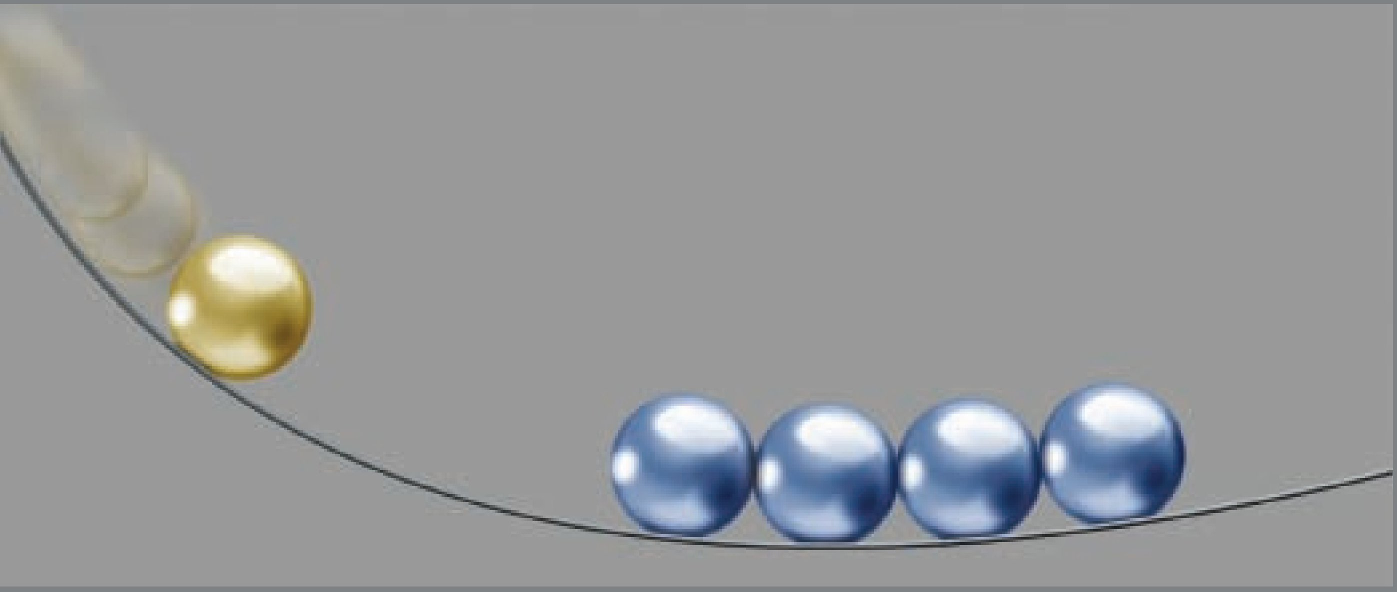
University of Notre Dame

Physics



"Physics is at the heart of most scientific exploration in our times."

Father Ted Hesburgh, CSC

Physics is the liberal arts of the sciences in providing the underpinning of knowledge in all of the sciences from biological systems, to chemical processes, to the most fundamental forces and interactions in studies of the universe on scales from the cosmological to the sub-nucleon.

Mission

Our mission is two-fold: to provide an outstanding and distinctive education to our undergraduate and graduate students and to expand our research enterprise via centers and institutes to achieve national and international prominence in strategic research areas.

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History

The Department of Physics at the University of Notre Dame had its beginnings as a graduate department in the Nuclear Physics program. It all started in the early 1930's with the construction of the first accelerator on campus. Shortly thereafter, Notre Dame became a significant part of the Manhattan Project during the second world war. The first accelerator was built by two professors, Dr. Jose Caparo and Dr. George Collins, as an open air machine with the ability to reach a potential of 1 million volts.

Figure 1 shows the accelerator in 1937 in today's Cushing Hall of Engineering before the floors were put in. A double row of windows allowed passersby to see the incredibly huge copper sphere sitting up on its spindly legs. The corona glow, which was a normal way of life for the accelerator, would at times fill the entire room. This monstrous machine bathed in a purple glow must have been quite a site for passersby on winter evenings.

Figure 1:
A photograph of the completely assembled and by then operating accelerator, taken facing southeast, early in 1937.

The accelerator, looking very much like an artificial monster from a science fiction movie, was dominated by the terminal in its sheer size. It had two hand-made copper sheet covered hemispherical sections. Each panel was hammered into shape with an air hammer, cut to fit the spaces in the frame, and then nailed into place. The long legs were pieced together with insulating tubing to raise the terminal high above the ground. The terminal was brought up to voltage by a 70 foot long charging belt. The construction of this first accelerator started a tradition of accelerator-based nuclear physics at Notre Dame that produced the first PhD's from the Department of Physics (and Notre Dame) which has lasted for nearly 70 years.

By 1942, experiments on the first accelerator were routine. A second accelerator was already in operation when most of the personnel were asked to serve on war-related research projects. Some of the outstanding scientific accomplishments of the first accelerator include:

- the confirmation of Cerenkov radiation
- the first electro disintegration of a nucleus
- the first pair production by electrons
- the experimental investigation of Mott scattering

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \cdot \cos^2(\theta/2)}{4\,E^2 \cdot \cos^2(\theta/2)}$$

In 1942, the Manhattan District Project took over the second accelerator putting fundamental research temporarily on hold. The Project concentrated on experimentation that would aid in the development of a nuclear bomb. This was done in utmost secrecy, illustrated by the fact that the logbooks during this time were not made public until very recently. Even after the war, Notre Dame's involvement with the development of the bomb was not immediately made public. Among others, Professor Walter Miller and Rev. Henry J. Bolger, CSC, were involved in running these experiments during the war.

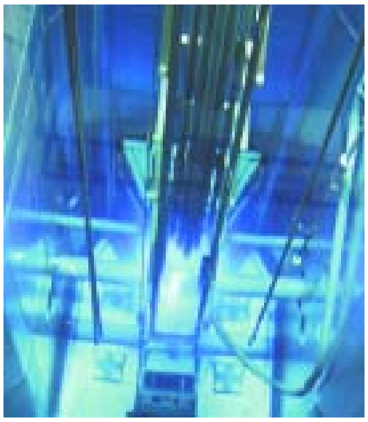


Figure 2:
Cerenkov radiation in the core of the nuclear reactor. Water surrounding certain radioactive substances emits a faint blue glow, which is termed Cerenkov radiation.

After the war ended in 1946, everyone returned to peace time research in fundamental Nuclear Physics. The old Science building soon proved to be too small for the rapidly growing Departments of Physics and Chemistry, allowing for the construction of Nieuwland Science Hall completed in 1953. Dr. Bernard Waldman and Dr. Walter Miller designed and constructed a new 4MV 32 foot long accelerator for continuing the electron beam based research program at the new location. This was supported through a grant of $35,000 from the Atomic Energy Commission. This third accelerator became the focus of a research program for the new PhD program at Notre Dame's Department of Physics, starting with 15 graduate students in 1955. A more detailed history of the Department of Physics can be found at http://www.physics.nd.edu/phys_history.htm.

The Physics Department presently has over 100 PhD students involved in a broad spectrum of research from Astrophysics, Atomic, Cosmology, Condensed Matter, Elementary Particle, and Nuclear Physics. Research on new materials and devices, studies of complex systems, and quantum computing all provide new opportunities in widely interdisciplinary areas of research. The Department of Physics is now home to several institutes and centers including the Center for Astrophysics (CANDU), The Institute for Theoretical Sciences (ITS), Institute for Structure and Nuclear Astrophysics (ISNAP), and a new NSF frontier center, the Joint Institute of Nuclear Astrophysics (JINA). We are also a member of the Center for Biocomplexity.

A Word From the Physics Chair

This is an exciting time for all areas of physics. Studies in Cosmology, Astrophysics, and High Energy or Elementary Particle Physics indicate that 95% of the matter of the universe is dark to us and there is some suspicion that the recently observed accelerated expansion of the universe is a form of "dark energy" opposing gravity. Nuclear physics involves studies of the nuclear reactions that produce 5% of the visible matter in the universe and the nuclear structure that hinders or speeds up these reactions. "We are all made of star stuff" is a quote from Carl Sagan and the logo for the new Joint Institute of Nuclear Astrophysics (JINA) in the Department of Physics. JINA, an NSF frontier center, studies the origin and processing of each atom in our bodies through many generations of stars, numerous supernova explosions before they were ejected into space and eventually condensed to form us in our solar system. The study of materials in Condensed Matter Physics focuses on the fabrication and study of new materials. There is now great interest in going beyond existing devices to develop faster/smaller computers using quantum effects. The studies of quantum dots and spin-electronics (spintronics) along with various aspects of nanotechnologies are the future. It is expected to lead to dramatic improvements in electronic systems and devices, such as memory elements, logic elements, spin transistors, spin valves and eventually to quantum computers.

Studies of the entire system are the core of the research focus in Biophysics in the department where the characteristics of complex biological systems, social networks, or the World Wide Web amongst other highly connected networks are examined and shown to follow a common blueprint, having scale-free characteristics. This result, discovered at Notre Dame, has potentially significant implications to many fields of research.

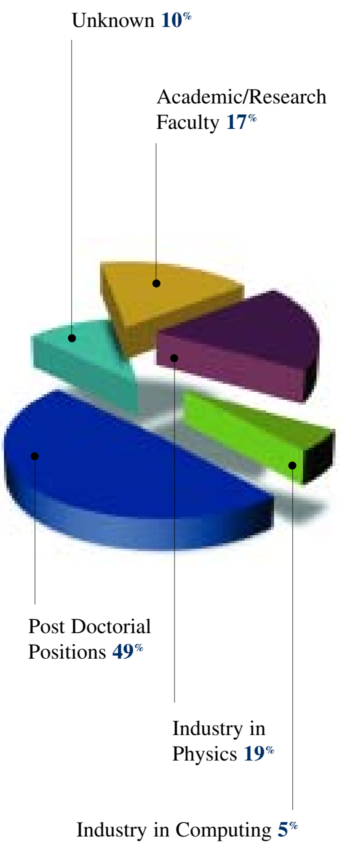
The Department of Physics is home to many centers and institutes that you will read about in this brochure. We bring you an introduction to the history of the department, a description of our programs both in Undergraduate and Graduate studies, followed by a brief synopsis of the strategic areas of research that we are engaged in as well as the biographical sketches of the faculty.

Ani Aprahamian

The Graduate Program

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, Atomic Physics, Condensed-Matter Physics, Elementary Particle Physics, Nuclear Physics, and Statistical Physics. Each area is represented by faculty known within their field for excellence in research. Faculty mentors are also known for their excellent teaching in the classroom. Notre Dame Physics provides a warm supportive environment characterized by a close community and active research interaction. Graduate students are valued members of the department. Faculty track the student's professional development and help them realize their goals.

2000 - 2004 Student Outcome



The Notre Dame Physics graduate program is primarily a doctoral program, leading to the PhD degree (Doctor of Philosophy). Because the graduate program is research oriented, the department does not normally accept students who plan to end their studies with a Master's Degree. Under certain conditions, a Master of Science degree is attainable, at an intermediate stage. In 2005 there were 39 tenure-track faculty in the department, 10 adjunct, 18 post-doctoral research associates, and 101 graduate students. A survey conducted in 2004 found that of the 41 students who completed their degrees from 2000 to 2004, 17% had accepted academic or research faculty positions; 19% were employed by industry in physics and 5% by industry in computing; 49% held post-doctoral positions; and 10% were unknown. The average time to complete a Notre Dame physics PhD degree is 6 years.

Notre Dame's physics graduate student population is internationally diverse, with approximately 50% of its students being international students. At the present time, there are physics graduate students from Brazil, Canada, Chile, England, Greece, Hong Kong, India, Korea, Malaysia, Mexico, P.R. China, Romania, Russia, Taiwan, and the United States. The department also prides itself on being a supportive environment for women and minorities; 5 of its faculty are female, and 23% of its graduate students are female.

A typical graduate student will take two years of course work, followed by three to five years of research. Students are placed with research groups early and students are required to become active participants in a physics research program by the second semester of their graduate work. Full-time participation in research typically starts in the third year.

PhD Program

Requirements for the PhD include thirty-nine credit hours in courses, seminars, and research. Courses taken include Methods of Theoretical Physics (**PHYS 70003**), Theoretical Mechanics (**PHYS 70005**), Methods of Experimental Physics (**PHYS 70010**), Quantum Mechanics I, II, and III **(PHYS 70007**, **70008**, and **80003)**, Electromagnetism and Electrodynamics (**PHYS 70006** and **80001**), and Statistical Thermodynamics **(PHYS 80002)**. Three physics electives are required, generally chosen from the set Astrophysics, Atomic Physics, Condensed Matter Physics, Elementary Particle Physics and Nuclear Physics (**PHYS 70201**, **80301**, **80501**, **80601** and **80701** respectively). There is no foreign language requirement for a PhD in physics.

Students who have satisfactorily completed courses equivalent to any of 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.

For a more complete description of the physics graduate program, please see the Graduate Bulletin.

For Web-based information, see:
http://graduateschool.nd.edu/pdf/bulletin0405.pdf (Graduate Bulletin in pdf format)

For additional information see the Department of Physics web site at:
http://www.physics.nd.edu/phys_students.htm.

Financial Support

Most students accepted into the PhD program are given financial support during the first two years. This support is usually in the form of a teaching assistantship (TA), which includes a nine-month stipend plus payment of tuition. Typical TA duties include assisting in the laboratories, proctoring, and grading examinations which average 12-16 hours per week. Graduate students are not required to teach in the classroom.

Fellowships are available to first-year graduate students and dissertation-year graduate students on a competitive basis. These fellowships provide 9-12 months of support and entail no teaching duties. The Department of Physics generally has 3-6 students per year on such fellowships.

Research assistantships (RA's) also provide 9-12 months of support with no teaching duties and are awarded as funds are available from external research grants. During the summer, most students hold research assistantships.

Financial support is guaranteed to physics graduate students in good standing through the third year. A typical physics graduate student at Notre Dame is a TA for the first 2-3 years of study, and becomes an RA in the last years of study.

Admission

Applicants who have the ability and intention to become candidates for the PhD degree are considered for admission. Entering graduate students are selected based on their academic record, their scores on the Graduate Record Examination (including the physics subject exam), and the recommendations of scientists who are acquainted with their undergraduate work.

Approximate ranges of the middle 50 percent of objective scores for entering PhD students are 3.4 to 3.8 for US undergraduate GPAs, 520 to 680 for verbal GREs, 650 to 750 for quantitative GREs, and 640 to 740 for analytical GREs (or roughly 4.5 to 5.5 on the new analytical writing GRE). The University of Notre Dame welcomes all people regardless of color, gender, religion, ethnicity, sexual orientation, social or economic class and nationality.

Applications

Applicants are advised to apply on-line at:
http://graduateschool.nd.edu/html/admissions/application_gateway.html

Additional information can be obtained from:

Chair of the Admissions Committee
Department of Physics
225 Nieuwland Science Hall
University of Notre Dame
Notre Dame, IN 46556
Telephone: (574) 631-6386
Fax: (574) 631-5952
Email: physics@nd.edu
http://www.science.nd.edu/physics/

Please contact the department if you are planning to visit campus and wish to meet with people within the Department of Physics.

The Undergraduate Program

The undergraduate physics program at Notre Dame offers students five tracks or options for a BS degree: Physics, Physics and Computing, Physics in Medicine, Applied Physics, and Physics Education. Physics majors at Notre Dame enjoy small classes with individual attention from their professors. Numerous opportunities exist for those interested in undergraduate research. They enjoy the same warm supportive environment that graduate students do, working closely with each other and the faculty on problem solving and learning. Quoting from current majors, we hear that “Being a physics major teaches you to be a smart person. It teaches you to learn.” And, “physics majors…are really creative problem solvers…physics…gives me a really fundamental understanding of everything around me.” Graduates from Notre Dame’s Physics program enjoy a wealth of opportunities. Recent physics graduates have attended Columbia, Harvard, Harvard Business School, University of Michigan, Stanford University and medical schools at a number of universities. Notre Dame’s physics undergraduate student population in 2005 was 60. Nineteen percent of our undergraduate students are female.

BS Degree Program

Physics majors typically take 18-21 credits in mathematics, 45-48 credits in physics, 8 in chemistry, 33 credits in general requirements including philosophy, theology, and foreign language, and approximately 18 credits in electives. Students following one of the other optional tracks in physics typically replace 15 credits in physics with courses from other disciplines. Second major options for physics exist. Additionally, many physics majors choose a second major in another discipline, e.g., Mathematics, Economics, Music, Philosophy, and Theology.

For a more complete written description of the physics program, please see the Undergraduate Bulletin. For Web-based information, see:
http://www.nd.edu/~ndreg/BOI.shtml (Undergraduate Bulletin in pdf format)
http://www.science.nd.edu/science_undergrad/phys/phys_main.htm
(description of requirements)

This and other information is also available through the departmental web site:
http://www.physics.nd.edu/

Admission

First-year students are admitted to the University of Notre Dame only for the fall semester of each academic year. The student who wishes to be considered must have the following items on file with the Office of Undergraduate Admissions: (1) a completed application; (2) an official high-school transcript; (3) a letter of evaluation from a secondary school teacher; and (4) an official report of scores on the Scholastic Assessment Test (SAT I) by the College Board or the Assessment by American College Testing (ACT). Admission to the University is a competitive process. Each year, over 10,000 students apply to be admitted to an entering class size of 1,935 students

Applications

New undergraduate application forms are available in August of each year. Students may apply online via the following Web site: http://admissions.nd.edu/

Academic requirements for admission are listed at this web site. Also available there is information on how to transfer to the University of Notre Dame. The University welcomes all people regardless of color, gender, religion, ethnicity, sexual orientation, social or economic class and nationality.

Contact information

Director of Undergraduate Studies
Department of Physics
225 Nieuwland Science Hall
University of Notre Dame
Notre Dame, IN 46556
Telephone: (574) 631-6386
Fax: (574) 631-5952
Email: physics@nd.edu
http://www.physics.nd.edu/

Please contact the department if you are planning to visit campus and wish to meet with people within the Department of Physics.

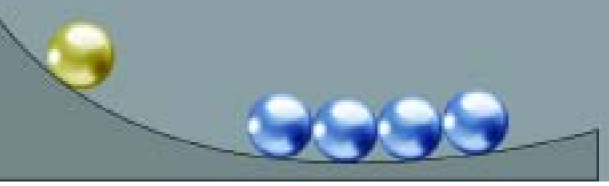
Physics Curriculum

The physics curriculum consists of five programs: Career Program, Physics-in-Medicine Program, Physics and Computing Program, Applied Physics Program, and Physics Education Program. All physics majors take the following sequence of core courses:

Introductory Physics	**(Phys 10411, 10422 and 20431)**
Mathematical Methods in Physics	**(Phys 20451, 20452)**
Sophomore Seminar	**(Phys 23411)**
Intermediate Classical Mechanics I	**(Phys 20455)**
Modern Physics	**(Phys 20464)**
Electricity and Magnetism	**(Phys 30471)**
Junior Seminar	**(Phys 33411)**
Modern Physics Lab I	**(Phys 40441)**
Topics in Modern Physics	**(Phys 40461)**
Senior Seminar I	**(Phys 43411)**
General Chemistry	**(Chem 10117, 10118)**

Mathematics:

Calculus I, II and III	**(Math 10550, 10560 and 20550)**
Physics or Mathematics Elective	



Physics Curriculum

In addition to core courses the following courses are required for each program:

Career Program:

Thermal Physics	**(Phys 30461)**
Quantum Mechanics I	**(Phys 40453)**
Electromagnetic Waves	**(Phys 30472)**
Modern Physics Lab II	**(Phys 40442)**
Physics or Mathematics Elective	

Physics electives can be selected from the following:

Lasers and Modern Optics	**(Phys 30432)**
Astrophysics	**(Phys 50445)**
Quantum Mechanics II	**(Phys 40454)**
Relativity	**(Phys 50472)**
Complex Variables	

Physics-in-Medicine Program:

General Biology A and B	**(Bios 20201, 20202)**
Genetics	**(Bios 20303)**
Organic Chemistry I and II	**(Chem 20223, 20224)**

Electives recommended for this program:

Thermal Physics	**(Phys 30461)**
Cellular Biology	**(Bios 30341)**
Physiology	**(Bios 30344)**
Biochemistry	**(Chem 40420)**
Medical Physics	**(Phys 40371)**

Physics and Computing Program:

At least 15 credit hours in the Department of Computer Science and Engineering

Applied Physics Program:

At least 15 credit hours in the Department of Electrical Engineering
(courses that deal with electrical properties of materials)

Physics Education Program:

33 credit hours in education courses

Many of our graduates have gone on to become doctors, lawyers, physicists, and many other professions.

Physics Alumni

Physics alumni are an interesting group. Upon graduation they head out into many diverse directions—from pure research to teaching to manufacturing to business school to medicine—physicists end up in fascinating places. Highly educated, intelligent and resourceful, physics alumni are an important part of what we do today.

Physics Alumni Survey

The Department of Physics created its very first survey for physics alumni during 2004. The main goal of the survey was to probe the perceptions of our alumni regarding Physics at Notre Dame today, as well as providing us with a glimpse of what our alumni are doing now! Fifty-six percent of our respondents are still doing physics! The survey was available on the physics web site and on paper by request during the late spring, summer, and early fall. Physics alumni responded enthusiastically. In total we received 163 responses to 39 questions. Not surprisingly most alumni who responded lived in the United States (95%) with 1% in Asia, 2% in Canada, 1% in Europe, and 1% in Puerto Rico. Sixty-three respondents earned their degree on or before 1970 with 32 earning their degree from 1971-1980, 22 from 1981-1990, 14 from 1991-1995, 21 from 1996-2000, and 11 from 2001-2004.

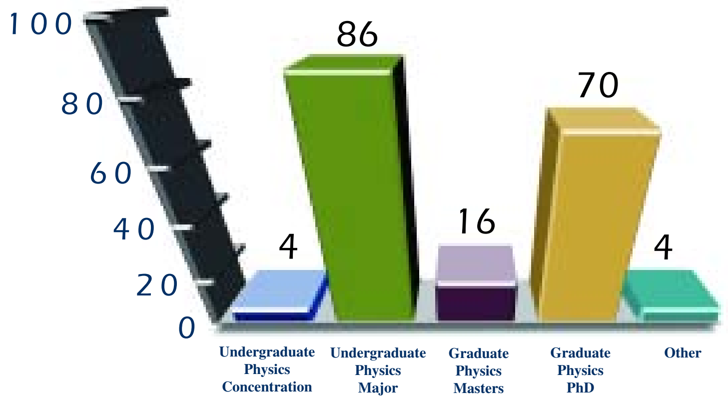


Figure 3:
An almost equal number of undergraduates and graduates responded to the survey

We were particularly pleased with the responses to two very important questions:

1) "What is your overall opinion of the Department of Physics at the University of Notre Dame?"
2) "What is your response to the following statement? 'I am proud to have graduated with a degree in Physics from the University of Notre Dame.'"

94% of alumni had a positive overall opinion of the department and 95% of alumni agreed they were proud to have graduated with a degree in Physics from the University of Notre Dame.

Comments

Below is a sampling of voluntary comments from survey respondents:

> *"I think this survey was a good idea. It's important to solidify your alumni base and keep people in touch with each other."*
>
> *"It's great to see the Physics Dept. reaching out to alumni to keep us involved in what's going on. "Physics Tracks" is a great idea, too."*
>
> *"There is no question that the quality of physics done at ND has improved markedly since my time there. It is almost impossible to judge the undergraduate teaching quality at this distance. If it, too, has improved, it would be fantastic!"*
>
> *"From what I have read and heard, it looks like the Dept. is doing a much better job on educating students then in my day in the early 70's. I say you are getting it right."*
>
> *"I am looking forward to my next visit to the department."*

As a result of the survey and respondents' suggestions, the Department of Physics has introduced physics alumni activities including an open house on a Friday afternoon before a home football game and an annual reception during alumni weekend. A complete copy of all survey responses is available in the Spring 2005 issue of "Physics Tracks" the official semi-annual newsletter of the Department of Physics. To receive a copy or subscribe please call the physics office at 574.631.6386 or email us at physics@nd.edu. We are proud of our alumni and look forward to a long and mutually beneficial relationship!

Student Life

The University of Notre Dame, founded in 1842, is a private co-educational independent school with more than 11,000 students; approximately 2,500 are graduate students. The undergraduate student population includes students from all 50 states and some 70 different countries. The total student body, including graduate students, is drawn from all 50 states and 104 countries. While approximately 84 percent of the undergraduate population is Catholic, the graduate student body reflects a broad spectrum of educational, religious, and geographical backgrounds. And while Notre Dame is professedly a Catholic place, it is also a place where all are welcome.

Both undergraduate and graduate students are welcome to participate in all University activities, which include a variety of lectures, cultural activities, concerts, and theatrical productions. The Snite Museum of Art contains five galleries in which the University art collection and special exhibits are displayed. Additional cultural attractions are offered at Saint Mary's College, located just across the street from the Notre Dame campus, and the South Bend campus of Indiana University. In Fall 2004, the University opened its new 123,000-square-foot Marie P. DeBartolo Center for the Performing Arts.

Student Life

The campus is located just north of South Bend in north central Indiana (about 5 miles from the Michigan border), and includes 1,250 acres, with two lakes, extensive wooded areas and tree-lined quadrangles. A collegiate gothic style of architecture is found on campus, including as prime examples, the ornate Main Building (with the well-known Golden Dome) and the Basilica of the Sacred Heart. Important for the future of the Department of Physics is the Jordan Hall of Science, a 202,000 square-foot addition to the campus costing $70 million that is scheduled to be complete by Fall of 2006.

The University provides superb facilities for both participatory and spectator sports. Graduate and undergraduate students both are welcome to use all facilities, including a 78,000-square-foot Rolfs Sports Recreation Center, an indoor ice-skating rink, two swimming pools, indoor and outdoor tennis courts and racquetball, handball, and squash courts. Many students participate in intramural programs such as basketball, softball, and volleyball. Two excellent golf courses, the 9-hole Notre Dame Golf Course and the 18-hole Warren Golf Course, are available close to campus. Both undergraduate and graduate students may obtain tickets to all home football, basketball, baseball and hockey games at a reduced price.

The city of South Bend, center of a metropolitan area with a population greater than 265,000, offers an active social and cultural life, including a resident symphony orchestra and many parks and recreational areas. Chicago and all of its attractions are readily accessible by plane, bus, or train; by car, Chicago is only an hour and a half away. The Michiana area (northern Indiana and southwestern Michigan) offers a large variety of outdoor activities. Excellent sandy beaches on Lake Michigan are about a 45-minute drive from campus, and swimming, sailing, and other water sports are available on a number of smaller lakes, including those on the Notre Dame campus. Downhill skiing is available 45 minutes away and cross-country ski trails exist in many of the local county parks.

More than 80 percent of undergraduate students live on campus in one of Notre Dame's 27 undergraduate residence halls. Each residence hall is unique, having an atmosphere and character of its own. The halls are staffed by rectors, assistant rectors, and resident assistants who support the students living in the halls. There are no sororities or fraternities at Notre Dame.

Approximately a quarter of the graduate students live in campus housing that includes apartments and townhouses for married students and townhouses for single graduate students. Dormitory space on campus is also available for single students. Off campus, a large number of apartments and houses for rent are located within easy walking distance. Campus parking is available.

Faculty in the Department of Physics are roughly grouped into the five areas listed below:

- **Astrophysics**
- **Atomic Physics**
- **Condensed Matter Physics and Biophysics**
- **Elementary Particle Physics**
- **Nuclear Physics**

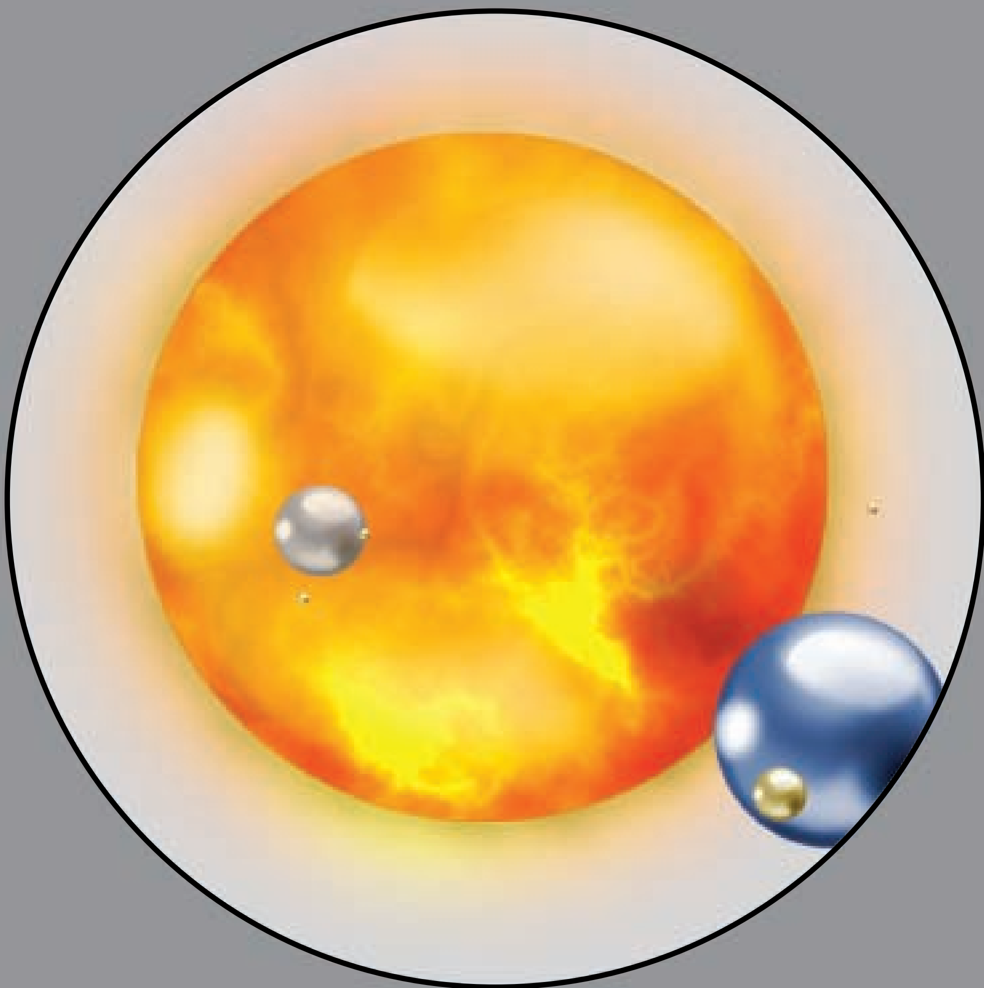
In addition to these areas, individual faculty members have interests in other areas of physics, e.g., Biocomplexity (Alber), Network Theory (Barabási), and Quantum Computing (LoSecco and Tanner). Many active collaborations exist between physicists in these and other areas. For example, it is not uncommon to find astrophysicists working with high-energy physicists or physicists working with computer scientists or biochemists or mathematicians. Please refer to individual faculty descriptions to see more details.

Research Facilities

The Department of Physics is housed in Nieuwland Science Hall. A research library for physics and chemistry is also located in the building, providing rapid and convenient access to research publications. In addition, the Radiation Laboratory of the Department of Chemistry and Biochemistry maintains a smaller library and reading room, while excellent biology, and mathematics/computer sciences, and engineering libraries are located nearby on campus. The spacious 14-story Hesburgh Library provides comfortable and convenient study space for more than 2,500 students, and houses a periodicals reading room with a wide range of publications. Electronic access is also available for the vast majority of journals.

All experimental groups in physics have physics laboratories and specialized instrumentation located within Nieuwland Science Hall. Additionally, the majority of the experimental physicists also conduct experiments at national or international laboratories. Also available to all experimental groups is a well-equipped machine shop, which is maintained by the department and staffed by highly skilled instrument makers, and a glass-blowing shop operated by the Radiation Laboratory. Other University resources include multiple electron microscopes, x-ray diffraction facilities, scanning-probe (AFM, STM, etc.) systems, semiconductor fabrication facilities, surface characterization equipment, magnetic resonance imaging, and other equipment and centers.

Computing facilities include university-operated computer clusters (Sun's, SGI's, PC's and Macintoshes), a university-run High-Performance Computing Center (HPCC), and a Beowulf cluster of over one hundred dual-processor Dells operated by the College of Science. Within the HPCC, researchers have access to SGI Origin 2000 and 3000 supercomputers, as well as a Sun Enterprise 420R cluster and an IBM Beowulf cluster. High-speed Ethernet connections are available in all University offices, laboratories, and residences. NOMAD wireless computer access is available throughout most of Nieuwland Science Hall.



Astrophysics

Faculty: Balsara, Garnavich, Howk, Mathews, Rettig
Research Faculty: Bennett
Visiting and Other Faculty: Wilson
Emeritus Faculty: Poirier

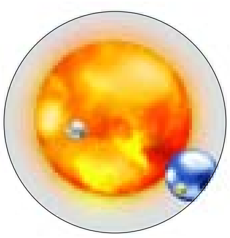
Astrophysics

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 at Notre Dame University (CANDU). The Center supports inter-disciplinary 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 eagerly anticipated the arrival of first light which occurred on October 15, 2004. The LBT is one of the most powerful and versatile telescopes in the world, estimated to be 10x the power of the Hubble space telescope. 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.

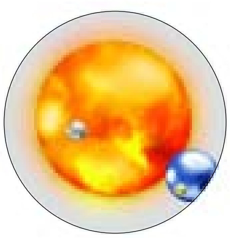


Theoretical Research

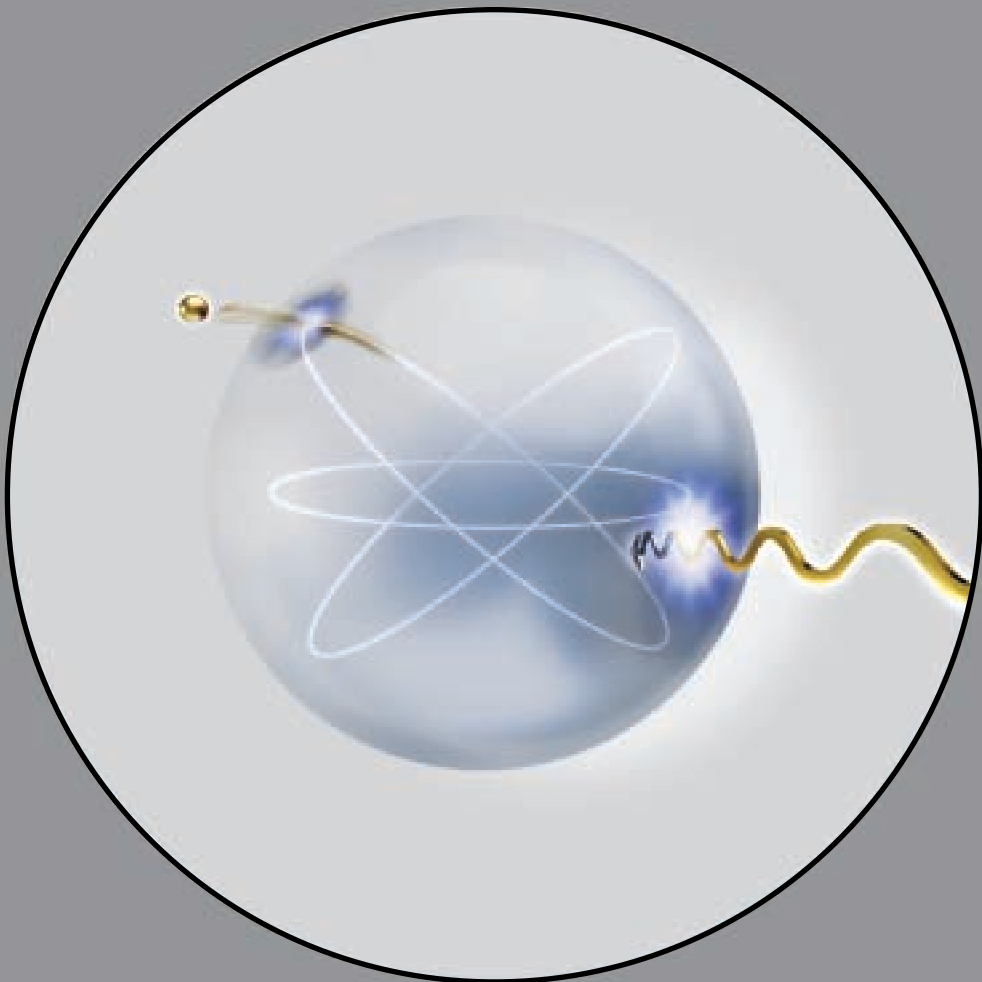
Ongoing theoretical research includes all aspects of the origin and evolution of the universe, galaxies, stars, planets, and the interstellar medium. The astrophysics theory group has pioneered the development of modern numerical methods for hydrodynamic simulations of complex astrophysical systems. Theoretical work concerning the formation and evolution of galaxies, stars and the interstellar medium is being investigated with complex adaptive mesh magnetohydrodynamics. The group also does 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 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 to 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

Faculty: Berry, Johnson, Livingston, Sapirstein, Tanner

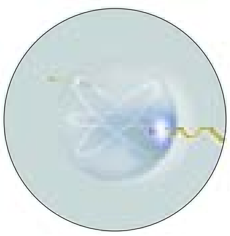
Visiting and Other Faculty: Safronova

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.

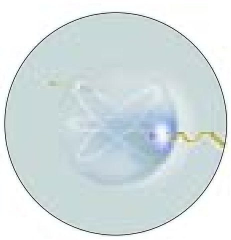
Highly stripped heavy-ion beams of 10-100 MeV energy are produced at the accelerator facilities of the ISNAP. Experiments are also performed at other off-site heavy-ion accelerators. Present investigations concentrate on the precision atomic spectroscopy of highly ionized atoms and the measurement of 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 Nieuwland Science

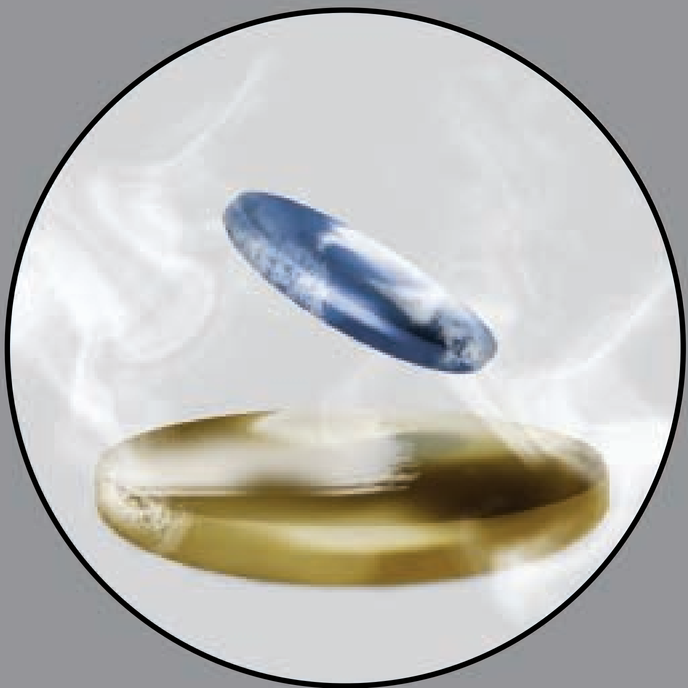
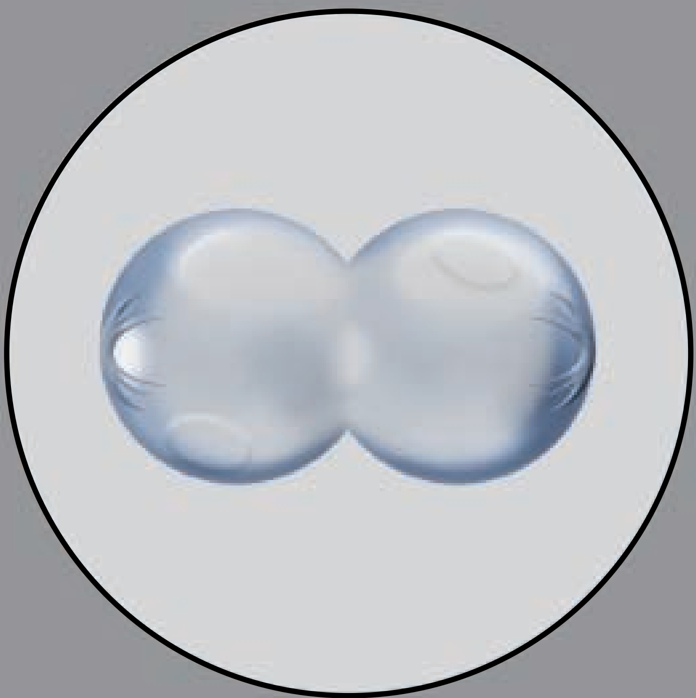


Hall, fast heavy ions (up to 200 keV energies) are used for Doppler-free laser studies of atomic hyperfine structures, precision lifetime measurements, and other studies of atomic collisions and structures.

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.



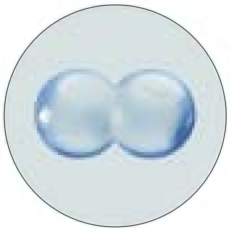
Condensed Matter Physics and Biophysics

Faculty: Alber, Arnold, Barabási, Blackstead, Bunker, Dobrowolska, Eskildsen, Furdyna, Jankó, Merz, Newman, Ruggiero, Toroczkai
Visiting and Other Faculty: Harshman, Terry, Liu
Emeritus: Jones

Condensed matter research at Notre Dame encompasses topics of research ranging from "hard" condensed matter problems such as semiconductor or superconductor systems to "soft" condensed matter 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.



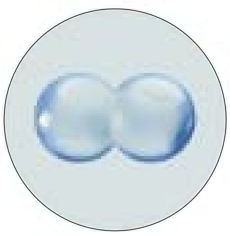
Semiconductor Physics and Magnetism

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 (NIST) 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 include 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 (ANL), where Notre Dame is a major participant.

Superconductivity and Vortices



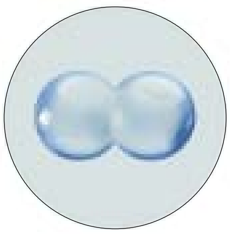
High-temperature superconductors are studied from the perspective of microwave absorption and other techniques with a view to probing fundamental mechanisms. These include investigations of the response of high-temperature superconductor thin-film systems to ultrashort duration, far-infrared light to 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 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.

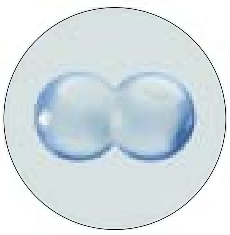


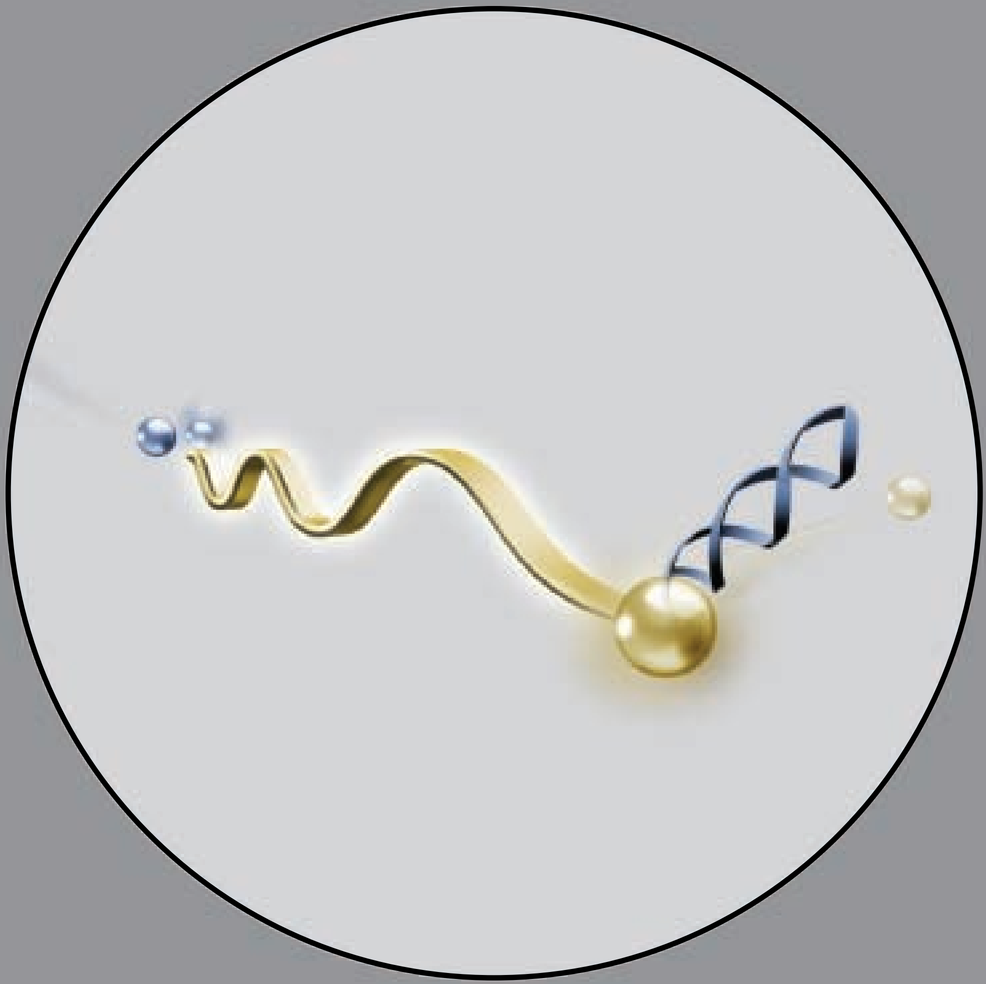
In one theoretical effort in superconductivity, finite temperature field-theory techniques are used to study two-dimensional antiferromagnets. Also studied are highly-correlated electronic systems, including disordered and frustrated ferromagnets, such as magnetic semiconductors, high temperature superconductors, 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.

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.





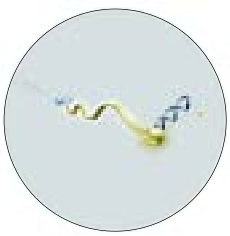
Elementary Particle Physics

Faculty: Bigi, Cason, Goussiou, Hildreth, Jessop, Kolda, LoSecco, Ruchti, Wayne
Research Faculty: Karmgard, Warchol
Visiting and Other Faculty: Baumbaugh, Lynker, Mooney, Tatar, Uraltsev
Emeritus: Bose, Kenney, McGlinn, Shephard

Experimental Program

An understanding of the fundamental constituents of matter and the forces with which they interact is sought in elementary particle 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 DØ experiment, currently operating at Fermi National Accelerator Laboratory in Run II of the Tevatron, and (starting in 2007) the CMS experiment at the CERN Large Hadron Collider (LHC) in Geneva, Switzerland. The physics objectives of this program are to study top and beauty quarks, 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. 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 Research and Development on new scintillator and waveshifter materials for improved calorimetry performance under high luminosity operation.

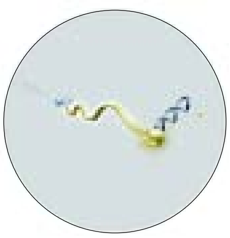


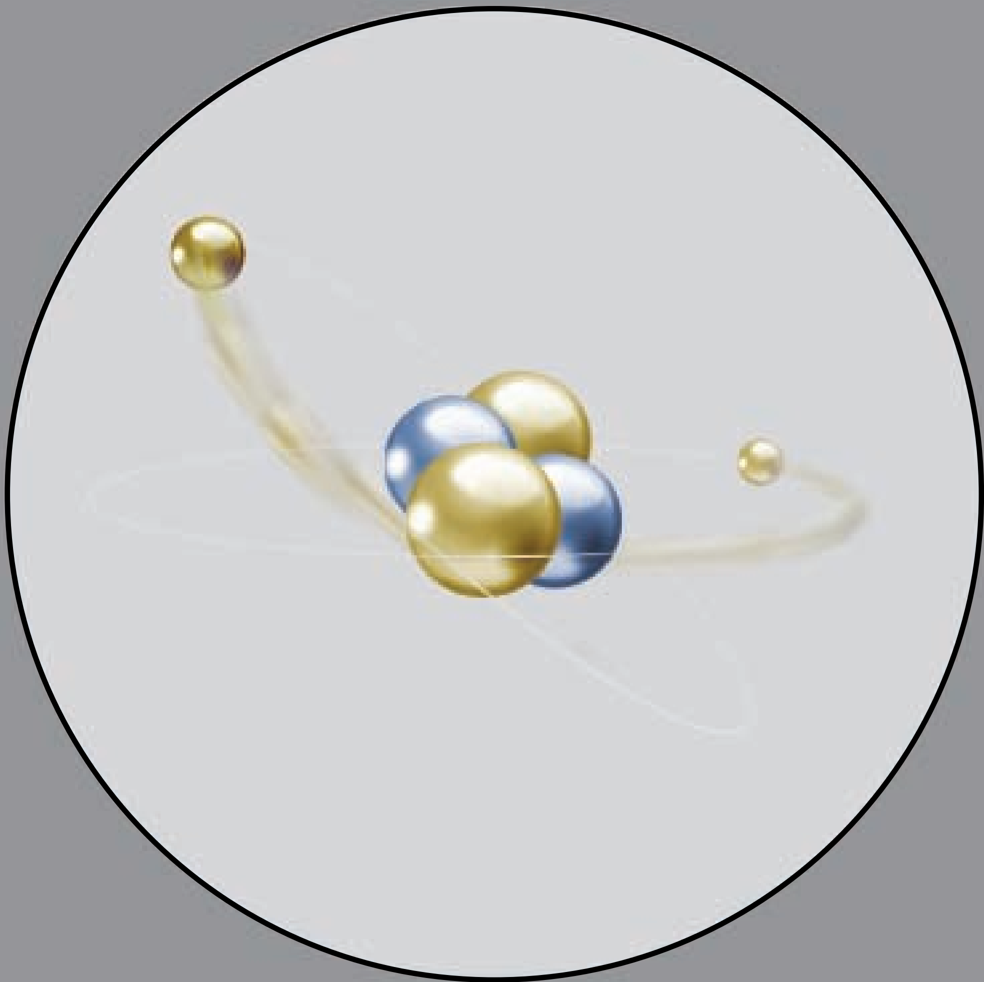
The electron-positron collider program is based upon the currently operating BaBar experiment at Stanford Linear Accelerator Center (SLAC). This program, too, has provided remarkable physics results, notably the observation by BaBar of CP violation in the b-quark system in 2000—the first observation of CP violation outside of KL 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 research and development 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 elementary particle 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. We also analyze 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 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

Faculty: Aprahamian, Collon, Frauendorf, Garg, Hyder, Kolata, Wiescher

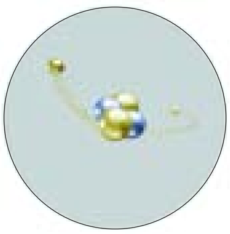
Research Faculty: Görres, Kaiser, Lamm, LaVerne, Pimblott, Stech, Woehr

Visiting and Other Faculty: Azuma, Janssens, Kratz, Sun

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 our department aims at studying the structure and dynamics of nuclear systems, especially in their relation to astrophysical phenomena. Work is carried out in our own Institute for Structure & Nuclear Astrophysics (ISNAP), as well as a large number of accelerator facilities around the world.

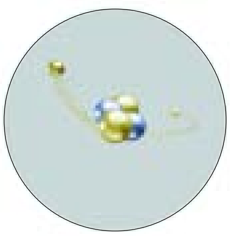


A pioneering focus in the ISNAP laboratory has been the development and application of short-lived radioactive ion beams (RIBs) for studies of the structure of nuclei at the very limits of particle stability. Examining nuclear matter under extreme conditions is crucial for understanding of the fundamental 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 many astrophysical processes. Currently we are focusing on the spectroscopy studies of very neutron- and proton-rich nuclei and on investigation of mechanism of reactions induced by Radioactive Ion Beams (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 our 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 our 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.

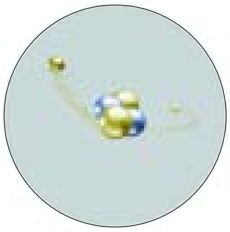


The major experimental facilities in the laboratory include an FN Tandem accelerator that can provide up to 11 MV terminal voltage for the acceleration of light and heavy ions; the Twinsol radioactive beam facility, based on two, coupled, 6 Tesla-meter superconducting solenoids for the focusing of the radioactive beam particles onto a target; a 4 MV KN and a 2 MV JN Van de Graaff accelerator 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 2007.

In addition to the high level of activity within the Institute, 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. We also have 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 our 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.

Center for Astrophysics (CANDU)

Great progress has been made in Astrophysics at Notre Dame. This area couples naturally into Notre Dame's new involvement with the Large Binocular Telescope and the Steward Observatory facilities. This area also includes nuclear astrophysics (e.g. nucleosynthesis in the early universe and in supernovae) and particle astrophysics (e.g. missing mass in the universe). The new Center for Astrophysics at Notre Dame University (CANDU), directed by Professor Grant Mathews, was established in 2003 and serves as a focus for this effort.

Some of the projects currently being worked on by the Center's members are Theoretical and Observational Cosmology (Professors Grant Mathews and Peter Garnavich), Computational Astrophysics (Professors Dinshaw Balsara and Grant Mathews), Observational Astrophysics (Professors Peter Garnavich, Terrence Rettig and David Bennett), Star and Planet Formation (Professors Terrence Rettig and Dinshaw Balsara), Galaxy Formation and Evolution (Professors Grant Mathews and Dinshaw Balsara), General Relativity (Professor Grant Mathews), Gravitational Microlensing (Professor David Bennett), Supernovae and Stellar Nucleosynthesis (Professors Grant Mathews and Dinshaw Balsara), and High Energy Astrophysics: Gamma-Ray Bursts/Cosmic Radiation/Solar Flares (Professors John Poirier, Grant Mathews, Peter Garnavich and David Bennett).

Center for the Study of Biocomplexity (ICSB)

Members of the University of Notre Dame Interdisciplinary Center for the Study of Biocomplexity (ICSB), directed by Professor Mark Alber, (http://www.nd.edu/~icsb/) come from eight departments from the colleges of science and engineering and are working together to meld physical, mathematical, and computational approaches with those of modern biology to understand this complexity in a quantitative and predictive way. One of the main goals of the ICSB is to improve communication between biological, mathematical and physical scientists with emphasis on developing techniques and tools of broad utility to bioscientists.

All ICSB projects combine quantitative experiments and computer simulation and build on the mutually complementary strength of the researchers at Notre Dame with support from collaborators at other institutions. Projects currently under way within the center include:

- Modeling Organogenesis and Tissue Development, including the mechanical properties of tissues.
- Modeling Biological Networks at the molecular level, including gene regulation pathways, transport and mechanical interactions in the cytoskeleton and intra-and inter-cell signaling networks.
- Modeling Cellular Dynamic, including the mechanical properties of cells.
- Population Dynamics and Ecological System.

Joint Institute for Nuclear Astrophysics (JINA)

The origin and fate of matter in our universe are fundamental questions in nuclear astrophysics. The rapid growth of observational results, the tremendously expanding computational capabilities, and the new experimental and theoretical opportunities to probe and simulate the behavior of nuclei under extreme conditions now brings within reach the answers to many open questions. The rapid progress and expanding scope of the different disciplines constituting nuclear astrophysics also introduce an enormous level of complexity to the field. The Physics Frontier Center JINA—Joint Institute for Nuclear Astrophysics—at the University of Notre Dame, Michigan State University, the University of Chicago, and Argonne National Laboratory operates as an intellectual center with the goal to enable swift communication and stimulating collaborations across field boundaries and at the same time provide a focus point in a rapidly growing and diverse field. JINA will provide research opportunities and thesis projects in experimental and theoretical nuclear astrophysics. For more information, see our website at www.JINAweb.org.

JINA is directed by Michael Wiescher, Freimann Professor of Physics, at the University of Notre Dame. Professor Wiescher is a Fellow of the American Physical Society and is the 2003 recipient of the American Physical Society Hans Bethe Prize. The prize recognizes outstanding work in theory, experiment or observation in the areas of astrophysics, nuclear physics, nuclear astrophysics, or closely related fields.

Center for Material Fabrication & Nanotechnolgy (CMFN)

Development of new materials and their design are at the heart of contemporary technology, from the semiconductor chip and lasers for various applications, to the design of entirely new man-made multi-functional materials for new detectors and new types of computation (e.g., quantum computing). Most of these applications involve either semiconductors or magnetics.

State-of-the-art materials fabrication techniques allow researchers to create “designer materials” that are built-up atom-by-atom into an architecture required by the specific function that is being sought. Notre Dame has been a pioneer in the development of materials which combine both semiconducting and magnetic functions, thus allowing one to integrate both those functions into a single designer material. This is accomplished by the technique of molecular beam epitaxy (MBE), where atoms are directed “on demand” to create desired atomic configurations aimed at performing specific operations. Our MBE facility has been at the forefront of designing and fabricating new multifunctional materials, including quantum structures for semiconductor blue laser systems, and most recently materials that combine electronic and magnetic properties with an eye at their future applications in the emerging field of spin-electronics (“spintronics”). The MBE Laboratory at Notre Dame collaborates on a continuous basis with over 50 other research institutions—

universities, industry, and national government laboratories—both by providing research materials and by sharing our expertise with scientists in those institutions.

The Center for Material Fabrication and Nanotechnology at Notre Dame is directed by Jacek K. Furdyna, Marquez Professor of Physics at the University of Notre Dame. Professor Furdyna is a Fellow of the American Physical Society and is the 2002 recipient of an Honorary Doctorate from the University of Warsaw. His work on spin entanglement, carried out in collaboration with scientists at the University of Michigan on materials fabricated in the MBE Laboratory, has been listed by Discover Magazine as one of the most significant scientific achievements of 2003.

Institute for Structure and Nuclear Astrophysics (ISNAP)

The ISNAP at Notre Dame, directed by Professor Ani Aprahamian, is built around three accelerators (JN, KN, and an FN-Tandem) and a broad program in low energy nuclear physics. The three accelerators offer a wide range of beam energies providing ideal conditions for nuclear structure and nuclear astrophysics experiments. The FN tandem accelerator operates with a Pelletron charging system up to a terminal voltage of 12 MV. The JN and KN accelerators provide high beam intensities with terminal voltages of up to 1 MV and 4 MV, respectively. We have the capability of producing both stable and unstable beams of various types for research interests that span from studies in Weak Interactions and Fundamental Symmetries, to Nuclear Structure, studies of Nuclear Reactions with Radioactive Ion Beams (RIBs), and Nuclear Astrophysics. In addition to our basic science interests, we have an interdisciplinary program in radiation chemistry, in bio-mechanics, materials testing, and a newly developing program in collaboration with the university's Snite Museum of Art using PIXE for element analysis in archeological samples. Our radiation chemistry program revolves around studies of the effects of ionizing radiation on the molecular decomposition of water and various organic materials, including polymers. Radiation affects our health and our environment. Knowledge on the fundamental interactions of ionizing radiation with matter, therefore, is central to both advances and problems facing society. This applied research program utilizes a mechanistic approach to examine the basic physical and chemical processes induced by ionizing radiation in condensed phases and at interfaces. Studies address the complex fundamental relationships between the transport of energy and the decomposition, diffusion, and reaction of medium molecules. Work in this project is multidisciplinary, ranging from probing the basic physics and chemistry of the interaction of radiation with matter to examining the practical consequences of that radiolysis in biology, medicine, and engineering. Primary processes involved in the radiolysis of water, organics, polymers, and nanometer oxides are examined experimentally with a wide variety of radiation types and energy. Radiation effects are often very dependent on radiation type because of the localized track structure and various facilities are employed to obtain gamma rays, fast electrons, protons, helium ions (alpha particles) and higher Z particles up to uranium. Interfacial effects involving the complex transport of energy and reactive species through heterogeneous boundaries are being explored for identification of the underlying mechanisms and for practical applications in the maintenance of nuclear reactors and the environmental management of radioactive waste materials. The practical aspect of this type of work has direct implications on the management of nuclear reactors, and treatment or storage of radioactive waste media. This work is carried out in collaboration with the Department of Energy funded Radiation Laboratory which is also located at Notre Dame and involves testing new detectors as well as artificial human body components for durability. The laboratory has a large number of users from some 14 US facilities inclusive of National Laboratories and Universities, 11 foreign countries, and 2 industries. For more information, see our website at http://www.nd.edu/%7Ensl/.

Institute for Theoretical Sciences (ITS)

The Institute for Theoretical Sciences (ITS), directed by Professor Boldizsar Jankó, promotes theoretical research at Argonne National Laboratory (ANL) and the University of Notre Dame (ND) by attracting internationally recognized leaders and junior researchers as well as graduate students in selected areas of basic and applied theoretical sciences. The Institute provides them with the opportunity to pursue research in the international, intellectually stimulating environments of the University of Notre Dame and Argonne National Laboratory. To achieve its aims, the Institute cooperates with all departments at Notre Dame and divisions at ANL which pursue research in theoretical sciences. Furthermore, the Institute coordinates its activities with other domestic and international academic institutions and promotes and encourages the participation of underrepresented groups, such as women and minority scientists at the highest levels of academia and research. For more information, see our website at http://www.theoryinstitute.org/.

Unique Programs at The University of Notre Dame Physics

QuarkNet is a teacher professional development effort funded by the National Science Foundation and the U.S. Department of Energy. Teachers and students work on particle physics experiments during the summer and join a cadre of scientists and teachers working to introduce some aspects of their research into their classrooms. This allows tomorrow's particle physicists to peek over the shoulder of today's experimenters.

QuarkNet centers are connected to high-energy physics experiments operating at CERN in Switzerland, at Fermilab in Illinois, at SLAC in California, and others. We have formed 52 centers associated with research groups at universities and labs across the U.S. and Puerto Rico. Our department provides management for the national program, and also operates the regional Notre Dame QuarkNet Center.

Physicists mentor and collaborate with high school teachers and students.
Through these collaborations:

- Students learn fundamental physics as they analyze live online data and participate in inquiry-oriented investigations.
- Teachers join research teams with physicists at a local university or laboratory.

Our *Research Experience for Undergraduates (REU)* program, 20 years old in 2005, is supported by the National Science Foundation's interdisciplinary research funds. Ours is among the largest such program in the country and provides opportunities for undergraduate students to experience hands-on participation in research during the summer.

Students are granted stipends, housing allowance, and assistance with travel and food expenses. The program lasts for ten weeks during which the participating students work closely with faculty and graduate students on a variety of current research projects. Our program aims at not only providing each student direct experience with a specific project, but also important exposure to all areas of physics research. The students prepare a research report based on their work and present their results at the REU Symposium held in the last week of the program. Other highlights of the program include field trips to nearby national laboratories, machine-shop training, and a computer-programming course.

We make extra efforts in providing this opportunity to students who are from groups that are traditionally underrepresented in physics (women, members of the disadvantaged minorities, and those with disabilities).

Associated with, and complementary to the REU program, is the *Research Experience for Teachers (RET)* program under which about a dozen high school teachers spend eight weeks during the summer doing research in various areas of physics. The main aim of the program is to provide the teachers a direct connection with modern science and research techniques as practiced by professional physicists, and to provide them opportunities of engagement as actual participants in scientific studies (rather than acting as casual observers or reporters).

Physics

UNIVERSITY OF
NOTRE DAME

Department of Physics
225 Nieuwland Science Hall
Notre Dame, IN 46556-5670 USA
Phone: 574.631.6386 Fax: 574.631.5952
web: www.science.nd.edu/physics/index.html
e-mail: physics@nd.edu