash C. Basu, regulation of glycosyltransferases during development, DNA polymerase-associated lectin in eukaryotic DNA replication.

Francis J. Castellino, in vivo and in vitro structure-function relationships of blood coagulation and fibrinolysis proteins.

Patricia L. Clark, protein folding in cellular environments, ribosomal interactions with polypeptide chain conformations.

Holly V. Goodson, dynamics of microtubule assembly, regulation of cytoskeletal structure.

Paul Helquist, design, synthesis, and mechanism of antibiotics and anticancer agents.

Paul W. Huber, RNA-protein interactions, RNA localization, regulation of transcription.

Marvin J. Miller, synthetic and bioorganic chemistry, microbial iron transport agents, amino acids, peptides and ß-lactam antibiotics.

Thomas L. Nowak, mechanisms of enzyme activation and catalysis, carbohydrate metabolism, biochemical applications of NMR spectroscopy.

Anthony S. Serianni, biomolecular structure determination via isotope-edited NMR methods.

Bradley D. Smith, biomimetic chemistry, biomembrane fusion, phospholipid flip-flop, antimicrobial agents.

Olaf G. Wiest, physical and computational organic chemistry protein-ligand interactions, rational drug design.

Further Information

For additional information about the Molecular Biosciences Program, write one of the codirectors, Dr. David R. Hyde or Dr. Paul W. Huber, at the addresses given above.

For information specific to the departments involved in the Molecular Biosciences Program, please write the corresponding graduate director:

Biological Sciences:

Dr. Gary Lamberti
Director, Graduate Studies
Dept. of Biological Sciences
University of Notre Dame
Notre Dame, IN 46556
Telephone: (574) 631-6552
E-mail: biosadm@nd.edu

Chemistry and Biochemistry:

Dr. Richard Taylor
Director, Graduate Studies
Dept. of Chemistry and Biochemistry
University of Notre Dame
Notre Dame, IN 46556
Telephone: (574) 631-5759/6705
E-mail: taylor.61@nd.edu

Physics

Chair:

Ani Aprahamian

Director of Graduate Studies:

Kathie E. Newman

Telephone: (574) 631-6386
Fax: (574) 631-5952
Location: 225 Nieuwland Science Hall
E-mail: physics@nd.edu
Web: http://www.science.nd.edu/physics

The Program of Studies

The graduate physics program at Notre Dame offers students a broad range of choice of research areas for a PhD degree. Almost all areas of study in physics are represented within the department, including astrophysics, biophysics, atomic, condensed-matter, high-energy, nuclear, and statistical physics. This program combines course work and research, preparing the student for a career in university, industrial, or governmental research or in college or university teaching. Students take a sequence of basic courses in the fundamental areas of physics. In addition, the student will take advanced courses and seminars in specialized areas. Students join in a physics research program of the department within the first year.

The graduate program is primarily a doctoral program, leading to the degree of doctor of philosophy. The department ordinarily will not accept students who intend to complete only the master's degree. However, a program leading to the degree of master of science is available; it involves satisfactory completion of graduate course work without any thesis requirement.

The master of science nonresearch program requires 24 credit hours of approved course work and passage of an oral Master's examination. Each program of course work is chosen in consultation with a faculty adviser.

Interdisciplinary programs between physics and chemistry or biology are also available.

Requirements for the PhD include thirty-six credit hours in courses, seminars, and research. Courses taken include Methods of Theoretical Physics (PHYS 503), Theoretical Mechanics (PHYS 505), Methods of Experimental Physics (PHYS 510), Quantum Mechanics I, II, and III (PHYS 507, 508, and 603), Electromagnetism and Electrodynamics (PHYS 506 and 601), and Statistical Mechanics (PHYS 602). Three physics electives are required, generally chosen from the set atomic physics, astrophysics, elementary particle physics, nuclear physics, and condensed matter physics (PHYS 607, 585, 617, 609, and 613, respectively). There is no foreign language requirement for a PhD in physics. Students who have satisfactorily completed courses equivalent to the required courses listed above will have the corresponding requirements waived or transferred. Students lacking the background to begin the basic curriculum may be advised to take some advanced undergraduate courses. Additional courses, supplemented by colloquia and informal seminars on topics of current interest, are available to the advanced student.

In addition to course work, there are three examinations to be passed for a PhD, a written qualifying examination on undergraduate physics, a written and oral PhD candidacy examination, and an oral PhD dissertation defense. Students first take the qualifying exam in the fall of their first year, and must pass it by the end of the second year. The candidacy examination is typically taken in the third year, after course work is complete. In this exam, the candidate must present a research proposal, demonstrate the ability to perform the proposed research, and show a broad understanding of physics. The post-candidacy student then concentrates on research, and generally writes the doctoral dissertation within three years of the candidacy examination. A dissertation is required and must be approved by the student's doctoral committee and defended orally by the student at the final examination, the PhD defense.

To remain in good standing, students are required to maintain a 3.0 grade point average, to pass the qualifying examination by the end of the second year, to pass the candidacy exam by the end of the fourth year, and to complete the PhD degree program by the end of the eighth year. The minimum residence requirement for the PhD degree is four consecutive semesters and may include summer session.

Research Areas

Astrophysics

Astrophysics research at Notre Dame is directed toward the study of astrophysical origins. The group's activities contribute to the recently established Center for Astrophysics. The center supports interdisciplinary research in three basic areas: theoretical astrophysics and cosmology, ground-based optical astronomy, and space science.

Ground-Based Astronomy. The flagship of Notre Dame's ground-based observational effort is the partnership with the Large Binocular Telescope (LBT) in Arizona. Notre Dame has joined a consortium of other universities for construction and use of this telescope. The members of this consortium are excitedly anticipating the arrival of first light in early 2004. The LBT will be one of the most powerful and versatile telescopes in the world. It will be the premier instrument for many astronomical problems ranging from studies of the early universe to searches for planets in other star systems.

Current observational programs involve a variety of telescopes around the world including the *Keck* observatory in Hawaii and the Hubble Space Telescope. Ongoing research includes studies in the mysterious dark energy which is accelerating the expansion rate of the universe, studies of distant supernovae and gamma-ray bursts, studies of planet formation in young stellar systems, and studies of gravitational microlensing to search for dark matter and planets in the Galaxy.

Theoretical Research. Ongoing theoretical research includes all aspects of the origin and evolution of the universe, galaxies, stars, planets, and the interstellar medium. The astrophysics theory group has pioneered the development of modern numerical methods for hydrodynamic simulations of complex astrophysical systems. Theoretical work concerning the formation and evolution of galaxies, stars and the interstellar medium is being investigated with complex adaptive mesh magnetohydrodynamics. The group is also doing cosmological simulations of the origin and evolution of the very early universe, from the birth at the Planck scale, through inflation and various particle-physics processes, primordial nucleosynthesis, the emission of the cosmic microwave background, and the formation of large-scale structure and galaxies. These simulations are used to constrain theories for the nature of space-time and the origin of the universe. General relativistic numerical hydrodynamic simulations are also being performed as a means to understand exploding supernovae, black-hole and neutron star formation, and the formation of jets and electromagnetic bursts from accreting systems.

Another focus is theoretical nuclear astrophysics. This includes nucleosynthesis in the big bang, in supermassive population III stars, during late stellar evolution (AGB stars), and explosive nucleosynthesis on accreting white dwarfs (novae), accreting neutron stars (X-ray bursts), and supernovae. The nucleosynthesis is simulated using complex nuclear reaction network models for stellar hydrostatic and/or hydrodynamic conditions. The nuclear-physics input is derived from nuclear structure and nuclear reaction models. The reaction flow is studied within the time scales of static or explosive stellar burning. Energy generation and nucleosynthesis are calculated and compared with observed luminosities and elemental abundance distributions.

Space Science. Research in space science divides into studies of cosmic-ray air showers and the development of a new Notre-Dame satellite mission. In cosmic-ray research, an extensive air shower array (Project GRAND) is used to study cosmic rays and measure angles with high precision. The production mechanisms for UHE cosmic gamma rays and stellar sources such as Cygnus X-3 and Hercules X-1 are being studied along with a search for an association with gamma-ray bursts.

The group's newest endeavor is the proposed Deep Impact Microlensing Explorer Mission (DIME) in which Notre Dame's contribution will be as the Science Analysis center. Scientists at Notre Dame will utilize the onboard telescope to make parallax measurements of distant gravitational microlensing events. These observations will be crucial to characterize the nature of dark matter in the Galaxy.

Atomic Physics

Experimental Program. The experimental atomic physics program at Notre Dame is directed toward the study of the structure, excitation, and de-excitation characteristics of atoms and ions. This work stimulates advances in the theoretical understanding of atomic systems at the most fundamental level, where relativistic and field-theoretic aspects of the atoms become important.

An experimental laser spectroscopy program focuses on precision measurements of transition amplitudes and energies. These measurements are of interest to the study of parity nonconservation effects in atoms which is motivated by the study of weak interactions and are part of a low energy test of the standard model. High-resolution spectroscopic techniques are also used in other applications. This program involves the use of tunable dye lasers and diode lasers. Highly stripped heavy-ion beams of 10-100 MeV energy are produced at the accelerator facilities of the Nuclear Structure Laboratory. Experiments are also performed at other off-site heavy-ion accelerators. Present investigations concentrate on the precision atomic spectroscopy of highly ionized atoms and the measurement of lifetimes of selected atomic states in these ions. The spectroscopic measurements test current relativistic and quantum electro-dynamic calculations of atomic structure for few-electron ions. The lifetime results reflect the effects of both electron correlations and relativistic contributions in the de-excitation rates of excited atomic states. These data are also important to the diagnostics and modeling of high-temperature astrophysical and laboratory plasmas.

At APAL, the Atomic Physics Accelerator Laboratory in the Nieuwland Science Hall basement, fast heavy ions (up to 200 keV energies) are used for Doppler-free laser studies of atomic hyperfine structures, precision lifetime measurements, and other studies of atomic collisions and structures.

Theoretical Program. Notre Dame atomic theorists work on problems at the interface of atomic and particle physics. Recently, they have been involved in calculations of electron electric dipole moment enhancement factors in heavy rare-earth ions in support of experiments to detect time-reversal (T) violation. The atomic theory group produced the most accurate available prediction of parity nonconserving (PNC) amplitude in cesium, which, when combined with experiment, served as a stringent test of the standard model. Systematic calculations of the PNC amplitudes induced by the nuclear anapole moment have also been carried out. Recently, the atomic theory group calculated isotope shifts in ions of interest in the search for time-variation of the fine-structure constant. Higher-order corrections to quantum field theories for hydrogen, helium, and positronium are other subjects of current investigations. In a different but related atomic theory project, *ab initio* studies of transport properties of warm-dense plasmas are underway.

Condensed Matter and Biophysics

Condensed matter (CM) research at Notre Dame encompasses topics of research ranging from "hard" CM problems such as semiconductor or superconductor systems to "soft" CM problems such as studies of multicellular aggregates or the application of network theory to biological systems. The topics studied are described below:

Physics on the Nanoscale. Single-electron charging effects and related phenomena are explored to probe the basic physics of few-atom clusters, fullerenes and other exotic systems comprised of only a few atoms. The growth and self assembly of quantum dots, quantum wires, and heterostructures in semiconductor systems is also studied extensively. Work on heterostructures includes the development of blue-light semiconducting lasers. Self-organized quantum dots and other nanophase systems are grown and characterized using optical, magnetic, transport, and x-ray techniques. Facilities include a dual-chamber molecular beam epitaxy machine, extensive facilities for optical and magneto-optical studies of nanoscale systems with micrometer-scale and sub-micrometer-scale (near field) resolution, and instrumentation for the study of electrical transport and magnetic properties.

Semiconductor Physics and Magnetism. Thin-film II-VI, III-V and other semiconductor samples are prepared by molecular beam epitaxy. III-V semiconductors which incorporate Mn ions in the lattice are ferromagnets and are expected to play a key role in future "spintronic" devices. These, as well as other magnetic samples, are studied by a variety of experimental techniques including laser magneto-spectroscopy, x-ray and neutron scattering, and electron transport. Facilities include extensive capabilities for the study of electrical properties, magnetization, and state of the art apparatus for the study of magnetic resonance. In addition, magnetic properties of solids are studied by neutron scattering, carried out off campus at the National Institute for Standards and Technology and at the University of Missouri Research Reactor Center (MURR).

Structural Studies. X-ray scattering and X-ray absorption fine structure (XAFS) are used to study the surfaces and internal interfaces of solids and liquids, phase transformations and ordering phenomena in condensed-matter systems. Examples of recent studies atomic-scale structure of "highly correlated" magnetic materials, interfaces and structure of magnetic semiconductors, the structure of complex nanophase materials, the structure of metalloproteins, and environmental systems on the molecular scale. Because of the unique advantages of synchrotron radiation, these experiments are conducted at national facilities located at the Advanced Photon Source, Argonne National Laboratory, where Notre Dame is a major participant.

Superconductivity and Vortices. High-temperature superconductors are studied from the perspective of microwave absorption and other techniques with a view to probing fundamental mechanisms. These include investigations of the response of high-temperature superconductor thin-film systems to ultrashort duration, far-infrared light to evaluate potential applications for and the intrinsic electronic properties of these novel materials. New materials are synthesized using the traveling solvent float zone (TSFZ) technique in a mirror furnace-based system.

In a separate effort, new superconducting systems based on dilute-doped elemental superconductors are being developed for micro-refrigerators and transition-edge x-ray sensors for space missions. Facilities include thermal evaporation and multi-source sputtering systems, a cold head for electro-optic studies down to 25K, a SQUID voltmeter, a 10 T superconducting magnet, low-temperature equipment for work to 1 K, and a clean room for contact lithography. A fiber optic link to the lab of a collaborating atomic physicist permits the piping of modulated laser light to these experiments. Collaborations with NIST, Boulder, provide access to an extensive class-100 clean-room, adiabatic refrigeration to 60 mK, and magneto-optic facilities.

Scanning tunneling microscopy and spectroscopy (STM/STS) are used to image vortices induced by an applied magnetic field and probe their spectroscopic properties. These measurements are complemented with studies of the vortex lattice structure using small-angle neutron scattering (SANS). Combined, the two techniques allow a study of how the superconducting gap and the vortex lattice symmetry and orientation evolves as a function of temperature and field. On-site facilities include a low-temperature, ultra-high vacuum STM (under construction) while the neutron scattering studies are largely conducted at the Institut Laue-Langevin, Grenoble, France.

Theoretical Condensed Matter Physics. Notre Dame theoretical condensed matter physicists study superconductors, semiconductors, soft matter, and properties of networks.

In one theoretical effort in superconductivity, finite temperature field-theory techniques are used to study two-dimensional antiferromagnets. Also studied are highly-correlated electronic systems, including disordered and frustrated ferromagnets, such as magnetic semiconductors, high temperature superconductors, the novel superconducting compound, MgB_2, and mesoscopic superconductivity. In semiconductors, an active collaboration exists between theorists and experimentalists studying mesoscopic and nanoscopic physics. In particular, Zeeman-induced nanoscale localization of spin-polarized carriers in magnetic semiconductor-permalloy hybrids is studied. In another project, Monte Carlo simulations are used to study the microstructure of strained semiconductor alloys and compounds.

Finally, the tools of statistical mechanics are applied to understanding real networks, including metabolic and genetic networks, social networks, the Internet, and the World Wide Web. A special focus is towards understanding the implications of the scale-free characteristics of real networks, a concept developed at Notre Dame.

Biophysics. The department hosts an active program in biophysics, focusing on modeling the structure and development of various biological systems. A strong focus is on understanding the topological properties of cellular networks--the networks formed by the Interactions between metabolites, genes and proteins, modeling both their structure and dynamical behavior. Using techniques from statistical mechanics, models of "convergent extension" cell rearrangements have been developed as a way to understand one step in embryonic development. At a higher level, multicellular aggregates, such as embryonic and mature tissues, are modeled. These systems often share the properties of "excitable media" and "soft matter," familiar to modern condensed matter physics and dynamical systems theory. Biological research is carried out in collaboration with other groups on the campus, involving faculty from biochemistry and biology, under the coordination of the Center for Biocomplexity.

High Energy Physics

Experimental Program. An understanding of the fundamental constituents of matter and the forces with which they interact is sought in high energy physics experimental programs that are performed at colliding beam accelerator facilities of two complementary types: Hadron colliders and electron-positron colliders. Each of these programs has a current, operating experiment and a future experiment in either the construction phase or the research and development phase.

The hadron collider program is based upon the currently operating Tevatron 2 Collider and DØ experiment at Fermilab to be followed (starting in 2007) by the CMS experiment at the CERN Large Hadron Collider (LHC). The physics objectives of this program are to study top and beauty physics, electroweak bosons W and Z, QCD processes, and to search for evidence of electroweak symmetry breaking (such as Higgs bosons or technicolor), supersymmetry, extra (hidden) spatial dimensions, and other new phenomena. This program has provided many important physics results over the last decade, among them the discovery of the top quark in 1995. Notre Dame graduate students have written dissertations in all these research areas. Additionally, Notre Dame has been involved in the recent upgrade of the DØ detector to magnetic tracking, being a pioneering group in the development of scintillating-fiber tracking technology. Notre Dame manages the operation of the Central Fiber Tracker for DØ, directs the offline track reconstruction effort for the experiment, and is involved in the building of an improved level-1 track trigger processor for enhanced detector performance at increased luminosity. Fiber-optic techniques are also critical to the operation of the CMS hadron calorimeters at the LHC, and Notre Dame has been extensively involved in the design and construction of key elements of the electro-optical readout of these CMS detector subsystems, and has been engaged in R and D on new scintillator and waveshifter materials for improved calorimetry performance under high luminosity operation.

The electron-positron collider program is based upon the currently operating BaBar experiment at SLAC. This program, too has provided remarkable physics results, notably the observation by BaBar of CP violation in the b-quark system in 2000 - the first observation of CP violation outside of K_L decays, which were discovered in 1964. Physics goals include systematic study of CP violating effects in a variety of decay modes in the b-system as well as studies of rare decays of beauty and charm mesons. Luminosity increases for the BaBar experiment are planned, and Notre Dame is engaged in refinements of the readout electronics of the central tracking chamber to improve track reconstruction.
A variety of R and D projects are underway for the future Linear Collider including, for detectors: scintillator and waveshifter development for fast triggering, calorimetry, muon detection, and tracking; and for accelerators: beam controls and diagnostics systems.

Theoretical Program. In theoretical high energy physics, refinements are pursued in the phenomenology of the standard model as well as 'new' physics beyond the standard model, particularly supersymmetry. This new physics can be manifested by its presence in CP asymmetries like the one recently measured at SLAC, the first new CP measurement in 40 years. Also being analyzed is supersymmetry and other attempts to tie the electroweak symmetry breaking in the standard model to a more fundamental understanding of nature, including connections to cosmology such as the dark matter and dark energy. Baryo- and lepto-genesis in the Universe is also studied as well as scenarios with extra space dimensions and even multidimensional time.

Nuclear Physics

Experimental Research. The nucleus is a tiny object with a very wide reach. Indeed, nuclear physics encompasses an enormous variety of phenomena--from the very beginnings of life (the CNO cycle), to determination of the age of stars and their demise in a fiery cataclysm (supernovae). In between, one finds applications of nuclear physics in fields as diverse as medicine, radiocarbon dating, energy, national security, and even detecting art forgeries. The nucleus, as a quantal many-body system, provides the bridge between quarks at one end and solids at the other. Probes of nuclear properties can answer many questions relating not only to the microscopic behavior of quantum systems, but also to the macroscopic behavior of the very largest stars.

Nuclear physics research in the department aims at studying the structure and dynamics of nuclear systems, especially in their relation to astrophysical phenomena. Work is carried out in the Nuclear Structure Laboratory, as well as a large number of accelerator facilities around the world.

A pioneering focus in the Nuclear Physics Laboratory has been the development and application of short-lived radioactive ion beams (RIB) for studies of the structure of nuclei at the very limits of particle stability. Examining nuclear matter under extreme conditions is crucial for understanding of the fundamental properties of nuclear forces, and development of the unified nuclear theory. An opportunity is provided by studies of exotic nuclei near and beyond the line of particle stability (drip line). Knowledge of the properties of exotic nuclei is also important for understanding of many astrophysical processes. Currently there is a focus on the spectroscopy studies of very neutron- and proton-rich nuclei and on investigation of mechanism of reactions induced by RIBs.

Research in nuclear structure focuses on the fundamental modes of motion in nuclei. Among the novel aspects of nuclear dynamics under investigation are wobbling motion (akin to that of a wobbling top), breakdown of chiral symmetry (the nucleus demonstrating left- and right-handedness), and anti-magnetic rotation (symmetric rotation of nucleonic currents). The "bulk" properties of nuclei are investigated by means of high-energy nuclear vibrations (the "giant resonances") to determine the incompressibility of nuclear matter, a crucial component of the nuclear equation of state that is critical to determining the properties of matter in the core of neutron stars.

A major research initiative of the laboratory is understanding the origin of the elements in the universe. This effort is the cornerstone of the newly-established Joint Institute for Nuclear Astrophysics (JINA), a national Physics Frontier Center. Measurements of nuclear reaction rates and decay processes at stellar temperatures and densities comprise a strong part of the experimental effort in nuclear astrophysics. The goal is to understand the origin and distribution of the elements in the universe. Research is directed towards simulating stellar nucleosynthesis in the laboratory, understanding late stellar evolution and explosive nucleosynthesis in novae and supernovae, and explaining the origin of the very high luminosity observed in stellar x-ray outbursts.

Developing Accelerator Mass Spectrometry techniques for astrophysics is another research focus of the laboratory. Accelerator Mass Spectrometry has traditionally been used to detect environment tracers at or below their natural abundance level (^{10}Be, ^{14}C, ^{36}Cl). Its main attribute is its power to accelerate and analyze ions of radioactive nuclei with extremely high sensitivity. Many aspects of this powerful technique can be used for research involving radioactive-beam physics, as well as the study of low cross-section nuclear reactions which are important in stellar evolution. That is the case where counting rates and voltages are very low and there are high isobaric backgrounds.

The major experimental facilities in the laboratory include an FN Tandem accelerator that can provide up to 11 MV terminal voltage for the acceleration of light and heavy ions; the Twinsol radioactive beam facility, based on two, coupled, 6 Tesla-meter superconducting solenoids for the focusing of the radioactive beam particles onto a target; a 4 MV KN and a 2 MV JN Van de Graaff accelerators capable of delivering the intense, low-energy beams necessary for recreating stellar conditions in the laboratory; a number of clover- and Compton-suppressed Ge detectors for gamma-ray spectroscopy measurements and, a superconducting solenoid system for decay studies. A recoil-mass spectrometer is currently in the design stage and is expected to be operational by 2005.

In addition to the high level of activity within the nuclear laboratory, the nuclear group's research is complemented by experiments done at various national facilities including the superconducting cyclotron at Michigan State University, and accelerator facilities at the Argonne, Berkeley, Oak Ridge, Los Alamos, and Thomas Jefferson National Laboratories. On the international scene, Notre Dame scientists also utilize the High Flux Beam Reactor at Grenoble, France, the GANIL facility in Caen, France, the ISOLDE radioactive ion facility at CERN, Switzerland, and various accelerator facilities in Belgium, France, Germany, Japan, and the Netherlands.

There is also a lively inter-disciplinary programs in radiation chemistry, bio-mechanics, materials testing, and elemental analysis of archaeological samples. The analysis of archaeological samples is a new initiative with the Snite Museum of Art at Notre Dame and uses the proton-induced x-ray emission (PIXE) technique. Collaborations with industries are also being carried out in testing new detectors and determining the durability of artificial human body components.

Theoretical Research. The structure of exotic nuclei, including those with unusual numbers of protons and neutrons, and rapidly spinning nuclei are the focus of the theoretical effort. The structure of such exotic nuclei is likely to become accessible to experimental studies with the development of new national and international facilities. Also investigated are transitions from the superconducting to the normal state in rapidly rotating nuclei, pair correlations in very proton-rich nuclei, and the properties of very neutron-rich nuclei, which play an important role in astrophysical processes. A recent result is the discovery of magnetic and chiral rotation of nuclei.

The methods of many-body theory of finite systems are quite general and can be applied both to nuclei and non-nuclear mesoscopic systems, including atomic clusters and quantum dots.

Education and Outreach

QuarkNet. QuarkNet is a federally funded national program partnering high school teachers with particle physicists working on high-energy colliding beam experiments at Fermilab, CERN and SLAC and on non-accelerator and fixed target experiments. Notre Dame is directly involved in the management of the National QuarkNet Program and also operates the Notre Dame QuarkNet Center located adjacent to the campus where high school teachers and students can participate "hands-on" in construction of state-of-the-art particle physics detectors.

Research Experiences for Teachers (RET). Notre Dame operates a Research Experience for Teachers (RET) program; which pairs high school teachers from the North Central Indiana/Southwest Michigan region with physics faculty in the department. Teachers in RET participate in a paid eight-week program of summer research and receive academic graduate research credit.

In principle, research is possible in any area of physics depending upon the mutual interest of the teacher and faculty mentor. Twelve high school teachers are supported in this program each summer.

Joint Institute for Nuclear Astrophysics (JINA). The Joint Institute for Nuclear Astrophysics (JINA) is funded by the NSF as a Physics Frontier Center. It is a research collaboration focused at the intersection of nuclear physics and astrophysics. JINA offers a wide range of educational outreach programs at all levels: K-12, undergraduate and graduate. For graduate students, JINA's educational outreach program offers collaboration opportunities in the exciting field of nuclear astrophysics, including research fellowships for graduate work at or from JINA sites (Notre Dame, Michigan State University, University of Chicago, Argonne National Laboratory, University of Arizona, University of California Santa Barbara, University of California Santa Cruz, and Los Alamos National Laboratory). One fellowship program offers a full year of research experience at Notre Dame for minorities and women to explore the field of nuclear astrophysics. JINA offers professional development training to K-12 teachers and graduate students may participate in these workshops and camps. JINA also has research experience programs for high school teachers and students in which graduate students often mentor teachers and work with them in the lab. For more information on JINA and its educational outreach programs, go to http://www.jinaweb.org.

Course Descriptions

Each course listing includes:

- Course number
- Title
- (Lecture hours per week—laboratory or tutorial hours per week—credits per semester)
- Instructor
- Course description
- (Semester normally offered)

500. Physics Colloquium
(1-0-0) Staff
A discussion of current topics in physics by guest lecturers and members of the faculty. (Every year)

503. Methods of Theoretical Physics I
(3-0-3) Staff
A study of the methods of mathematical physics. Topics include linear vector spaces, matrices, group theory, complex variable theory, infinite series, special functions, and differential equations. (Every year)

505. Theoretical Mechanics
(3-0-3) Staff
Lectures and problems dealing with the mechanics of a particle, systems of particles, and rigid bodies. The Lagrangian and Hamiltonian formulations of classical mechanics; theory of small oscillations. Introduction to special relativity. Introduction to nonlinear dynamics and chaos; bifurcation theory. (Every year)

506. Electromagnetism
(3-0-3) Staff
Electrostatics; Laplace's and Poisson's equations; Legendre's and Bessel's equations; Green's functions; static multipole expansions; magnetostatics; magnetic vector and scalar potentials; Maxwell's equations; plane waves. (Every year)

507, 508. Quantum Mechanics I and II
(3-0-3) (3-0-3) Staff
General Hilbert Space formulation of Quantum Mechanics; Schrödinger vs. Heisenberg picture; symmetries and conservation laws; Feynman path integrals; harmonic oscillator; the Coulomb problem; the Bohm-Aharonov effect; the theory of angular momentum; EPR correlations and Bell's inequality; Bose-Einstein and Fermi-Dirac statistics; elementary approximation methods; scattering theory. (Every year)

510. Methods of Experimental Physics
(2-2-3) Staff
A lecture and laboratory course on methods of all aspects of modern experimental physics, from instrumentation and data acquisition to statistical treatment of data. The course is designed around ten experiments in different areas of physics. The course includes learning about equipment design, various detection systems, electronic pulse-processing, and computer interfaces. (Every year)

531, 532, 533. Current Topics in Physics
(3-0-1) (3-0-1) (3-0-1) Staff
Discussion of topics of current interest in physics. (Offered as needed)

581. Relativity: Special and General
(3-0-3) Staff
An introduction to relativity, both special and general. Special relativity; Lorentz transformations of events, geometry of space-time, relativistic kinematics (energy-momentum), Lorentz transformations of electromagnetic fields. General relativity, gravity and light, principle of general covariance, Einstein field equations, Schwarzschild solution, precession of perihelions of planets, deflection of light, black holes. (Every year)

585. Astrophysics
(3-0-3) Staff
An introductory course in astrophysics covering such topics as spectral and color indices, photometry, variable stars, mass functions, theoretical stellar models, synthesis of elements, white dwarfs, neutron stars, supernova, cosmic rays, galaxies, and cosmology. (Every year)

587. Interpretive Problems in Quantum Mechanics
(3-0-3) Staff
This course is intended for graduate students in physics and in the history and/or philosophy of science who wish to examine in some reasonable detail the roots, both historical and philosophical, of quantum mechanics and the profound conceptual problems to which that theory has given rise. The main vehicle for this will be a study of original seminal papers in the field (e.g., those by Planck, Bohr, Heisenberg, Schrödinger, Born, Einstein, Podolsky and Rosen, von Neumann, Bell, Bohm) and of related papers in the foundations of physics literature. Some background in physics, especially in the formalism of quantum mechanics, is desirable. However, the relevant physics and philosophy will be presented in the course itself. (Offered as needed)

Directed Research Courses

These courses are for high school teachers participating in research in the physics department, for example as participants in the RET (Research Experience for Teachers), QuarkNet (598Q), or similar programs which partner high school teachers with physicists. Research areas available include atomic physics, biophysics, condensed-matter physics, nuclear physics, particle physics, and astrophysics. Participants will be introduced to research physics in informal lectures with faculty, with course notes and reference texts available. Additionally, they will participate in directed research associated with current experiments being carried out by department faculty. Students maintain a research logbook and submit a written research summary at the conclusion of the research period. (Offered as needed)

598A. Directed Research in Atomic Physics
(V-V-V) Staff

598B. Directed Research in Biophysics
(V-V-V) Staff

598C. Directed Research in Condensed Matter Physics
(V-V-V) Staff

598N. Directed Research in Nuclear Physics
(V-V-V) Staff

598Q. Directed Research in Particle Physics
(V-V-V) Staff

598R. Directed Research in Particle Physics
(V-V-V) Staff

598S. Directed Research in Astrophysics
(V-V-V) Staff

Advanced Courses

601. Electrodynamics
(3-0-3) Staff
Scattering and diffraction; special relativity; covariant formulation; radiation from charges; multipole expansions; radiation damping. (Every year)

602. Statistical Thermodynamics
(3-0-3) Staff
Review of basic elements of phenomenological thermodynamics; kinetic theory and transport equation; dilute gases in equilibrium; classical statistical mechanics; microcanonical, canonical and grand canonical ensembles; quantum statistical mechanics; the renormalization group, critical phenomena and phase transitions. (Every year)

603. Quantum Mechanics III
(3-0-3) Staff
Advanced topics in nonrelativistic quantum mechanics: advanced approximation methods, partial wave expansions, and the optical theorem, Berry's phase; relativistic quantum mechanics; the Dirac equation, the electromagnetic interactions of the Dirac particle, the fine structure of atoms, Klein's paradox; basic elements of quantum field theory: Lagrangian and Hamiltonian formulation, the existence of antiparticles, the Feynman rules with elementary applications; one-loop renormalization and the renormalization group. (Every year)

604. Quantum Field Theory
(3-0-3) Staff
General formulation of quantum field theories; the spin-statistics theorem; CPT invariance and its tests; local gauge theories; symmetries, conservation laws, Ward identities and anomalies; Feynman path integrals; Feynman rules for abelian and nonabelian gauge theories; ghosts; the general renormalization program for gauge theories and the renormalization group; asymptotic freedom and slavery; spontaneous realization of symmetries and the Higgs mechanism; grand unification; and supersymmetry. (Offered as needed)

606. Many Body Theory
(3-0-3) Staff
Second quantization; density matrix; double-time Green's functions; temperature Green's functions; static and time-dependent properties of a system of electrons in the normal state; superconductivity; Goldstone theorems; phase transitions in one and two dimensions. (Offered as needed)

607, 608. Atomic Physics
(3-0-3) (3-0-3) Staff
Atomic structure and properties. Spectroscopy of simple and complex atomic systems, the Schrödinger and Dirac equations, Hartree-Fock methods, allowed and forbidden radiative transitions, and hyperfine splitting. Further topics that may be covered are laser-atom interactions, laser cooling and trapping, photoionization, atomic collisions, many-body perturbation theory, quantum electrodynamics, and atomic parity nonconservation. (The first semester is offered in the fall of odd years; the second semester is offered as needed.)

609, 610. Nuclear Physics I, II
(3-0-3) (3-0-3) Staff
The nucleus as a Fermi gas; the Von Weiz-säcker mass formula; tensor algebra and the Wigner-Eckart theorem; isospin; independent-particle motion; the many-body problem in nuclear physics; the Hartree-Fock self-consistent field; the shell model; collective nuclear motion; rotations and vibrations; pairing forces; nuclear reaction theory; electromagnetic and weak interactions; fundamental symmetries and searches for "new physics" in the context of the nucleus; nuclear astrophysics; the solar neutrino problem; use of electron scattering as a tool to investigate the structure of the nucleon and the nucleus; quarks and gluons in relativistic heavy ion collisions. (The first semester is offered every year; the second semester is offered as needed.)

612. Quantum Optics
(3-0-3) Staff
This course will cover properties of the quantized electromagnetic field as it interacts with atoms and other forms of matter. The interaction of light with matter is the basis for the phenomena of photoelectric detection, measurement, and nonlinear optics which will be used to investigate the quantum mechanical nature of photon correlations, coherent states of light, squeezed states, and the basics of quantum computing. (Offered in the fall of even years.)

613. Solid State Physics I, II
(3-0-3) (3-0-3) Staff
Free electron theories of solids; Drude and Sommerfeld theory; crystal and reciprocal lattices; diffraction; Bloch electrons; band structure and the Fermi surface; cohesive energy; classical and quantum theory of the harmonic crystal, phonons; dielectric properties of insulators; semiconductors; paramagnetism and diamagnetism, magnetic ordering; superconductivity. Further topics covered in PHYS

614 are chosen from such areas as: critical phenomena; high-temperature superconductivity; quantum fluids; spin glasses; quantum wells and quantum dots; quantum Hall effect; "soft" condensed-matter systems; survey of modern experimental techniques such as molecular-beam epitaxy; dilution refrigerators; XAFS, ESR, x-ray, and neutron scattering. (The first semester is offered every year; the second semester is offered as needed.)

617, 618. Elementary Particle Physics I, II
(3-0-3) (3-0-3) Staff
Relativistic transformations and kinematics; symmetries and conservation laws; selection rules; basic elements of group theory; the quark model and fundamental interactions in nature; abelian and nonabelian gauge theories; the Standard Model of High Energy Physics, its Feynman rules and renormalization; the Higgs mechanism; the CKM matrix; Supersymmetry and Supergravity; Grand Unification; empirical foundations: accelerators, detectors and experimental techniques; crucial experiments. (The first semester is offered every year; the second semester is offered as needed.)

619. Stars and Stellar Evolution
(3-0-3) Staff
Observables of stellar astronomy and star classification, astrophysical hydrodynamics, stellar interiors, hydrostatic equilibrium, energy transport, stellar opacities, equation of state, thermonuclear reaction rates, nucleosynthesis. The evolution of main sequence and post main sequence stars along the Hertzsprung-Russell diagram, stages of thermonuclear burning. Stellar pulsations and transients. Basic theory of star formation and gravitational collapse. Formation and evolution of planetary systems. Relativistic hydrodynamics including white dwarfs, neutron stars, black holes, accretion discs and x-ray transients. Binary star evolution. Stellar collapse and supernovae. (Offered as needed)

620. Galactic Dynamics and Theoretical Cosmology
(3-0-3) Staff
A course on stellar systems, galaxies, and the large-scale structure of the universe and microwave background. Observational properties of galaxies and galactic clusters. Galaxy morphology. Galaxy models including: gravitational collapse and star formation, galactic halos, galactic chemical evolution, potential theory, stellar orbits, and the theory of the equilibrium configurations of stellar systems. The theory of spiral structure, collisions and encounters between stellar systems, and two-body relaxation in the approach to equilibrium. Dark matter content of galaxies, clusters, and the intergalactic medium. Models of large-scale structure including cold, hot, and mixed-dark matter models. The formation and evolution of galactic and extragalactic cosmic radiation. The origin, radiation transport, and structure of the cosmic microwave background radiation and other diffuse backgrounds. Inflationary cosmology, cosmic phase transitions, primordial nucleosynthesis. (Offered as needed)

623, 624. Topics in Contemporary Physics
(3-0-3) (3-0-3) Staff
A study in depth of selected topics of current interest. (Offered as needed)

625, 626. Special Topics in Physics
(3-0-3) (3-0-3) Staff
Discussions of topical concepts in physics. (Offered as needed)

651, 652. Nuclear Physics Seminar
(2-0-2) (2-0-2) Staff
Discussions of research and current literature in nuclear physics. (Every year)

653, 654. Atomic Physics Seminar
(2-0-2) (2-0-2) Staff
Discussion of research and current literature in atomic physics. (Every year)

655, 656. Elementary Particle Physics Seminar
(2-0-2) (2-0-2) Staff
Discussion of research and current literature in elementary particle physics. (Every year)

657, 658. Theory Seminar
(2-0-2) (2-0-2) Staff
Discussion of research and current problems in theoretical physics. (Every year)

659, 660. Condensed Matter Seminar
(2-0-2) (2-0-2) Staff
Discussion of research and current literature in condensed matter physics. (Every year)

661. Astrophysics Seminar
(2-0-2)(2-0-2) Staff
Discussion of research and current literature in astrophysics. (Every year)

671. Early Universe Seminar
(2-0-2) Staff
Application of particle and nuclear physics to the early universe. Subjects covered will include: isotropy and homogeneity of the universe, microwave background radiation, "Big Bang" cosmology, inflation models, the "standard model" of high energy physics, baryosynthesis and "Grand Unified" theories, nucleosynthesis, cosmic strings, and "dark" matter. (Every year)

699, 699A. Research and Dissertation
(V-V-V) Staff
Research and dissertation for resident graduate students.

700. Nonresident Dissertation Research
(0-0-1) Staff
Required of nonresident graduate students who are completing their dissertations in absentia and who wish to retain their degree status.

In addition to the foregoing, certain advanced undergraduate courses may be taken for graduate credit.

Faculty

Anatoli Afanasjev, *Research Assistant Professor*. M.S., Latvian State University, 1984; Ph. D, ibid., 1993; Habilitation, ibid., 1999. (2003)

Mark Alber, *Concurrent Professor*. M.S., Moscow Institute of Technology, 1983; Ph.D., University of Pennsylvania, 1990. (2003)

Ani Aprahamian, *Chair and Professor.* B.A., Clark Univ., 1980; Ph.D., ibid., 1986. (1989)

Gerald B. Arnold, *Professor.* B.S., Northwestern Univ., 1969; M.S., Univ. of California, Los Angeles, 1972; Ph.D., ibid., 1977. (1978)

Richard E. Azuma, *Adjunct Professor*. B.S., University of British Columbia, Canada, 1951; Ph.D., The University, Glasgow, Scotland, 1959. (2003)

Dinshaw Balsara, *Assistant Professor.* M.S. (Physics), Indian Inst. of Tech., Kanpur, 1982; M.S. (Astronomy), Univ. of Chicago, 1989; Ph.D., Univ. of Illinois at Urbana-Champaign, 1990. (2001)

Albert-László Barabási, *the Emil T. Hofman Professor of Physics.* B.A., Univ. of Bucharest, 1989; M.A., Univ. of Budapest, 1991; Ph.D., Boston Univ., 1994. (1995)

David P. Bennett, *Research Associate Professor.* B.S., Case Western Reserve Univ., 1981; Ph.D., Stanford Univ., 1986. (1996)

H. Gordon Berry, *Professor*. B.A., Oxford Univ., 1962; M.S., Univ. of Wisconsin, 1963; Ph.D., ibid., 1967. (1994)

Ikaros I. Bigi, *Professor*. M.Sc., Univ. München, 1973; Ph.D., ibid., 1976; Habilitation, Aachen, 1984 . (1988)

Howard A. Blackstead, *Professor.* B.S., North Dakota State, 1962; M.A., Dartmouth College, 1964; Ph.D., Rice Univ., 1967. (1969)

Bruce A. Bunker, *Professor.* B.Sc., Univ. of Washington, 1974; Ph.D., ibid., 1980. (1983)

Neal M. Cason, *Professor.* A.B., Ripon College, 1959; M.S., Univ. of Wisconsin, 1961; Ph.D., ibid., 1964. (1965)

Philippe A. Collon, *Assistant Professor.* Licencie, Univ. Catholique De Louvian, 1993; Ph.D., Univ. of Wien, 1999. (2003)

Malgorzata Dobrowolska-Furdyna, *Professor.* M.S., Warsaw Univ., 1972; Ph.D., Polish Academy of Sciences, 1980. (1988)

Morten R. Eskildsen, *Assistant Professor.* B.Sc., Univ of Copenhagen, 1992; M.Sc., ibid., 1994; Ph.D., ibid., 1998.(2003)

Stefan G. Frauendorf, *Professor.* M.S., Technical Univ. of Dresden, 1968; Ph.D., ibid., 1971. (1998)

PHYSICS

Jacek K. Furdyna, t*he Aurora and Tom Marquez Professor of Physics and Fellow of the Nanovic Institute for European Studies*. B.S., Loyola Univ., Chicago, 1955; Ph.D., Northwestern Univ., 1960. (1986)

Umesh Garg, *Professor*. B.S., Birla Institute of Technology, Pilani, India, 1972; M.S., ibid., 1974; M.A., State Univ. of New York, Stony Brook, 1975; Ph.D., ibid., 1978. (1982)

Peter M. Garnavich, *Associate Professor.* B.S., Univ. of Maryland, 1980; M.S., Massachusetts Inst. of Technology, 1983; Ph.D., Univ. of Washington, 1991. (1999)

Erika L. Gibb, *Visiting Assistant Research Professor*. B.S., Northern Arizona University, 1996; Ph.D., Rensselaer Polytechnic Institute, 2001. (2003)

Joachim Göerres, *Research Professor.* B.S., Univ. of Munster, 1974; Diplom., ibid., 1979; Ph.D., ibid., 1983. (1989)

Anna Goussiou, *Assistant Professor*. B.S., Aristotle Univ. of Thessalonika, Greece, 1989; M.S., Univ. of Wisconsin-Madison, 1995; Ph.D., ibid., 1995. (2003)

Herman A. Grunder, *Visiting Professor*. B.S., University of Karlsruhe, Germany, 1958; Ph.D., University of Basel, Switzerland, (1967). (2004)

Michael D. Hildreth, *Assistant Professor.* A.B., Princeton Univ., 1988; Ph.D., Stanford Univ., 1995. (2000)

Anthony K. Hyder, *Associate Vice President for Graduate Studies and Research and Professor.* B.S., Univ. of Notre Dame, 1962; Ph.D., Air Force Institute of Technology, 1971. (1991)

Boldizsár Jankó, *Associate Professor.* Univ. Dipl., Eötvös Univ., Budapest, Hungary, 1991; Ph.D., Cornell Univ., 1996. (2000)

Robert V. F. Janssens, *Adjunct Professor*. Univ. Dipl., Universite Catholique de Louvain, Louvain-la-Neuve, Belgium, 1973; Ph.D., ibid 1978. (2004)

Colin Philip Jessop, *Associate Professor*. B.A., Univ. of Cambridge (Trinity College); M.A., ibid.; Ph.D., Harvard Univ., 1994. (2003)

Walter R. Johnson, *the Frank M. Freimann Professor of Physics.* B.S.E., Univ. of Michigan, 1952; M.S., ibid., 1953; Ph.D., ibid., 1957. (1958)

Gerald L. Jones, *Professor.* B.S., Univ. of Kansas, 1956; Ph.D., ibid., 1961. (1963)

Daniel Karmgard, *Research Assistant Professor*. B.S. Mathematics; B.S. Physics, UCLA, 1993; M.S., Cal. St. U. at Long Beach, 1995; Ph. D., Florida St. U., 1999 (2003)

Avtandyl (Avto) Kharchilava, *Research Assistant Professor*. B.S., Moscow State Univ., 1975; M.S., ibid., 1978; Ph.D., Tbilisi State University, 1990. (2003)

James J. Kolata, *Professor.* B.S., Marquette Univ., 1964; M.S., Michigan State Univ., 1966; Ph.D., ibid., 1969. (1977)

Christopher F. Kolda, *Associate Professor.* B.A., Johns Hopkins Univ., 1990; M.S., Univ. of Michigan, 1992; Ph.D., ibid., 1995. (2000)

Karl-Ludwig Kratz, *Adjunct Professor*, Univ. Dipl., Universite Mainz, 1967; Habilitation, ibid., 1979; (2002)

Larry O. Lamm, *Research Professor.* B.S., East Carolina Univ., 1978; M.S., ibid., 1983; Ph.D., Univ. of Notre Dame, 1989. (1994)

Jay A. LaVerne, *Concurrent Research Professor*. B.S., Lamar University, 1972; Ph.D. University of Nebraska, 1981. (2004)

A. Eugene Livingston, *Professor.* B.Sc., Univ. of Alberta, 1969; M.Sc., ibid., 1970; Ph.D., ibid., 1974. (1978)

John M. LoSecco, *Professor.* B.S., Cooper Union, 1972; A.M., Harvard Univ., 1973; Ph.D., ibid., 1976. (1985)

Grant J. Mathews, *Professor and Director of the Center for Astrophysics.* B.S., Michigan State Univ., 1972; Ph.D., Univ. of Maryland, 1977. (1994)

James L. Merz, *Concurrent Professor*. B.S., University of Notre Dame, Physics, 1959; M.A., Harvard University, Applied Physics, 1961; Ph.D., ibid., Applied Physics, 1967. (2001)

Patrick J. Mooney, *Adjunct Research Assistant Professor*. B.S., University of Notre Dame, 1978; Ph.D., ibid., 1986. (1998)

Kathie E. Newman, *Director of Graduate Studies and Professor.* B.Sc., Michigan State Univ., 1974; Ph.D., Univ. of Washington, 1981. (1983)

Simon M. Pimblott, *Concurrent Research Professor*. B.A., Oxford University, England, 1985; M.A., ibid., 1988; D.Phil., ibid., 1990. (2004)

Terrence W. Rettig, *Professor.* B.A., Defiance College, 1968; M.S., Ball State Univ., 1970; M.A., Indiana Univ., 1972; Ph.D., ibid., 1976. (1983)

Grigory V. Rogachev, *Research Assistant Professor*. M.S., Moscow Engineering Physics Institute (State Univ.), 1996; Ph.D., Russian Research Centre "Kurchatov Institute", 1999. (2003)

Randal C. Ruchti, *Professor.* B.S., Univ. of Wisconsin, 1968; M.S., Univ. of Illinois, 1970; Ph.D., Michigan State Univ., 1973. (1977)

Steven T. Ruggiero, *Professor.* B.S., Rensselaer Polytechnic Institute, 1975; M.S., Stanford Univ., 1977; Ph.D., ibid., 1981. (1983)

Ulyana I. Safronova, *Adjunct Professor.* M.S., Moscow Physical-Technical Inst., 1958; Ph.D., Vilnus Univ., 1964. (1998)

Jonathan R. Sapirstein, *Professor.* B.S., Stanford Univ., 1973; Ph.D., ibid., 1979. (1984)

Yang Sun, *Visiting Associate Professor*. B.S., Xuzhou Normal Univ., People's Republic of China, 1978; Diploma, Technical University Munich, Germany, 1988; Ph.D., Technical University Munich, Germany, 1991. (2002)

Carol E. Tanner, *Associate Professor.* B.S., Univ. of Illinois, Urbana-Champaign, 1980; M.A., Univ. of California, Berkeley, 1982; Ph.D., ibid., 1985. (1990)

Erdinch R. Tatar, *Adjunct Assistant Professor.* Ph.D., Univ. of Notre Dame, 2000. (2000)

Jadwiga Warchol, *Research Professor*. B.S., University of Warsaw, 1963; Ph.D., ibid., 1969; Habilitation, ibid., 1979. (1984)

Mitchell R. Wayne, *Associate Dean of the College of Science and Professor.* B.S., Univ. of California, Los Angeles, 1977; M.S., ibid., 1980; Ph.D., ibid., 1985. (1991)

Michael C. F. Wiescher, *the Frank M. Freimann Professor of Physics and Director of the Joint Institute for Nuclear Astrophysics.* Vordiplom, Univ. Munster, 1972; Diplom, ibid., 1975; Ph.D., ibid., 1980. (1986)

James R. Wilson, *Adjunct Professor*. B.S., University of California, Berkley, 1943; Ph.D., ibid., 1952. (1996)

Andreas Woehr, *Research Assistant Professor*. M.S., University of Stuttgart, Germany, 1986; Ph.D., Johannes Gutenberg Univ. Mainz, Germany, 1992; Certificate in Medical Physics, Univ. of Kaiserslautern, Germany, 1999. (2003)