Department of Physics
2007 Self Study

Department of Physics[1]

March 7, 2008

[1]This document was prepared with the able assistance of Ivy Mason, Assistant to the Chair. The programs ©TEX and ©LATEX were used in the preparation. Some documents originally prepared in ©Word were converted to TEX using the program ©Word2Tex.

Contents

Executive Summary

The Department of Physics continues to carry out an extremely strong research program which is preeminent in several areas and has participated in several of the leading discoveries of the past decade. It provides excellent instruction at both the graduate and the undergraduate level which is recognized in the successful placement of its students and with national recognition of its program. The overall evaluation of the Department is summarized in Chapter 1. Details of the research program are presented in Chapter 4 and the graduate and undergraduate programs are discussed at length in Chapters 9 and 7.

With the help of the additional resources made available after the last 10 Year Review and support from the College, the Department has made ten faculty appointments, nearly maintaining its size. These appointments have enabled the Department to rebuild Atomic Physics, provide a base for Elementary Particle Experiment, maintain Nuclear Experiment and Physics Education, and make a start on building an Astrophysics Group.

Condensed Matter physics remains problematic despite having made two appointments in the last ten years — the Department has been unable to create a clear vision of where it wants to go and is having great difficulty in providing the facilities needed in that area.

The Evening Masters Program in Applications of Physics discussed in Chapter 8 is also problematic. It provides an active outreach program for which the Department has has requested inclusion in the University's Educational Outreach but this request has been denied on the grounds that the transfer of the student FTE would be a loss to the state funded portion of the University. The ability of the Department to continue the program is doubtful.

Chapter 1

General Self-Evaluation

1.1 Strengths, Roles and Responsibilities

The Department of Physics is preeminent in the areas of Nuclear Physics and Physics Education. In addition, it has very strong efforts in Atomic Physics and Elementary Particle Theory. In the area of Nuclear Physics, neutrino physics is especially strong and members of the Department were leading participants in the discovery of the neutrino mass cited by Science as the Discovery of the Year in 2005. The Institute for Nuclear Theory is an independent unit but its faculty hold appointments in Physics and it, in combination with the Nuclear Theory group, is arguably the strongest such group in the country.

The Physics Education Group is the strongest group engaged in Physics Education Research, nationally and internationally. Its members have received numerous awards and invitations to discuss their work. Most recently, the group received the American Physical Society Award for its leadership in physics education research and its development of research-based curricula.

The strength of the Atomic Physics group since the retirement of Hans Dehmelt has been in the measurement of fundamental properties of atoms and electrons. They have set the best limits on the electric dipole moment of an atom and are now beginning to work on clocks, quantum information, and quantum degenerate gases.

The Particle Theory Group is engaged in diverse areas such as the development of improved methods for recognizing evidence of new physics in collider data, innovative models of possible new physics beyond the standard model, applications of gauge/string duality to QCD-related physics, and improved techniques in lattice gauge theory.

The Elementary Particle Experiment Group played a significant role in the discovery of the single top quark last year and has spent the last decade building the muon detector, part of the ATLAS detector at the Large Hadron Collider (LHC) in Geneva, Switzerland. The members of the group expect to play a strong role in the experiments and discoveries which come out after the collider starts, hopefully this summer.

The Graduate Program is strong and discussed in detail in Chapter 9. The Department has 134 students in the PhD program. Many of these students proceed to post-doctoral positions in leading institutions, and all succeed in obtaining employment. There are another 46 students in the Evening Masters program who have more diverse career paths, which include teaching, working for industry (for example, Boeing, Microsoft, local medical technology, biotechnology, and marine technology companies), and other non-academic goals. Our MS students also include high school teachers, community college and voc-tech instructors, and military officers based nearby, for whom a masters degree in physics provides immediate advancement and longer-term career enhancement.

The Undergraduate Program is one of the largest in the country. The Department recently received a Presidential Citation from the American Association of Physics Teachers for its sustained increase in the number of physics majors. The Department offers a very flexible program allowing students to enter at any time. In addition, students whose interests do not include graduate study in physics are allowed to follow many paths to their degrees.

1.2 Areas for Improvement

The Department has not been successful in renewing its effort in Condensed Matter Physics as faculty have aged and retired. The active faculty have not been able to come together to decide upon a plan and a direction for renewing themselves. The Staffing Committee discussed below has recommended that the five current faculty, possibly in conjunction with the seven adjunct faculty in that area, develop a plan for their renewal. The Deans of Arts and Sciences and of Engineering are interested in developing an initiative to strengthen connections between Engineering and Physics which would help in providing the resources needed for such an effort.

The Department offers an MS in Physics to graduate students who pass the Department's Qualifying Examination or who complete an independent study project under the guidance of a faculty member. As discussed in Chapter 8, the Department also has an Evening Master's Program in Applications of Physics that was started thirty years ago as a program for employees in local industry, mostly Boeing, who were interested in improving their knowledge of physics. Now we have a trickle of applicants from industry and a few K-12 teachers. There is a declining pool of faculty interested in teaching in the program. The Department has requested inclusion of the Evening Master's Program in the University's Educational Outreach program so that it could become completely self-sustaining and have access to the Educational Outreach resources for recruiting students. At present the Department does not have the resources to strengthen the program, a situation that we believe would be remedied by its inclusion in Educational Outreach. The University has not approved the transfer and the program is likely to die if the transfer is not approved.

1.3 Changes

The Department has embarked upon a program of building up an Astrophysics program. Ten years ago, Christopher Stubbs in experiment was joint with Astronomy as was Craig Hogan in theory. Stubbs has left for Harvard and Hogan is expected to accept an offer from the University of Chicago and Fermilab. On the other hand, the Department has recruited Leslie Rosenberg and Miguel Morales[1]. Rosenberg's work is discussed in Section 4.11, page 100. The Department is committed to searching again in astrophysics experiment in 2009-10 and in astrophysics theory this year.

Ten years ago Atomic Physics was led by Hans Dehmelt, Nobel Laureate, and Norval Fortson, both members of the National Academy of Sciences. Both faculty members have retired. However, the Department has recruited Boris Blinov and Subhadeep Gupta who are giving every indication of developing into prominent researchers. Blinov has recently received NSF funding, a striking accomplishment in the present climate.

The then Nuclear Physics Laboratory was focused on nuclear physics with a side interest by Eric Adelberger in precision measurements of gravity. Now,

[1]Morales will arrive in Fall, 2008.

it has become the Center for Experimental Nuclear Physics and Astrophysics. The interest in gravity has become much stronger with Adelberger's efforts augmented by those of Jens Gundlach and Blayne Heckel. The Center is now the focus of much of the strongest experimental work in the Department.

Ten years ago the Elementary Particle Experiment group was largely focused on building the muon detector for the LHC, now it is moving more into experiments and their analysis and is positioned for strong resurgence in publications, output of students, and physics results.

During the past ten years, the amount of support for Teaching Assistants has significantly decreased. As a result much less support is provided for courses at all levels. In addition, this limits the ability of the Department to provide support to its students.

Due to the high costs of running independent operations, the Department was forced to close its stores and the Helium liquefier. It was unable to provide the services at a cost competitive with outside suppliers. In addition, the glass blower has retired and the Department is unable to recruit a replacement (the total demand for glass blowing on campus is insufficient to justify even a half-time glass blower).

From today's point of view, computing played a minor role ten years ago. Faculty were expected to pay for the limited computer support offered and the main use for most faculty was word processing. Email played an important, but secondary role and Department Administration and teaching were largely untouched. Now, the Department pays for computer support, computer use is pervasive, and the demand for high performance computing is nearly overwhelming. As examples, Professors Bertsch, Bulgac, Rehr, and Savage have all acquired multi-node clusters and have received grants to support high-performance computing. The Department, along with the Institute for Nuclear Theory and Astronomy, has recruited a highly competent Director of Computing and an expert in high performance computing.

The Department has long felt that the Sophomore year courses were the weakest part of the instructional program, a sentiment that has been confirmed by student reports. In addition, the University's systems did not make it feasible to enforce prerequisites, a situation which has now changed. The Department has embarked upon a program of upgrading the Sophomore courses, providing a stronger background in statistical mechanics, quantum mechanics, and relativity and requiring satisfactory performance in the prerequisites before admission to more advanced courses. These changes have only recently been made and are on an experimental basis. After evaluation of the results, we expect to make some of the changes permanent and to make corollary changes in the more advanced courses.

1.4 Expectations

The Department has a long history of excellence in fundamental research in physics. Just at a time when, nationally, recognition of the importance of the physical sciences is increasing[2] the University appears to be focusing its efforts on the biological sciences so that fewer resources are available to the physical sciences. One of the main conclusions of the National Academy of Sciences report is that the balance between the physical and biological sciences must be restored. Physics is experiencing great difficulty in finding the resources needed to support start-ups and research initiatives. Also, at a time when instruction in the Science, Technology, Engineering, and Mathematics (STEM) disciplines desperately need reinforcing, the Department finds it increasingly difficult to provide the research, teaching, and support for students that it needs in order to do its part.

1.5 Faculty Participation in Governance and Planning

The faculty participate by means of a committee structure which makes recommendations through the Executive Committee to the faculty as a whole which then passes on the recommendations. Staffing is currently handled through a Staffing Committee which started in 2003 and is charged with charting the future directions of the Department. The six member committee which is elected to overlapping three year terms has produced a series of reports, the most recent of which is in Appendix E. During the past four years, the committee's recommendations have resulted in the re-invigoration of the Atomic Physics Group, hires in Condensed Matter Theory, Neutrino Physics, and Elementary Particle Experiment.

Departmental issues are handled through and extensive set of committees. A list of the committees and their chairs are given in Table 1.1.

[2] See "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future", The National Academies Press (2007)

Committee	Chair
12x Coordinating	Pedigo
Admissions	Gundlach
Advising	Seidler
Aesthetics	Chaloupka
ASE Advisor	Shaffer
Awards	Karch
CDO Advisor	Schick
Chilled Water	Sorensen
Computer Support	Savage
Course Assignments	Rehr
Development	Boulware
Diversity	Olmstead
Evening Masters Program	Wilkes
Events	Lehner
Examination	Garcia
Executive	Boulware
General Education	Boynton
Graduate	Rehr
Graduate Program Coordinator	Sharpe
Implementation	Rothberg
Instructional Quality	McDermott
Library	Spivak
Majors	Heckel
Research Experience for Undergraduates	Haxton
Safety and Security	Doe
SPS Advisor	Schick
Summer Session	Fain
Teacher Education	McDermott
Technical Services	Wilkes
Undergraduate Advisor	Van Dyck

Table 1.1: List of Departmental Committees and their chairs.

1.6 Mentoring Junior Faculty

Junior faculty are largely mentored by the members of the groups in which they work. Mentoring for teaching responsibilities is discussed in Chapter 3. The senior members of the research groups provide advice on research, research funding, and service. In addition a review committee consisting of three faculty senior to the junior member and from outside the group meets with the junior faculty member each year to assess progress and recommend raises, reappointment and possible promotion. The Chair meets annually with each Assistant Professor to discuss progress, plans for the next year, and the promotion schedule.

1.7 Staffing Levels

Over the preceding ten years the number of state-funded faculty has nearly remained constant in size in the face of a significant number of retirements and a decreasing size of the College of Arts and Sciences. During the next ten years we expect about a quarter of our faculty to retire. The staffing plan, Appendix E, outlines the needs in various research areas and every group has expressed its need for new faculty in Chapter 4. The continued health of the Department, both in its research programs and in its ability to serve the students at all levels, depends upon its ability to renew itself. It is of critical importance that it be able to continue its recruitment efforts.

1.8 Salaries

As shown in Table 1.2, University of Washington salaries as of 2006-2007 continue to lag behind those of our peers. Although the University has been systematically attempting to address the issue it remains a problem. We anticipate that not only will we continue to suffer from the morale problems which this imbalance creates, we will lose faculty as other institutions address their own staffing problems. The average deficit is 14.8%; if private universities with which we actually compete are included the deficit becomes 20.1%.

Rank	UW Salary	Survey
Professor	$ 96,265	$ 113,924
Associate Professor	$ 78,141	$ 77,521
Assistant Professor	$ 67,323	$ 68,538

Table 1.2: OIS: Nine month salaries compared to the OFM Peer Group of Research I Universities w/ Medical Schools.

Chapter 2

Facilities

2.1 CENPA

The Center for Experimental Nuclear Physics and Astrophysics (CENPA) was formed in 2000 to provide an appropriate institutional framework for the broadly based fundamental science program that was developing at the Nuclear Physics Laboratory and elsewhere in the Department. An overarching theme is major experiments directed at an understanding of basic questions in nature. CENPA presently hosts 5 fairly distinct research areas, for which CENPA provides significant facility support.

1. Dark Matter (See Section 4.11, p. 98.)
2. Fundamental interactions, astrophysics, neutrons. (See Section 4.7, p. 80.)
3. Gravitation. (See Section 4.6, p. 76.)
4. Neutrino Physics. (See Section 4.8, p. 83.)
5. Relativistic Heavy Ions. (See Section 4.7, p. 80.)

CENPA not only provides laboratory space, design and shop services, and some unique physical capabilities, but also provides office space for students, postdocs, faculty, and scientific staff. This close proximity among people with a variety of roles in a variety of research programs produces a lively exchange of ideas and exposes students to an unusual breadth of research. Two or three Ph.D.s are awarded each year to students who did their research at CENPA.

Machine Shop and Electronics Shop

CENPA operates a machine shop with two full-time instrument makers and a student shop with one half-time instrument maker. These shops complement the Physics Shop[1], providing very high precision machining of a variety of equipment from high vacuum systems to parts for the gravity research experiments. The instrument makers work closely with the researchers, especially the students, in the design of the parts, and this collaboration provides an important component of the training of experimental physicists. The student shop provides hands-on experience for graduate and undergraduate students as well as a place where any of the research personnel can make simple parts quickly.

The electronics shop has equipment for designing and building modern surface mount printed-circuit boards with a high density of components. The shop has built multiplexers and other data acquisition hardware for the SNO Neutral Current Detectors, the emiT experiment, and now for the KATRIN experiment. Many of these boards revolve around Programmable Gated Arrays. The shop is staffed by two people who share design and construction tasks.

Engineering Staff

CENPA has five engineers who provide mechanical and electrical engineering design in support of the research groups. In addition there are two software engineers who maintain the computer systems and design data acquisition systems for various experiments. Recently CENPA implemented a data acquisition system for a TPC project at Livermore National Laboratory. This project was directed by Prof. Leslie Rosenberg and others at Livermore. The Livermore people were impressed with the speed with which a properly working system was delivered. CENPA is heavily involved in design of the hardware for the detector for KATRIN as well as in the development of the data acquisition system. These separate projects require several engineers. The engineering staff also maintains the Tandem van de Graaff accelerator and the associated equipment for low energy nuclear physics and nuclear astrophysics experiments.

Physics and Astronomy Computing Services[2] recently installed a large

[1]See Section 2.5, page 21.
[2]See Section 2.2, page 15.

supercomputer in space at CENPA using power and cooling that was available in the building. This work was done in collaboration with the CENPA engineering and technical staff, assisted by undergraduate hourly workers. Because of the knowledge and creativity of the engineering staff, this installation was done for well under $100k. This figure can be compared to a $500k estimate that some outside consultants gave the University to put in a smaller computer cluster about a year earlier.

Accelerator

CENPA continues to operate its model FN Tandem van de Graaff accelerator. A number of modifications have been made to this classic machine over the years to enable it to do a variety of experiments. Much of the work in recent years has involved intense, low-energy beams that are provided by the terminal ion source. They are useful for a variety of nuclear astrophysics experiments. The first radioactive beam experiment was completed two years ago, using negative ion injection to make 24-MeV Li and 35 MeV-B beams. These produced ^{8}B and ^{12}N radioactive beams, respectively, which were used to search for the (twice forbidden) beta-decay of ^{8}B to the ground state of ^{8}Be.

The superconducting linac, commissioned in 1987, has been shut down since 2000. The Tandem, on the other hand, is an ideal accelerator for intermittent use, as (unlike the cryogenic linac) it requires no attention when not in use, and requires little attention for steady beam production. The Tandem is an ideal instrument for graduate student training, as the experiments usually involve just a few people and the graduate students are able to take a role with major responsibility for all parts of the experiment. Often students who are doing thesis research on large, outside experiments, will assist the students running an experiment on the Tandem.

Unusual Laboratory Space

The large circular room that housed the 60-inch cyclotron is now used for research in gravitation. This large high-bay room is built into a hillside, and is fairly well isolated from external vibration.

Part of the room housing the Tandem will be used for the Axion-Dark Matter search experiment of Prof. Rosenberg. This experiment involves a tall vertical superconducting solenoid, and it will be installed in a hole that will be bored in the floor of the basement of the accelerator room. The magnet will be far enough from the accelerator that the fringe magnetic fields will be manageable. The design and planning for the move of the cryostat and for its installation were done by CENPA engineering staff. For more information on the Axion-Dark Matter eXperiment, refer to page 4.11.

Clean Room

CENPA has a clean room that was installed for the construction of the superconducting linac. This is not presently clean enough for work planned for the Majorana double-beta decay experiment, but it will be refurbished to bring it to the required standards.

CENPA Administration

Partly because CENPA is remote from the Physics building, and also because of the size of its operation, CENPA has its own administrative staff who handle our budget, travel expense claims, purchasing, payroll, and help with grant and report preparation. The office has two people who handle this workload. The entire staff is supervised by an Executive Director, a Research Professor who also takes a leading role in proposal and report preparation.

University, College, and Department Financial Support for CENPA

The core operations grant for CENPA from the DOE Office of Science is approximately \$3.5M, and the laboratory also hosts the gravity research, with several separate grants. There are additional grants for various equipment projects. The axion dark matter experiment will be supported by a grant from the High Energy Physics section of the Office of Science. As listed in the beginning of this section, CENPA provides support for a number of major research efforts of the Department.

In appreciation for the quality and value of the research done at CENPA, the Office of Research, the College, and the Department have provided the salary of the Executive Director. In addition, The Department has provided a small portion of the office staff's salary and has supported some work in the machine shop. This support is renegotiated every three years in concert with the three year cycle for our major DOE grant proposal.

2.2 Computing

Computing Support

Ten years ago computing was an important but not central activity for the Department. The Department provided support for email, some backups, and system management. These services were supported by a 'head tax' paid by the grants and the Departments (Physics, Astronomy, and the Institute for Nuclear Theory). The Departments now directly support the computer staff[3].

Introduction

The Physics and Astronomy Computing Services (PACS) group has aligned its focus with the core areas of the departments and institutes it serves over the last few years. Pursuing direct collaboration with faculty, staff, and students, PACS has developed a draft service level agreement which presents what the PACS team has learned and develops a vision of the future. This vision hopes to accelerate and enhance research, education, and administration of the organizations PACS services. The future is unclear, but in order to survive, Information Technology (IT) must move from a service model to a highly collaborative model.

The Terrain of Collaboration

The PACS team collaborates with the various individuals and groups throughout the University of Washington. This is qualitatively different than the standard models of service or support, in that both parties seek a solution to a problem or a request together. In a sense, this model allows for a "middle way" between the IT professional and the end user. More often than not, a collaborative solution actually solves a problem better than either of the parties defining the solution alone.

PACS has mapped the terrain of collaboration for Physics, Astronomy, and the Institute for Nuclear Theory (INT). Each of the three main missions of the departments, Education, Research, and Administration are equally important to the success of these departments. PACS currently provides the core tools and services, authentication, storage, disaster recovery, email, web,

[3]Astronomy utilizes a cost center to provide part of its support, see p.18.

and desktop operating system maintenance that are required. The PACS team prides itself on the maintenance of these core functions and ensuring that the day to day IT operations of the departments can rely on this core.

Education

The primary mission of any university or college is that of education and learning. PACS maintains systems that support this mission in the Departments of Physics and Astronomy at the University of Washington. Students use two computing labs open to all on campus in rooms AM018 and B101. PACS manages computing in 6 classroom labs on the first floor, 1 classroom lab on the second floor, and 1 classroom lab on the third floor. In addition, PACS manages Tycho, a homework and grade book system used by the large introductory courses.

Research

Research requires a full spectrum of services from application maintenance to high-performance computing (HPC). In Physics, a small contingent (George Bertsch, Aurel Bulgac, Toby Burnett, Martin Savage, and John Rehr) have been utilizing HPC systems. Most of Physics and INT have only recently begun to use high-performance computing as a serious tool in research. While Astronomy has led the way in HPC, they have been limited by a very small equipment budget compared to their needs. Both groups are now demanding increased services such as cluster computing, distributed file systems, extensible storage, and even some are asking for assistance in scientific programming and computing.

Administration

The principles of the administrative function are service, strategy, and management. The critical applications are email, calendaring, word processing, database access, campus enterprise applications, and state and federal tools for grants. We service student databases, which are used to collect incoming student information and track their performance throughout their education. There are also databases to maintain our grants and contracts, track our keys, allocate rooms, and track spending. Billing for the shop is managed using a computer-based system that must be maintained.

The Future: 2008 and Beyond

PACS intends to increase its integration with the educational, research, and administrative missions of the departments. The team will explore ways to utilize central resources on campus and eliminating redundant technologies. PACS will work hard to roll documentation and provide technologies to the users to enable rapid "self-service". We will also help teach classes in computing. PACS will continue to simplify the administration of the current services it offers in an effort to be able to more efficiently service the specific and special requests users have daily. Finally, PACS will also have to work to obtaining more funding for personnel to provide these additional services.

Commodity Services: Eliminating Redundancy

Up until 1999, managing your own email server and authentication systems were required if you wanted a high-level of local service. Email was relied upon but not a primary form of communication and certainly not considered a "can't fail" service. Centralized authentication systems had not really settled out until recently. Within the last 3 years, vendors and open software sources have been building their authentication systems off of the internationally accepted LDAP standard. While there are still significant variances in additional services that use LDAP, most vendors (even Microsoft's implementation) have commonalities. There are a few remaining good reasons why we need to continue to maintain these services, but it is hoped to eventually turn over control to the University's central UW Technology group[4].

Self-Service *vs.* Full Service

Another tough decision coming down the pipe once again addresses the role of IT: should PACS provide more "self-service" applications and services? Users within the department could be free to reload their own operating systems, backup and recover their own data, and download and install their specific applications on all supported platforms (MacOSX, RedHat, Enterprise Linux, Windows XP/Vista). PACS might then be able to shift its focus to setting up and maintaining the "self-service" systems instead of helping users directly with these needs.

[4]Formerly Computing and Communications.

Funding for Personnel

While the equipment budget is important to PACS, we manage to control this budget by avoiding monolithic solutions, driving vendors hard to give us deep discounts, standardizing desktops and servers, and enforcing better and longer hardware warranties. Personnel is what hits the department budgets the hardest. Nearly 6 times the cost of the equipment, this number could potentially double in two years if the departments' needs grow at their current rate.

As a reminder, PACS operates under a non-cost center model within Physics and the Institute for Nuclear Theory. Astronomy has opted for a cost center charge model managed by the Astronomy front office which taxes on a dollar/month model. The benefits of a non-cost center model are that we avoid a complex bookkeeping problem that potentially incurs 2.5 FTE to manage it, ward off "entitlement" problems, and it has the flexibility for our service level agreement based upon the trends of the research, academic, and administrative missions. This directly reflects the funding models on the campus for faculty start-up packages, new classes, and disciplines.

Since the growth of PACS is driven by one of the three missions (academic, research, administrative), hiring additional personnel resources requires PACS to be aligned along one of the missions. In essence, the needs not only drive demand but justify (and sometimes pay directly) for service. For research, this may mean that PACS staff may need to be paid directly off of grants. In the academic realm, the department might have to readjust its other funding. And in the administrative mission, some responsibilities may need to pushed up to the campus. How PACS will predict these needs will require greater collaboration with professors and staff.

Sustainability

As of today the PACS team has been driven to work at pace just beyond sustainability. While exciting and temporarily fruitful for the departments, the team cannot maintain this level of effort. Over the next year, PACS will be refining project management to develop better metrics and improve predictability of staffing needs in the future. Part of this process is enabling the staff as self-managing as possible. This not only requires patient management and self-actualization, but the support of the faculty, staff, and students. Maintaining mutual respect as equal professionals and working together towards discovery and innovation, are absolutely critical to inspiring the creativity, passion, and drive in all of us.

In Conclusion

This document is a testament to the extensive needs and demands for IT within the three departments PACS serves. This is truly an great time for PACS and the user communities it serves and we look forward to an exciting and productive future for us all.

2.3 Institute for Nuclear Theory

The Institute

The Institute for Nuclear Theory (INT) is the third component of a nuclear physics program at the University of Washington — along with the nuclear theory group and CENPA in the Physics Department — which is regularly ranked in the top two nationally along with MIT. The INT itself is independent of the Physics Department. It is the Department of Energy's (DOE) national center for nuclear theory, beginning operations in 1990 and founded to help the nuclear physics community by serving as an intellectual center hosting visitor programs and workshops. It is also plays an important role fostering young researchers through its post-doctoral research program. Half of the recipients of the DOE's prestigious Outstanding Junior Investigator awards in nuclear theory previously held positions at the INT.

The INT is administered by its Director, who reports within the University of Washington to the Dean of Arts and Sciences on daily matters, and to the Provost on matters involving the Department of Energy, inter-university relations, and long-term planning. The INT director is also reports regularly to a National Advisory Committee and to the DOE's Office of Nuclear Science. In addition to the Director, the scientific staff of the INT consists of three Senior Fellows, one or two 5-year Fellows, and a number of post-doctoral researchers. While the INT is operated completely independently from the Department of Physics, the scientific staff has academic appointments through the Physics Department: the current Director (Kaplan) and Senior Fellows (Bertsch, Haxton, Son) being Professors, the 5-year Fellow (Romatschke) being a Research Assistant Professor, and the post-doctoral researchers having the appointment of Research Associate.

Through an explicit arrangement with the Department of Energy, INT faculty can teach, with a quid pro quo in the form of teaching relief for Physics Department faculty members who help organize INT programs. Relations between the INT and the Physics Department have historically been close and cordial, with INT faculty serving on Physics Department committees, attending faculty meetings, mentoring graduate students, teaching classes (at a reduced level), and being actively involved in hiring and promotion decisions.

Infrastructure and eScience

Located within the Physics and Astronomy building, the INT consists of over two dozen offices to house visitors, staff and administrators; it shares lecture space through an amicable arrangement with the Physics Department. Recently the INT has spearheaded an ambitious project enabled by the Vice-Provost for Research (Lidstrom) to construct a supercomputer ("Athena") housed at CENPA and facilitating research in nuclear theory and experiment, as well as astrophysics. The machine is capable of $\sim$2 TFlops sustained using real scientific code, making it the most powerful machine on campus presently. Athena is not only expected to lead to advances in the theory of hadronic, nuclear and galactic structure, but also to provide the model for collaborative eScience about which a campus-wide eScience Institute may grow.

Research

Aside from hosting visitor programs and training young scientists, maintaining a vigorous research effort which plays an influential role on the national nuclear theory community is part of the INT's mandate. All of the INT's senior faculty are American Physical Society (APS) Fellows, George Bertsch has been awarded the APS Bonner prize for his work on nuclear structure, and has been chosen as scientific director of a massive computational nuclear physics project ("UNEDF") sponsored by the DOE; and Wick Haxton has not only received the APS Bethe prize for his work in nuclear astrophysics, but is also a member of the National Academy of Sciences. The research programs of the INT faculty members are discussed in Chapter 4.9, p. 89.

2.4 Library

While a part of the University Library system and thus not "owned" by the Department of Physics, the Physics-Astronomy library is a critical and highly valued resource for Physics faculty and students. Although we tend increasingly to use online access for the most popular technical journals, many smaller journals are still available only in print form. Very few of the books we use for course preparation, and as references for research, are (or will be in the near future) available online, so the library remains an important place for study by faculty as well as students. After-hours access to the library for faculty and grad students is another very significant benefit for our Department.

The Department as a whole also benefits enormously from the services of our outstandingly competent and helpful library staff, under the supervision of Librarian Pam Yorks, who provide much-needed assistance to faculty and students in learning to use our rapidly changing set of information resources, as well as setting up reserves and other resources for our classes.

2.5 Instrument Shop

The Physics Department Instrument Shop is a fully equipped machine shop. Its focus is on research and developmental work for members of the entire University of Washington community. This work generally involves producing unique, high precision parts and assemblies that are not available from commercial suppliers. In the last decade, the shop has produced parts that have gone to Mars on the Rover exploration vehicles, detector parts for the Atlas experiment at the Large Hadron Collider in Switzerland, and instrumentation that survives in the corrosive, high temperature, ocean floor vents called "smokers".

The shop has a full time manager and four to six full time Instrument Makers, depending on the workload. Hundreds of jobs are completed each year, with 8000 - 12,000 hours billed to a wide variety of University of Washington faculty and students.

Most of the work done in the Instrument Shop is for research scientists and their students; the work has often not been fully engineered when it comes in to the shop. Therefore, our customers often need an ongoing dialogue with the Instrument Makers who are working on their parts, to solve issues that come to light during the fabrication process, a dialogue that is often difficult to achieve with commercial shops. The researchers who bring their projects to the shop trust in the collective experience and creativity of the Instrument Makers there to help guide their ideas into practical devices that are robust and cost effective to produce.

The Instrument shop has an array of up to date machine tools. These include 4 vertical Computer Numerical Control (CNC) machining centers, 1 CNC high precision lathe, 1 wire Electro-discharge Machine (EDM), 1 sinker EDM machine, 5 manual mills, 5 manual lathes, and 2 radial arm drill presses. There is also a variety of surface and tool grinders, basic sheet metal forming equipment, 3 bandsaws, a table saw, and a sandblasting booth. The Instrument Shop weld area has 2 Tungsten Inert Gas (TIG) welding machines, 1 Metal Inert Gas (MIG) welding machine, a plasma cutting torch, and a heat treating oven. The equipment is amortized to assure continued funding of modern equipment.

An important component of the Instrument Shop is the student shop. This is a separate room dedicated for use by University of Washington students to machine parts for their research projects. The student shop has 4 manual mills, 3 manual lathes, 1 CNC lathe, 2 drill presses, and 2 bandsaws. One of the Instrument Makers teaches an 8 week class each quarter, with 24 hours of instruction in the use of all the machines in the student shop. Students get hands on experience making parts in the classes. These classes are well attended by students and faculty from many departments on campus.

Chapter 3

Teaching and Learning

This chapter addresses the teaching and learning of physics in the context of the guidelines provided by the Graduate School. Sections 3.1 - 3.4 describe efforts to monitor and improve teaching effectiveness that are centered on the faculty. Section 3.5 - 3.9 focus on the assessment of student learning of specific content. In Section 3.10 is a discussion of faculty plans for further development of some existing or proposed courses.

3.1 Teaching Responsibilities of Faculty

State-funded faculty are expected to teach one course per quarter. Most take this teaching responsibility very seriously. In addition to fulfilling their duties as course instructors, faculty serve on various committees that are charged with overseeing the introductory, upper-division, and graduate courses. Individual faculty supervise independent study projects, which may or may not be directly related to their own research. They also advise students who are formally assigned to them and mentor many more on a voluntary basis.

New faculty who are beginning their careers are given release time for one or two quarters as part of their initial offer. The College of Arts and Sciences grants two additional "Faculty Development Quarters," one before the three-year renewal of the appointment and the other prior to the tenure decision. Faculty with heavy research or administrative responsibilities are sometimes given less demanding teaching assignments and, in rare instances, are granted release time. It is also possible for faculty to double-teach in one quarter in order to work full time on their research another quarter.

3.2 Teaching Effectiveness as Evaluated by Surveys and Class Visits

Evaluation of the instructional effectiveness of faculty by the Department is primarily through student evaluations on questionnaires developed by the Office of Educational Assessment (OEA) and through reports of class visits by faculty on the Instructional Quality Committee. The Department also follows up on the outcome of consultations between faculty and the Center for Instructional Development and Research (CIDR).

Summary of Evaluation Data from OEA Surveys

OEA student evaluations of teaching effectiveness are required at least once every year. A 5-point scale is used, in which a rating of 5 corresponds to excellent and a rating of 0 means very poor. Special attention is directed to the first four questions, in which the students are asked to rank (1) the course as a whole, (2) the course content, (3) the instructor's contribution, and (4) the instructor's effectiveness in teaching the subject matter. The Physics Department averages for these questions are shown in Table 3.1. When compared with the average scores for all courses and instructors in the Natural Sciences and in the University, the averages for the Department are slightly lower, whereas for the upper division courses, the Department's averages are slightly higher.

The Chair reviews the ratings each quarter, discusses any problems with the instructor involved and makes suggestions that may include mentoring by other faculty or consultation with CIDR. Often there is a significant improvement in subsequent ratings.

Rank	Averages of Questions 1-4			
	Q1	Q2	Q3	Q4
Assistant Professor	3.7	3.7	4.0	3.8
Associate Professor	3.6	3.7	3.8	3.7
Professor	3.5	3.6	3.7	3.4

Table 3.1: Departmental Averages of OEA Surveys.

Class Visits by the Instructional Quality Committee

The Instructional Quality Committee of the Department is charged with the responsibility of helping faculty improve their teaching of undergraduate and graduate courses. Visits by two members of the Committee to classes are made once every year for assistant professors, once every two years for associate professors, and once every three years for full professors. In addition to attending the class, the Committee members examine the instructional materials (*e.g.*, web-site, homework assignments, and examination questions). The class visit takes place on a day that is convenient for the instructor. After the visit, the Committee members prepare a report that describes the instructor's role, comment on the most effective aspects of the instruction, and make suggestions for improvement if weaknesses are identified. At least one member of the Committee meets with the instructor to discuss the Instructional Quality Committee Report. The Report is used during the consideration of a faculty member for tenure and/or promotion.

3.3 Faculty Mentoring Through Course Coordination

Informal mentoring takes place on a regular basis in the examination and transition meetings of instructors in the large introductory calculus-based physics sequence to which new faculty are often assigned. Faculty are also encouraged to consult with one anther when they begin a new course assignment.

Examination Meetings

Prior to all of the examinations in the introductory calculus-based sequence, there are meetings of the faculty who teach each course and the Lead TAs. The three midterms and the final examination in each of these courses include questions written by the lecturer and the tutorial instructors. The Physics Education Group is responsible for the questions based on the tutorials, which constitute about 25% of each exam. Laboratory instructors contribute a question for one midterm and the final. During the exam meetings, all of the questions are reviewed and modifications are made based on comments from all of the instructors. This process helps ensure that each exam is well constructed and provides fair and balanced coverage. Most faculty who have taught in the sequence believe that these meetings improve the overall quality of the examinations.

The examination meetings occur every 2-3 weeks during the academic quarter and have been ongoing since introduction of the tutorials. The meetings, which are coordinated by members of the Physics Education Group, serve as a forum for the instructors to discuss important issues that may arise. They also help ensure that the instructors stay close in coverage and pace, which is important in a large course with several sections. In addition, they provide an opportunity for mentoring new faculty.

Transition Meetings

At the end of each academic quarter, incoming and outgoing instructors for the calculus-based sequence meet to discuss the overall pace, coverage, and other intellectual and administrative aspects of the course. Daryl Pedigo, the coordinator for the introductory calculus-and algebra-based sequences, coordinates these meetings. All lecturers, laboratory instructors, and the tutorial instructors who are members of the Physics Education Group attend. Feedback from the outgoing instructors guides changes to the course that are implemented by faculty in the following quarter. The meetings facilitate systematic, ongoing changes to the course. They also help ensure that all faculty who are teaching in the sequence are familiar with the goals and structure.

3.4 Tracking and Promoting Innovations and Best Practices

The Department tracks and promotes innovations and best practices in undergraduate and graduate teaching in several ways. Pedigo and faculty in the Physics Education Group regularly attend national meetings of the American Association of Physics Teachers (AAPT), where they discuss their work and learn about other instructional innovations. In addition to participating in invited and contributed sessions and workshops, they visit exhibits that feature new instructional materials. Additional sources of information are articles in the *American Journal of Physics*, *The Physics Teacher*, and other publications on the teaching of physics and other sciences.

Personal Response ("clicker") System

Among other innovations adopted by the Department is widespread use of a "Personal Response System" (also known as "clickers" or PRS). This system was introduced several years ago and has been vigorously promoted by Pedigo. Until recently, most lectures in the Department were based solely on the transmission mode of teaching. The lecturer would use the blackboard, overhead transparencies, or PowerPoint slides, occasionally asking the class if there were any questions. However, there has been a lot of research that demonstrates that most students are intellectually passive during lectures and do not develop a meaningful understanding. Pedigo recognized that instruction could be improved using clickers. These are hand-held units with buttons that students press to respond to questions posed to the class by the lecturer. A receiver at the front of the room collates the responses so that the instructor can determine how the students responded. By asking questions several times during a lecture, the instructor can tailor the instruction to the level of understanding of the students. Perhaps more importantly, this process enables students to assess their own understanding and to become active agents in their own learning.

Currently, Pedigo tries to meet with each new instructor in all of our lecture-based courses. He maintains a bank of questions that have proved useful in various courses and makes them freely available to other instructors. A present, most instructors in our lecture halls use the clicker in their courses.

On-line Homework Systems

Another innovation implemented in our introductory courses is the use of on-line homework systems. One problem with traditional paper-based homework is that students do not receive feedback on their work for, at best, several days after they have completed it. Unless they are required to resubmit, most students pay little attention to the feedback they receive. An on-line homework system can provide immediate feedback. The system in use since 2001 is the Tycho Homework System, developed in the Physics Department at the University of Illinois, Urbana-Champagne.

At the time we adopted the Tycho Homework System, it was one of the only systems that could provide tailored feedback to students. Most homework systems had questions that provided "hints" to students if they were struggling with a particular homework question. However, the Tycho system includes “Interactive Examples,” in which the help provided is based on the particular responses of a student. Thus, a well-designed question in this system can try to provide feedback based on specific difficulties that a student seems to have. Response to the Tycho Homework System has been very positive. Most students rate the Interactive Examples as the most useful part of the homework.

The Department has continued to examine other homework systems, (*e.g.*, *Mastering Physics, Physics Portal,* and *WebAssign.* Some of these contain questions that can provide hints tailored to an individual.

3.5 Assessment of Student Learning of Specific Content

Results from course examinations alert individual faculty to aspects of their instruction that were or were not as effective as they might have thought. Most physics instructors are aware that there is a gap between what is taught and what is learned. However, many do not recognize just how great that gap can be, especially at the introductory level. They often assume that students who can solve “end-of-chapter” quantitative problems on homework and course examinations have a reasonably good conceptual understanding of the material. Results from physics education research, however, demonstrate that this type of learning assessment, which is typical in physics, is not a reliable indicator of a sound conceptual understanding.

As discussed in Section 4.12, the Physics Education Group conducts research on student understanding of physics before and after instruction. Most of this research has been conducted in the large calculus-based physics sequence (Physics 121, 122, and 123). In recent years, the scope of research has expanded to include more advanced courses, such as special relativity, quantum mechanics, and advanced laboratory courses.

The group seeks to identify specific difficulties that students encounter with the concepts, reasoning, and representations of physics and to develop instructional strategies that help students overcome these difficulties. The strategies are incorporated in a type of instruction that can be characterized as guided inquiry. Instruction is through the posing of carefully sequenced questions that are intended to guide students through the reasoning needed to develop a functional understanding of the material, *i.e.*, the ability to do the reasoning necessary to apply a concept, principle or representation in situations that have not been explicitly memorized.

The group produces two types of research-based curriculum: one is self-contained and is intended for use in courses where there are no lectures (See Section 3.8); the other consists of tutorials that are intended to supplement the lectures, laboratory, and textbook of a standard lecture-based course (See Section 3.6). Embedded in both curricula are pretests and post-tests. Comparison of these scores provides a measure of student learning of specific content.

3.6 Improvement in Student Learning in Introductory Physics

The Department of Physics offers two introductory sequences that provide a foundation in basic physics. Although intended for students planning to major in physics or another scientific or technical discipline, both sequences are open to all students. The courses are often called "service courses" because they are expected to lay the foundation for more advanced study in physics and other sciences. Basic concepts and principles are introduced and students are provided with practice in their application to the solution of quantitative problems. Since for most undergraduates, the introductory sequences are terminal courses in physics, it is important that students emerge from them with more than memorized facts and formulas that they are likely to forget. As they progress through introductory physics, students should develop ability in (1) scientific thinking — understanding the nature of science, methods of investigation, and the use of models as a basis for explanations; (2) critical thinking — distinguishing scientific reasoning from personal belief or opinion, and (3) reflective thinking — asking the questions necessary for recognizing whether or not they understand a concept or principle. These goals transcend the study of physics and are difficult to achieve, especially in large courses.

Structure of the Introductory Courses

Both introductory sequences begin with classical mechanics in the first quarter, continue with basic thermodynamics, followed by and electricity and magnetism, and concluding in the third quarter with waves, optics, and basic modern physics. The calculus-based sequence generally covers these topics in more depth than does the algebra-based sequence. At least one section of each of the six courses is offered during each quarter.

The enrollment in calculus-based physics is about 1000 students per quarter. This sequence (PHYS 121, 122, and 123) is required for majors in physics, other physical sciences, mathematics, and engineering. Each of the 5-credit courses includes a laboratory. There are three 50-minute lectures per week, a 50-minute small group tutorial session, and a three-hour lab session. The laboratory sections are taught by TAs under the supervision of a faculty member. The tutorials are also taught by TAs, who are specially prepared and supervised by faculty in the Physics Education Group. The laboratory exercises are graded, as are the homework assignments associated with the tutorial sessions. These grades are combined with examination scores and online homework to produce a single composite grade for the 5-credit course. Examination scores provide the largest fraction of the course grade.

The enrollment in algebra-based physics is about 700 students per quarter. This sequence (PHYS 114, 115, and 116) is intended for students aspiring to careers in other sciences and medicine. Each component is a 4-credit course that meets four times per week in 50-minute lecture sessions. Grading is based primarily on examinations, but online homework and other assignments chosen by the professor are factored into the course grade. The separate 1-credit laboratory courses are PHYS 117, 118, and 119. These laboratories meet once per week in 3-hour sessions that are taught primarily by TAs under the direction of a faculty member. All laboratory courses are graded pass-fail and are offered only on a credit-no credit basis.

Research as a Guide for Improving the Effectiveness of Instruction

As discussed in Section 3.5, p. 28, and in Section 4.12, the Physics Education Group has been conducting much of its research on identifying student conceptual and reasoning difficulties in the introductory calculus-based course. The faculty, post-docs, and graduate students in the group collaborate in designing and testing instructional strategies that can be effectively used within the constraints of a large fast-paced, lecture-based course, preferably in small sections but also in lecture settings. The group has produced (and is continuing to produce) research-based and research-validated curriculum that is used nationally and internationally.[1] *Tutorials in Introductory Physics* is not intended to replace lecture and laboratory instruction in the traditional introductory course, nor to provide practice in the solving of numerical problems, but rather to help students develop a functional understanding of the physics that they are taught[2]. This level of understanding connotes the ability to apply concepts and principles to situations that have not been explicitly memorized. Each tutorial addresses a concept, or group of closely related concepts, identified as difficult for students. Ongoing development of the tutorials occurs in an iterative cycle in the Department's courses and at several pilot sites.

Tutorial worksheets (both published and not yet published) provide the basis for instruction in small-group sessions (∼22 students) that meet for 50 minutes each week. Students work together in collaborative groups of three or four. The worksheets contain qualitative questions that are carefully sequenced to guide students through the reasoning required for developing a functional understanding. The TAs who lead the tutorials guide the introductory students by Socratic questioning, not by presenting the answers.

Assessment of Student Learning

Assessment of student learning in the tutorials is done through pretests and post-tests. (It is also an integral part of the process through which tutorials are developed and modified,) Pretests are given before every tutorial, usually after a topic has been covered in lecture. Post-tests are administered on midterm and final examinations after students have worked through the relevant tutorials and completed the associated homework assignments. The tutorial question usually constitutes 20-25% of an exam. No student is ever given the same question as a pretest and a post-test. The difference in the average pre-test and post-test scores in all sections of the course is a measure of the effectiveness of a tutorial. As discussed in Section 3.7, the TAs in the introductory courses take the same pretests that the introductory students will be given later. A tutorial is deemed sufficiently successful when the av-

[1] The tutorials have been used in institutions that range from large research universities (*e.g.*, Colorado, Illinois, Purdue) to two-year colleges. The tutorials have been (or are being) translated into several languages, including Spanish, Greek, German, and Korean).

[2] L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics* (Prentice Hall, 2002).

erage post-test score of the introductory students matches (or surpasses) the average pretest score of the TAs.

Comparison between pretest and post-test performance indicates that the tutorials have brought about significant gains in the quality of student understanding. Pretest scores typically vary from 15% - 40%, while the range in post-tests is from 60% - 90% [3]. Although some instructors have expressed concern that one hour/week spent on qualitative problems means there is less time for practice in quantitative problem-solving, the data indicate that the success rate on standard numerical problems is not adversely affected and often increases. There is also evidence of longer retention by students who have worked through tutorials than by those who have not had this experience [4].

3.7 Preparation of TAs for Their Instructional Role

All first-year TAs and all those currently assigned to the calculus-based course must attend a weekly Graduate Teaching Seminar (Physics 501, 502, and 503) conducted by the Physics Education Group. During the Seminar, which lasts from 1 to 1.5 hours, the TAs take the same pretest as will be given to the introductory students. They then work through that week's tutorial in small groups, just as the undergraduates will do later in the week. Experienced TAs demonstrate by example how to ask the types of questions that can guide the introductory students to an understanding of the material. After working through the tutorial, the TAs examine responses given by the undergraduates and try to identify specific conceptual and reasoning difficulties. After these group discussions, the TAs are given a brief overview of the results from research that guided development of the tutorial. In addition, the TAs are sometimes asked to read a relevant paper on the learning and teaching of the topic addressed in the tutorial.

Besides improving their competence as instructors, the Teaching Seminar helps the TAs strengthen their own understanding of basic physics. It

[3] P.S. Shaffer and L.C. McDermott, "A research-based approach to improving student understanding of the vector nature of kinematical concepts," *Am. J. Phys.* **73**, 1062 (2005).

[4] G.E. Francis, J.P. Adams, and E.J. Noonan, "Do They Stay Fixed?" *Phys. Teaching.* **36**, 488 (1998)

often has been several years since they studied the material. Their advanced undergraduate and graduate courses are often no help on basic topics. In addition to training the TAs, the Teaching Seminars have contributed to the development of tutorials. TA performance on a pretest provides a benchmark for deciding whether or not further modification of the associated tutorial is likely to make a substantial difference in learning by the introductory students.

3.8 Student Learning in Courses for K-12 Teachers

Preparing K-12 teachers to teach science is an important (but often unacknowledged) responsibility of science faculty. A steadily increasing number of physics departments have begun to take a more active role in the preparation of K-12 teachers of physics and physical science. The APS and AAPT strongly support this trend.

Need for Special Physics Courses for K-12 Teachers

The only courses in science departments that are generally available to prospective elementary and middle school teachers are almost entirely descriptive in nature. A great deal of material is presented, for which students have neither the background nor the time to absorb. Such courses cannot help teachers develop the concepts and reasoning skills that they need to teach physical science in a way that is meaningful to their students. Neither can the courses in methodology that are typically offered by Education faculty fulfill this need. Methods courses that include “hands-on” activities are not enough.

Often high school physics teachers are not much better prepared than university students who have taken a standard introductory course. Although this course covers the content of high school physics, it is not adequate preparation for teaching the same material. The breadth of topics and the pace allow little time for acquiring a sound grasp of the underlying concepts. The accompanying laboratory courses do not prepare teachers to teach physics as a process of inquiry. The relatively few students who decide early that they want to teach high school physics may major in physics. However, the abstract formalism that characterizes upper division courses is not of much use in the precollege classroom. Courses on “cutting-edge” topics may be motivational but do not help teachers distinguish between memorization and substantive understanding.

There is a need for special physics courses for teachers from the elementary through high school grades. These courses should be laboratory-based and have intellectual objectives and an instructional approach that are mutually reinforcing. The topics should be relevant to the K-12 curriculum and taught in a manner that is consistent with how teachers are expected to teach. This perspective on teacher preparation results from a distillation of what the Physics Education Group has learned from more than 30 years of experience in preparing preservice and inservice teachers to teach physics and physical science at the elementary, middle, and high school grades.

Description of Special Physics Courses for K-12 Teachers

The Department teaches two sets of courses for K-12 Teachers: one for elementary and middle school teachers and the other for middle and high school teachers. Physics 407, 408, and 409 are taught for preservice middle and high school teachers during the academic year and for inservice teachers as part of an NSF Summer Institute for K-12 Teachers. Physics 101 -102, 103 are currently not offered during the academic year but are taught during the summer for elementary and middle school teachers as Physics 405 and 406.

The summer courses are part of annual NSF Summer Institutes for K-12 Inservice teachers. For more than 30 years, the Institutes have been funded through competitive, merit-based grants to the Physics Education Group. About 40 teachers are admitted each summer. They may attend for up to three years. During the academic year, NSF also supports an ongoing Continuation Course (Physics 410, 411-413) that meets once/week and is open to all teachers who have previously participated in any of the special courses for teachers taught by the group. The Continuation Course enables local teachers to continue their study of physics, to get help from the staff in modifying what they have learned for use in their classes and also to get help on science topics that they have not studied. Most importantly, the Continuation Course provides an environment in which K-12 teachers develop a sense of community and professional identity as teachers of science. Many are the only ones in their schools who teach physics or physical science.

The instructional approach in all of the courses for teachers can be summarized as guided inquiry. Teaching is not by telling but by asking carefully structured questions to help students do the reasoning required to develop a functional understanding of the material. All instruction takes place in the laboratory. There is no lecturing and only simple equipment is used. The curriculum for these courses is provided by *Physics by Inquiry (PbI)*, a research-based set of laboratory modules that have been (and are continuing to be) developed by the Physics Education Group.[5] *PbI* is designed expressly for the subject-matter preparation of teachers. The modules consist of experiments and exercises that guide students through carefully sequenced questions in making observations, developing concepts, and constructing scientific models in an ongoing process of inductive and deductive reasoning. This type of guidance helps teachers develop the depth of understanding required to teach physics and physical science with competence and confidence as a process of inquiry.

The topics for elementary school teachers have been selected to provide a firm foundation for teaching elementary school science. For example, in the module entitled *Properties of Matter*, students begin by constructing operational definitions for mass, volume, and density. They apply these concepts in predicting and explaining outcomes in situations of gradually increasing complexity, culminating with sinking and floating. Formulas are not acceptable explanations. In the courses for high school teachers, the students revisit many of the main topics that they have studied in the prerequisite introductory university course. These include kinematics, dynamics, waves, optics, electric circuits, and a few topics from modern physics. Graduate students in physics, mathematics, and other sciences often enroll in these courses, which are also good preparation for teaching undergraduate physics. Emphasis is on the development of a deep conceptual understanding and the ability to do the reasoning necessary to apply the concepts and their formal representations to real world objects and events.

Besides learning specific subject matter, the teachers learn how to recognize whether or not their students understand important basic concepts and the associated reasoning. From their own experience and exposure to findings from research, they learn how to identify and to address the intellectual difficulties that their students are likely to have.

[5] L.C. McDermott and the Physics Education Group at the University of Washington, *Physics by Inquiry* (Wiley, New York, 1996).

Assessment of Learning by K-12 Teachers and K-12 Students

As in the introductory course, assessment of student learning in the courses for K-12 teachers is conducted through pretests and post-tests. However, the standards for what constitutes an explanation in physics are higher than for the introductory students. In addition, the teachers are expected to write several papers in which they reflect on how their own understanding of a given topic evolved during the courses. There is evidence that teachers who have been taught in the way described develop both a sound conceptual understanding and retain what they have learned well beyond the course[6].

Members of the Physics Education Group have observed inservice teachers in their own classrooms before and after they have taken these courses. For most, there is an observable positive change in the way they teach science. The group has also examined pretests and post-tests that teachers have administered to their own classes. In some cases, they have documented that K-12 students of teachers who have participated in the special courses for K-12 teachers have developed a deeper understanding of the material than students taught by teachers who have not participated [7].

3.9 Improvement in Student Learning in Advanced Courses

The Physics Education Group has developed (and is continuing to develop) tutorials for courses in Special Relativity and Quantum Mechanics. Faculty who have taught Physics 311 have incorporated the tutorials on Special Relativity into that course by devoting one of the three scheduled lectures/week to tutorials.

Within the last few years, the Department has raised the credit allocated to junior-level Quantum Mechanics (Physics 324, 325) and to Electromagnetism (Physics 321, 322, 323) from three to four for each course in the two sequences. These courses, which used to meet three times each week now have a fourth session in which the students meet in smaller sections. During this

[6] L.C. McDermott, P.S. Shaffer and C.P. Constantinou, "Preparing teachers to teach physics and physical science by inquiry," *Phys.Educ.* **35**, 411 (2006)

[7] L.C. McDermott, P.R.L. Heron, P.S. Shaffer, and M.R. Stetzer, "Improving the preparation of K-12 teachers through physics education research," *Am. J. Phys.* **74**, 758 (2006)

session, tutorials in Quantum Mechanics developed by the group have been used to address specific conceptual difficulties that research has shown to be common in the study of this topic. Student response has been very positive. The added weekly sections in the Electromagnetism sequence are currently used for practice in problem- solving. The results have not proved very successful, partly because the TAs in charge of the sections cannot provide the assistance needed by the students without the level of support available from carefully designed tutorials, as is the case in Quantum Mechanics.

Research on student understanding in two of the eight Advanced Laboratory Courses that are identified at the beginning of Section 3.10 was begun relatively recently. Results from pretests designed by MacKenzie Stetzer, a Research Assistant Professor in the Physics Education Group, demonstrate that there is a need to help students in upper-division labs improve their understanding of important basic concepts that faculty often assume are well understood by the students. Stetzer has been collaborating with the faculty in charge of Physics 334 and Physics 434 and is assisting them in making modifications.

3.10 Courses Undergoing Further Development

Advanced Laboratory Courses

The advanced laboratory courses, comprised of Physics 331 (optics), 334, 335 (electronics), 431 (condensed matter), 432 (atomic and molecular physics), 433 (nuclear and particle physics), 434 (computers in experiments), and 575 (optics and modern physics for the evening masters program) provide instruction and training in experimental techniques to our undergraduate majors and evening masters-program students. The lab facilities also supply space and apparatus to students conducting independent research. Since Spring of 2006, a total of 463 students have taken one or more of the advanced laboratory courses. Typical enrollments during the regular academic year are 35-50 students in the 300-level courses, 20-35 in the 400-level courses, and 10-15 in the evening course, Phys. 575.

The equipment in the advanced laboratories is supported by Department funding of approximately $15,000 per year for operation and maintenance. In 2004, we also benefited from am additional $30,000, half from the college of Arts and Sciences and half from the department, to upgrade and expand the apparatus from the 433 lab course (equipment which is also used in the other courses). The special funds for Physics 433 allowed us to add three new experiments to that collection and increase the number of setups for the others, making it feasible to serve the increased enrollment seen in that course. Apart from the improvements to Physics 433, we have been working to improve the quality of the overall laboratory experience along two main lines. First, we have enhanced the use of computers in the labs. In 2003, there were five workstations in the 431-433 labs, two of which were obsolete DOS machines; we now have twelve workstations, complete with data acquisition hardware and LabVIEW applications, that allow students tot take and analyze data from various experiments. Second, we have completely revised the instructional materials and how they are distributed to students. All of the labs now have course websites, which contain instructions equipment information, additional reading and reference materials, as well as course syllabi and related documents. The websites have helped to unify the experiment documentation, which had previously been a paper-based collection from various incarnations over many years. Now students can print or save to their computer only what they need, which has reduced staff time and expense formerly spent on copying, and we can easily update documentation as necessary.

The Department plans to continue improving the quality and depth of information that is made available to our students, revising and upgrading existing experiments, and introducing new ones. Some of the new experiments will be based on work done by the independent-research students (mostly Evening Masters Program). (Six students have recently worked on independent research in the same lab space.) For example 2d and 3d visible light diffraction projects have produced useful apparatus we hope to begin using this year. While a few of the new experiments can be put together with little additional cost, some apparatus would require significant funds, comparable to what was spent for Physics 433. For example, we used to offer experiments in electron spin resonance, atomic force microscopy, and Josephson junction physics, but the apparatus for each of the experiments has failed (or become obsolete). The replacement cost of this equipment would exceed our current operating allowance. In the longer term, we would like to introduce experiments and techniques that reflect more current trends in such areas as nanotechnology, modern optics and current methods in particle-physics instrumentation. These needs will make it necessary to seek additional funding for the teaching labs.

General Education Courses

Over the past decade, we have become increasingly aware that the public at large, the College, and the Department can benefit from undergraduate physics courses designed specifically for the large population of non-science, liberal arts majors. The General Education Committee has promoted and maintained a stable of liberal-arts outreach offering over the past few years. These currently include: *Light & Color* (Physics 214), *Physics of Music* (Phys 207), *Science and Society* (Phys 216/SIS 216). *A Way of Knowing* (HA&S 220/CHID 270 — sponsored by Physics), and Liberal Arts *Physics* (Phys 110). These General Education courses, with enrollments between 30 and 100 students, are enthusiastically supported by the subscribing students as well as by the faculty who teach them. At the Spring 2007 Symposium on Teaching and Learning, UW's Executive Vice-Provost departed from her prepared remarks to highlight the novel aspects of the renovated Phys 216. Student interest in Phys 110 has recently expanded to the point where enrollment was closed for lack of space a few days after registration opened.

In addition to retaining the existing General Education courses, the Committee has decided to develop a new class of courses that provide physics-oriented educational outreach to larger numbers of non-science majors. To that end, the Committee submitted a proposal to the Chair in June 2006, which was subsequently approved by the Department's Curriculum Committee and Executive Committee. No detailed curriculum for these courses has yet been defined. The Committee is attempting to establish a sustainable process and an open-source library of resource materials as structural support for motivated faculty to develop a succession of General Education Courses. It is anticipated that they will follow loose guidelines that the Committee sets out and evolve in a direction that improves the effectiveness of this outreach effort.

The Committee proposes to launch an experiment that is in keeping with the principles of open-source development. Only the nature and general form of the experiment are specified. The details will become apparent as the first faculty participant, Jeffrey Wilkes, assisted by the Committee, develops the initial offering. The Department will provide an incentive in the form of release time for the initial course construction and implementation. Initiating and building the open-source library may require such incentives for the first several faculty participants. Beyond this startup phase, it is anticipated that the process will be largely self-sustaining — an outcome that will have to be demonstrated.

A concept central to the proposal is that lectures should not follow the linear, sequential character of typical physics courses (including Phys 110), in which comprehension of each lecture depends on the retention of details from preceding sessions' content. As in a typical evening lecture series, it is hoped that individual lectures will be comprehensible. One important goal is to spin off such evening lecture courses, thereby expanding this outreach effort into the broader non-student community.

Biophysics Courses

In recognition of the growing interest in biophysics and the fact that six members of the faculty spend at least part of their time doing biophysics the Department has introduced a Senior level course: *Biophysics* (Phys 429). Originated by Michael Schick, the course is being further developed by Gerald Miller who is teaching it this year.

Chapter 4

Research

4.1 Atomic Physics

The UW was long considered one of the best places in the US for atomic physics. Then with gradual attrition, including the retirement of Nobel Laureate Hans Dehmelt, the UW Atomic Molecular Optical (AMO) group entered a precarious phase. Now the group is rebounding, with the addition in the past 3 years of 2 junior faculty, Boris Blinov and Subhadeep Gupta, who have brought with them 2 of the most active areas in atomic physics, quantum information and quantum degenerate gases, to go with the existing – and still thriving – precision measurements research in atomic electric dipole moments and optical clocks. To maintain this resurgence and completely regain a position of leadership in atomic physics, it is important that: 1) The junior faculty secure reliable funding, 2) The ongoing program in high precision AMO be enhanced, 3) New ideas for broader initiatives continue being pursued vigorously, and 4) The department add one, possibly two, new AMO experimentalists and an AMO theorist over the next 5 years

Brief History

A unifying theme in the UW atomic physics program has been precision measurements of basic forces. There have been two main branches: 1) Trapped ion research pioneered by Dehmelt and colleagues, leading to ultra precise measurements of the electron and positron g factors, atomic masses, and atomic ion transitions for optical clocks; and 2) atomic probes of electroweak physics and possible new physics such as supersymmetry through measurements of atomic parity violation and the most precise searches yet for a permanent edm. The UW program over the years has left its mark on AMO physics and on the AMO community as grad students and postdocs moved on to positions elsewhere. For example, Dave Wineland, Jerry Gabrielse, Mike Romalis and Steve Lamoreaux are internationally recognized AMO leaders who spent their major formative years here. Overall, among former grad students and postdocs in this modest-sized UW program, 3 are members of the National Academy of Sciences (NAS), 19 have become faculty members at universities or liberal arts colleges (including Harvard, Princeton, Yale, Williams and Swarthmore) and 13 have attained coveted permanent positions at National Institute of Standards and Technology (NIST), Jet Propulsion Laboratory (JPL) or National Labs. Parts of the UW heritage – atomic edms and optical clocks – remain vital ongoing local programs today, which together with the new activity of Blinov and Gupta will define the future direction of AMO at the UW.

AMO Faculty

Projected AMO faculty strength without further additions is between 2 and 3 state faculty positions and one grant-funded senior research position. In addition to Blinov and Gupta, the state faculty include Blayne Heckel, who devotes crucial but part-time effort to AMO, and Bob Van Dyck, who is terminating his research and thus ending an extraordinary run of world famous $g - 2$ and atomic mass measurements at the UW. Fortson, though retired, continues his hight level of activity. In senior research positions, new Senior Research Scientist Tom Loftus brings needed strength in precision measurements and atomic clocks, but Research Professor Warren Nagourney lost his funding, and is on leave this year with only a small chance of staying on next year.

Funding

Overall AMO grant funding has dropped considerably from former times, but there remains a substantial NSF grant which has been renewed for decades; currently it is \$ 330K/year led by Fortson as PI and Heckel and Nagourney as coPIs now beginning its 3^{rd} of 4 years. Fortson, Heckel, Loftus, Blinov, and Gupta may all join forces next year to propose renewal of this grant for another 4 years, with reasonably good prospects to continue at the current level of support.

Meanwhile, Blinov, Gupta and Loftus separately have substantial proposals under consideration by the NSF this year. In addition, Blinov, Gupta, Loftus and Fortson are joining with counterparts in Chemistry on an NSF major instrumentation initiative, with long-range plans for an ambitious interdisciplinary program in ultrafast optical science, including a frequency comb for optical clocks.

Students

Over the years, as described above, atomic physics has attracted a number of outstanding graduate students and postdocs. In the past year there have been 4 AMO PhDs awarded (2 of them under Fortson – making a career total of 26 for him). The field remains attractive to students; Blinov has 5 graduate students working with him, and Gupta, in his first quarter, already has applicants.

Current research and future directions

1. Electric Dipole Moments (edms) and clocks

   Fortson, Heckel, Loftus, and Blinov are engaged in ongoing studies of parity and time reversal and optical atomic clocks focus on three related areas: 1) improving the search for the ^{199}Hg electric dipole moment (edm) to higher precision than the world leading 2001 UW limit (2 x 10^{-28} e-cm) in order to probe Supersymmetry and other theories of physics beyond the Standard Model; 2) developing the current experiment with single ^{137}Ba^{+} ions to produce an ultra-precise optical clock and also measure the ^{137}Ba nuclear octupole moment; and 3) building on previous UW studies of cold Yb atoms in order to conduct frequency comparisons of the ^{137}Ba and ^{171}Yb optical clock transitions at the parts in 10 ^{17} level with a view to searching for time variation of alpha and other fundamental constants.

2. Quantum information

   Blinov is engaged in quantum computation and information is an active and rapidly growing area of physics research. Quantum computers and quantum communication systems have many unique features which make them important for fundamental physics research, computer science, and national security. Blinov is implementing plans to use individual atoms as quantum bits ("qubits") and interface these atomic qubits with single photons to enable quantum computation and to transfer quantum information over long distances. One test will be transmission ("teleportation") of a coherent single-ion state from PAB across campus to CENPA.

3. Quantum degenerate gases

   Gupta is engaged with the recent progress in the production and manipulation of ultracold and quantum degenerate gases which has opened up opportunities to improve atomic physics measurements as well as explore model condensed matter systems. Gupta is constructing an ultracold atoms apparatus in which two atomic species (lithium and ytterbium) can be cooled and trapped simultaneously enabling studies of multi-component degenerate systems and allowing for the production of ultracold heteronuclear dipolar molecules. Such molecules present major scientific possibilities including explorations of novel quantum phases and improved tests of fundamental symmetries. Gupta's future research interests include ultracold atom interferometry heading toward a precision test of Quantum Electrodynamics (QED) by carrying out an independent measurement of α to compare with $g-2$ measurements.

Summary

With the new research of Blinov and Gupta added to ongoing atomic experiments here (some still called "the gold standard" by outsiders) the department is in a good position to continue building a broad-based AMO program and attract new outstanding AMO experimentalists to replace

4.2 Biological Physics

Free energy of protein interactions

Gerald Miller is extending his research interests beyond nuclear theory (Section 4.9) to medical and biophysics. This activity started with the funding of a 2005 request for a supplement to an existing National Institute of Health

(NIH) grant (of PI K. Bomsztyk (UW Med School). Prof. Hong Qian, (UW Applied Mathematics) and a supported graduate student also participate. The aim of our proposal is to develop a mathematical and physical analysis to better understand the interaction between proteins in the cell. The ultimate goal is to describe and predict the details of how DNA controls cellular behavior. As first step, we have originated a model, based on free energy, that describes the statistical properties of the interactions between proteins.

"Free-energy distribution of binary protein-protein binding suggests cross-species interactome differences"

Major advances in large-scale yeast two hybrid (Y2H) screening have provided a global view of binary protein-protein interactions across species as dissimilar as human, yeast, and bacteria. Remarkably, these analyses have revealed that All species studied have a degree distribution of protein-protein binding that is approximately scale-free (varies as a power law) even though their evolutionary divergence times differ by billions of years. We developed a detailed mathematical model of the protein-protein interaction network based on association free energy that reproduces the degree distribution of all of the large-scale Y2H data sets available, and allows us to extract the distribution of free energy, the likelihood that a pair of proteins of a given species will bind. We find that across-species interactomes have significant differences that reflect the strengths of the protein-protein interaction. Our results identify a global evolutionary shift: more evolved organisms have weaker binary protein-protein binding. This result is consistent with the evolution of increased protein unfoldedness. We also applied the model to compute clustering coefficients which describe the interactions between three proteins. We reproduce all available data and also show that models with essentially the same degree distributions can have very different clustering coefficients.

Future Plans

The next step involves finding mathematical ways to exploit data obtained using very new and exciting techniques that Dr. Bomztyk has developed in his laboratory. He is studying the time-dependence of the transcription process (how DNA makes RNA that eventually makes protein). We are developing a quantitative model, based on solving the Fokker-Planck equation, to reproduce the time dependence and eventually codify how DNA works to make different proteins.

A compeletely different project is "Radiative Transfer Equation Images the Human Body Using Diffuse Optical Tomography to detect cancer" This is the title of a proposal I am developing. The Boltzmann equation technology in this problem is the same as we are using in heavy ion nuclear physics. Diffuse optical tomography (DOT) is a new novel method for functional imaging of human tissue by continuously monitoring blood oxygenation levels. This could be very useful for tumor detection and brain imaging. Noninvasive-infrared light is used. This light propagates in complicated ways. Therefore developing fast and robust reconstruction methods is the main challenge in making DOT a viable tool for clinical diagnostics. This proposal is concerned with improving the model of light propagation by improving the fundamental equations and the speed and accuracy of their solutions. I have initiated discussions with experimentalist Xingde Li, Bioengineering, who has indicated precisely what computations need to be improved by future theoretical work.

Biological Lipids[1]

Ten years ago, I was working on block copolymers, particularly on their modulated phases. I realized that biological lipids displayed the very same phase behavior as block copolymers. Believing that the biological community did not know a great deal about the methods of polymer physics, I decided to apply my knowledge to systems of biological lipids. The first major publication in this area was in the year 2000. I continued along twin tracks of investigating block copolymers, and biological systems.

The major projects in the study of block copolymers was, first, a consideration of the defects which occur in their ordered structures and second, the effect of an electric field on their patterns. This is particularly important as an electric field is often used to align the randomly oriented domains of ordered structures for technical applications.

The major project in biological systems was the study of the fusion of biological membranes, one which I consider to have been very successful. The most recent paper in this series, on the fusion of small vesicles, was just accepted for publication in Biophysical Journal. I believe that we have brought a new level of understanding and of rigor to this important field.

[1] This work is done by Michael Schick.

The other major project has been the study of organization in lipid bilayers, such as the plasma membrane. This continues in close collaboration with my colleague in Chemistry, Sarah Keller.

I am particularly proud of the fact that I pioneered an introductory course in Biological Physics which I taught on four occasions. The last time, there were twenty students registered and about twenty-five actually attending. The Physics Department and University have now approved it to be part of the regular curriculum, Phys. 429 Biophysics.

I am a member of the Oversight Committee for the Max Planck Institute in the Physics of Interfaces, Teltow. I am also the United States representative to the C3 Commission to the International Union of Pure and Applied Physics.

In the last ten years, I have published forty-three papers, mentored two undergraduate students, four graduate students, and six post-doctoral fellows.

Neurological Physics[2]

The human brain is arguably the most complex structure known to mankind. It is on the verge of starting to grasp its own inner workings. The physics and the technology of the brain speaks to everyone's imagination. It dominates popular science, even over quantum mechanics, string theory, and cosmology. Physics currently has a large fraction of its practitioners working on complexity with some success. What could be more natural than for physicists to turn their attention to the most complex structure we know?

By physics standards, the current experimental work on the brain as a synergistic complex system is primitive, and most associated theoretical work lacks physics sophistication. There is clearly a tremendous opportunity here for both experimental and theoretical physicists. Understanding the brain will clearly require physics. Understanding the physics of the brain will clearly enrich physics. The proper domain of physics is to understand all natural phenomena – that's why Newton called it Natural Philosophy. We have discovered that there is real physics to be done on the brain today and tomorrow.

How does the brain compute? How fast does it compute? Stimulated by mentoring Kai Miller – an extraordinary M.D./Ph.D. student in physics – we

[2]This work is done by Marcel den Nijs and Larry Sorensen.

have crucial new information and an exciting new approach to these age old questions. Ever since the first studies of electroencephalography (EEG) in 1936, the study of the associated electrical activity of the human brain has focused on its prominent low-frequency features. This has been like trying to understand the operation of a computer by studying its reset signals. Traditional EEG studies have only studied these signals up to 100 Hz. Kai discovered that these signals persist up to beyond 1 kHz. More importantly, these high-frequency components increase when the brain is computing. The low-frequency components paradoxically (until now) decrease when the brain is computing. Kai has already demonstrated that his high-frequency signals provide the best brain computer interfacing (BCI) now in existence. More importantly, these new signals provide the opportunity to learn completely new information about the operation of the brain. Everything that has been so extensively – and so dissapointingly – studied in the low-frequency region (power spectra, cross correlation, evoked response, $\cdots$) must now be studied in the high frequency region where the signal make sense. This is our agenda.

The core of the collaboration is the experimental set-up involving patients with electrocorticographic (ECoG) arrays placed directly on their cortex. ECoG records changes in the power of specific spectral bands in a local area of the brain associated with specific tasks. The subjects are epilepsy patients waiting for surgery (at Harborview and Childrens Hospitals). They have volunteered to participate in these task specific tests. The set-up is similar to conventional EEG, but there the electrodes are placed outside the brain on top of the skull. The ECoG signal is 100 times stronger, probes local brain areas, and has opened a completely new band of frequencies, above 80Hz all the way to and beyond 1KHz. The ECoG electrode array allows us to examine specific tasks – for example, we separate and study the brain's computation signals that control the movement of each finger.

The neuroscience ECoG interdisciplinary group at the University of Washington has a rapidly increasing foot print within the Physics Department. It is a close collaboration between us, Jeff Ojemann (Department of Neurological Surgery), and Rajesh Rao (Departments of Computer Science and Electric Engineering). The group also involves one postdoc and several graduate students based outside Physics. This collaboration brings together expertise in: neuro surgery (Jeff Ojemann), in electric engineering (Rajesh Rao), in experimental physics (Larry Sorensen), and in strongly correlated statistical physics phenomena (Marcel den Nijs). We maintain connections with the broader neuroscience community at the UW, in particular with

Eberhard Fetz and Adrienne Fairhall (both in Physiology/BioPhysics). Our focus shifts back and forth between clinical issues, engineering issues, and fundamental physics issues. Our current "power law in the brain project" (with overtures to scale-free network-type statistical physics) is new physics at the PRL level. The research funding for this effort currently comes from outside the Physics department, except for summer salary support for Marcel, derived from his own statistical physics NSF grant.

Any Physics department, embedded in a university like ours, with such strong biological and medical research programs, should be eager to explore the new frontiers of physics that are being born in the overlapping interdisciplinary areas. We strongly believe that our department should include experimental and theoretical neuro-physicists in its future faculty searches. Superb physics will be done by excellent young physicists in these areas.

The study of the brain is posed on the brink of a revolution. Physicists have great potential to facilitate and participate in this revolution. Both our world view and our expertise (experimental and theoretical) are essential. In his epilogue, Feynman tells his students: "you may want to join in the greatest adventure that the human mind has ever begun." The physics of the brain is certainly such an adventure. Our future looks very interesting and exciting.

Nanopore Sequencing

In the last few decades the life sciences have undergone a major transformation from being phenomenological science to being a quantitative information science. The ability to sequence DNA has played a key role in this transformation. At the same time, a variety of methods and tools that originated in physics have contributed to this transformation by enabling the study biological processes at molecular sizes and time scales.

Research at the University of Washington and at a variety of local institutes and companies has made the Seattle area a hub for this biotech revolution. The Physics Department should participate in the enormous opportunities that this exponentially growing field offers to us by initiating and supporting biophysics research. The Department has to integrate itself in the Universities interdisciplinary academic community in both research and education. Motivated by intellectual interest and ever-growing job prospects, both the undergraduate and graduate student community within the Physics Department has expressed a strong desire to study biophysics.

In the 2002 Jens Gundlach, together with graduate student Tom Butler, launched an experimental biophysics research project. Gundlach and Butler set out to investigate a system wherein single stranded DNA (ssDNA) is electrically driven through a small nanometer-sized pore. This process can be observed at the single-molecule level because entry of ssDNA into the pore causes a measurable blockade of an ionic current that is also being driven through the pore by the applied electric field. Single stranded DNA has nearly the same cross-sectional diameter as the pore, so the nucleotides must pass through the pore in a sequential, single-file manner. The small remaining ion current that flows through the pore during DNA passage has sensitivity to the DNA's nucleotide composition. A Harvard/UC Santa Cruz/NIST research group had realized such a system in 1996 using α-Hemolysin, a naturally occurring protein pore that was embedded in a lipid bilayer membrane.

The project got its start when Tom Butler was awarded an IGERT Nanotechnology fellowship to explore the nanopore-DNA system. The group found enthusiastic interest and intellectual support from various departments on campus. Gundlach and Butler formed an interdisciplinary collaboration with Mark Troll, who held a research appointment in the Microbiology and Electrical Engineering departments. Using loaned equipment, parts built at CENPA, and equipment purchased with a $3000 allocation that came along with the Nanotechnology fellowship, they set up their nanopore apparatus in Mark Troll's lab in the Health Sciences building. They soon learned how to conduct the delicate "single channel" experiments. In 2003 Gundlach received an UW internal $30,000 research grant through Royalty Research Fund award and in 2004 Gundlach was given $75,000 startup support through the Physics Department.

The new group's first scientific contribution was made by recording and comparing signals from entirely homogeneous RNA molecules and RNA molecules consisting of two distinct homogeneous regions within a single molecule. The group was able to demonstrate that the current signal of RNA homopolymers is strongly dependent on the directionality (3' to 5' vs. 5' to 3') of the RNA molecule during translocation. This result was published in the Biophysical Journal, a primary journal in the field.

The group then published a second paper in the Biophysical Journal that involved a detailed investigation of a highly prevalent partial current blockage that had been neglected by all previous studies. They demonstrated that this partial blockage can be attributed to ssDNA molecules residing in a "vestibule" region adjacent to the entrance to the protein pore. A kinetic model of the pore-DNA interaction provided a very nice description of the trends in the data and provided new insight into the microscopic mechanisms governing the process. A detailed understanding of the mechanisms governing the dynamics of single biomolecules in nanoscale systems, such as can be derived from the nanopore/DNA experiments, is of fundamental importance to modern life sciences.

In 2005 the UW nanopore group made contact with a group at the University of Alabama, Birmingham, led by Michael Niederweis. Michael Niederweis and his collaborators had just published the structure of a newly discovered protein pore called MspA. The UW nanopore group realized that the hour-glass-shaped geometry of MspA appeared far more conducive to sequencing than α-Hemolysin, which has a narrow, $\sim$5 nm long cylindrical channel spanning the bilayer. MspA has an equally narrow constriction but it is only $\sim$1nm long, presumably increasing MspA's spatial resolution. Initial experiments conducted by the UW team showed that ssDNA would not pass through naturally occurring "wild-type" MspA pores. Negatively charged amino acid residues near the constriction and at the entrance of the pore prevented the negatively charged ssDNA from approaching and translocating through the pore. A collaboration was formed with Niederweis' group to engineer MspA by mutagenesis. This biological technique involves the replacement of any amino acid in the pore by a different amino acid, making it possible to modify the geometry, charge distribution and hydrophobicity of the pore at the sub-nanometer level. A joint proposal with Gundlach as PI was submitted to the NIH and funded ($606K for 2 years). Recent experiments indicate that the group has successfully engineered and MspA mutant that allows ssDNA translocation. They have found that the kinetic approach used to interpret their previous α-Hemolysin experiments is also applicable to the MspA mutant system. These results are being written up for publication and the collaboration is now concentrating on further developing the MspA pore for DNA sequencing and other single molecule detection applications.

In collaboration with CENPA a low-noise, high-bandwidth amplifier has been developed for use in the single molecule nanopore experiments. An evening master's student helped to characterize the amplifier's performance, and it appears to significantly exceed that of commercially available devices.

Early in 2007 the group moved into a laboratory in the basement of the Physics/Astonomy Building. Tom Butler graduated in Spring 2007 and he may perhaps be the Department's first PhD in experimental biophysics with

Physics faculty advisor. Tom Butler accepted a post-doc position with the nanopore group. Physics Graduate student Ian Derrington joined the team in 2007. The group has had 2 summer NSF-REU students, one Amgen Summer Student, and has currently three undergrad students taking independent studies (one of whom received a Mary Gates Scholarship). Furthermore the group has one master student and has one undergraduate lab assistant.

4.3 Condensed Matter Experiment

The CME group consists of five tenured faculty members (in alphabetical order, David Cobden, Samuel Fain, Marjorie Olmstead, Gerald Seidler and Larry Sorensen). Its faculty count has decreased from seven members in 1997 to its current size due to the retirement of Stern, Ingalls and Vilches, with the addition of Cobden. The tenured faculty with their graduate students has been and is engaged in research on several areas, which are detailed individually below. In addition, the CME group has been one of the largest supporters of, and providers of guidance for undergraduate research projects, and for projects for the MS in Applications of Physics. The CM experimentalists share many common interests with the CM theory group (separate report), with strong collaborations between subsets of members of both groups as well as with some of the Adjunct faculty in other Departments of UW.

Faculty Research Activities

Cobden came to UW as an Assistant Professor in 2001. His research in the main has involved using electrical transport through nanowires and carbon nanotubes to investigate a number of fundamental physical phenomena, including the Kondo effect, spin properties of one-dimensional quantum dots, the Luttinger liquid state, charge pumping, nonlinear magnetoresistance, and phase transitions in reduced dimensions. To start his program he had to build from scratch a laboratory to synthesize nanotubes and nanowires, plus acquire optical, electronic, and variable temperature facilities to do his measurements. In the coming years the work is expected to focus increasingly on nanostructures and interfaces of strongly correlated materials and to involve optical and other probes complementary to electrical transport, as well as on the interplay between electrical and elastic properties of carbon nanotubes with various physisorbed atoms and molecules (in collaboration with Vilches)

Fain's research has been on ice dynamics near – 5^oC, crystalline cluster growth near 133^oK on amorphous ice surfaces, Pd cluster growth between 300 and 800^oK on alumina single crystals, and quantitative understanding of scanning force microscopy techniques. A new surface science facility with sample preparation, x-ray photoelectron and ion scattering spectroscopy, low energy electron diffraction, and scanning force and tunneling microscopy has operated in his lab since 2001. Olmstead and Fain and adjunct faculty Ohuchi and Campbell supervise students and postdoctoral fellows using this system. Data obtained on this system has been a major component of five Ph.D. theses and more than a dozen journal publications.

Olmstead continued her collaboration with Adjunct Prof. Fumio Ohuchi to study heteroepitaxial growth of dissimilar materials and the resultant properties of these structures. Notable accomplishments in the past 10 years include development of epitaxial semiconducting layers of GaSe on Si, work described in 8 Ph.D.'s and 17 original publications.

Seidler came to the UW as an assistant professor in 1996 and participated in the construction of sector 20 (now PNC/XOR) of the Advanced Photon Source. He was promoted to associate professor in 2002. His group has recently completed construction and commissioning of the LERIX spectrometer, a world-class inelastic x-ray scattering instrument now available to general users at the Advanced Photon Source. His group is using LERIX to study magnetism and orbital hybridization in f-electron systems, the local electronic structure in III-nitride compounds, and applied problems in battery technology and in soot formation from the combustion of hydrocarbons.

Sorensen's group developed new state-of-the-art coherent x-ray scattering techniques and did pioneering experiments using them. They studied liquid crystals and modern (perpendicular) magnetic disk drive materials. The liquid crystal measurements were in the time domain and set the world's record for high-speed photon correlation spectroscopy. The magnetic film measurements were in the space domain and pioneered the use of x-ray speckle to study the effect of nanoscopic disorder on magnetic memory. He is involved in an incipient group studying neural networks. His contributions to the evening MS program have been very extensive, having supervised 35 MS research projects in the last 10 years. Larry has supervised 6 PhD students and has 21 original publications.

Emeritus and Adjunct Faculty

The CME Emeritus faculty consists of five members, Frederick Brown,

J. Gregory Dash, Robert Ingalls, Edward Stern and Oscar Vilches. Dash, Stern and Vilches remain active in research but are currently not chairs of PhD students supervising committees. Dash is working on ice growth, wetting, one-dimensional solids and supersolid helium, collaborating with Vilches in experimental physisorption studies. Stern's activities include continuing contributions toward a time-resolved XAFS facility at the Advanced Photon Source. He has a new NSF grant focusing on a new technique to minimize radiation damage effects in protein crystallography using synchrotron x-ray sources. Vilches, the most recent retiree, has studied the phase diagrams of two-dimensional helium isotopic mixtures, and the thermodynamics and structure of films physisorbed on carbon nanotube bundles. His current work involves the study of the structure of Ne films adsorbed on carbon nanotube bundles using neutron diffraction and the adsorption of gases on single carbon nanotube devices (in collaboration with Cobden).

A relatively large number of adjunct faculty in other UW Departments (see list elsewhere) offer some possibilities of different CM areas of research for graduate students and collaborative work. Several Physics dissertations have been completed under the direction of adjunct faculty (see list below). The Olmstead-Fain-Ohuchi and the Olmstead-Krishnan collaborations have been close enough to generate joint federal funding. Sarah Keller in Chemistry has been particularly involved with students wanted to address issues in soft condensed matter.

Regular and adjunct CME faculty [Olmstead, Fain, Vilches, Vogel (then Adjunct Associate Professor) and Campbell] were instrumental in the creation of the UW Center for Nanotechnology. Olmstead serves currently as the director of the Nanotechnology PhD program.

Staffing History and Needs

The predictions for this group in the 1997 ten year review report came to pass. Stern, Ingalls, and Vilches retired, with Stern and Vilches currently remaining engaged in research and being PIs of grants. Ingalls taught, and Vilches is teaching part-time under the State 40% rehire policy. During the same period one CM experimentalist was hired, David Cobden. The CME faculty is now down to five members in the State line positions. At least one of them, Fain, is likely to retire in the next 10 years. Given that CM experiment is the largest area of physics worldwide, the most likely to induce collaborative research partnerships with engineering, biophysics and applied sciences, a possible nucleus of strong collaborations for future Materials Research Initiatives, and a very strong provider of projects for undergraduate research, and MS and PhD graduate projects, it has become urgent that the CME faculty count in Physics be increased (see Vision statement below).

Vision Statement

An emerging theme in condensed matter physics is nanoscale studies of materials with strong electron-electron correlations, in particular oxides, including high-temperature superconductors, magnetic layers, and materials exhibiting electronic phase transitions. Over the next decade the extended CME group (including adjuncts in the School of Engineering)intends to focus increasingly in this area of huge opportunity. As the fields of nanotechnology and correlated materials have approached each other, many interesting questions have arisen concerning such things as spontaneous nanoscale structure in correlated electronic phases; effects of dimensionality on correlations; new correlated phases occuring at interfaces; and the combination of mesoscopic effects with strong correlations. Our current expertise at UW includes synthesis of nanoscale systems and films of oxides and magnetic materials; nanoscale transport, optical, scanning probe, and X-ray scattering techniques; and theory of mesoscopic physics. To become leaders in this new field it is of great urgency for us to add an experimentalist with extensive experience in fundamental measurements of correlated materials. In addition, adding local expertise in crystal growth, neutron scattering, high speed optics, microwave studies, and theory of strong correlations, would be highly desirable.

A list of students in the all groups is available in Appendix 9.6, page 188.

4.4 Condensed Matter Theory

The Condensed Matter Theory (CMT) group consists of five tenured faculty members (in alphabetical order, Anton Andreev, Marcel den Nijs, John Rehr, Michael Schick and Boris Spivak) and one Emeritus Professor (David Thouless). The group has been very successful during the past ten years; all faculty are funded and support a number of graduate students. The overall funding level for the group is currently around $ 800,000 per year. The group currently supports 10 graduate students and 2 postdocs. It has graduated

19 Ph.D. students and supervised 13 postdocs, two undergraduate students over the past 10 years.

In addition to their individual research programs, CMT faculty have been and are interacting closely with members of CME group and with other Departments. David Cobden has had close collaborations with Boris Spivak on nonlinear transport in carbon nanotubes and metal-insulator transition in vanadium oxide nanostructures and frequent interactions with Anton Andreev on these subjects. Marcel den Nijs collaborates with Larry Sorensen and Jeff Ojemann (UW neuro surgery) on electromagnetic response of neurons in a human cortex. Michael Schick and Sarah Keller (UW Chemistry) hold regular joint group meetings because of a shared interest in biological membranes. John Rehr has close collaborations with Jerry Seidler and Ed Stern on x-ray physics and with faculty in Chemistry and Materials Science on photonics, in addition to occasional interactions with Sam Fain, Marjorie Olmstead and Larry Sorensen and others in the Department. The individual activities and accomplishments of CMT faculty with their graduate students and postdocs are listed below.

Staffing History and Needs

Although our group is now very strong nationally, its most distinguished member David Thouless has recently retired, and only one junior hire (Anton Andreev) has been made during the last ten years. Now only two out of the five tenured CMT faculty are under the age of sixty, and within the next ten years two or three retirements are anticipated. Thus in order to maintain the current excellence of the group in this important and diverse field of theoretical physics, a minimum of three CMT hires must be made over the next ten years.

Vision Statement

Condensed matter theory is the largest branch of theoretical physics and is very closely tied to experiment. Of all the branches of theoretical physics, it has always shown the greatest potential for technological applications. The field deals with systems with a complexity and an abundance of regimes that result in a wealth of phenomena and sometimes renders their microscopic description intractable. The area encompasses a diverse range of topics including statistical physics, physics of ultra-cold atoms, biophysics, nanoscience, strongly correlated materials, magnetism, liquid crystals, and polymers, the interaction of radiation with condensed matter and biological tissues. These are all exciting areas in which rapid progress is being made. A hire in any of these sub-fields would strengthen our Department and foster fruitful collaborations within Physics and with other departments on campus.

Historically the strength of condensed matter physics at UW was built on close interactions between theory and experiment *e.g.*, in the field of critical phenomena and phase transitions, involving interactions between Greg Dash, Sam Fain, Marcel den Nijs, Michael Schick, John Rehr, Eberhard Riedel, and Oscar Vilches. We aim to continue this tradition, and believe that one of the areas where a similar synergy between CME and CMT can be built centers on the nanoscale studies of materials with strong electron-electron correlations. This is an emerging theme in condensed matter physics nationally and also one of the central themes of future CME activity at the UW (see CME statement). Indeed, interaction between theory and experiment is very important in this emerging field, and we expect that at least one CMT hire will be made in the area of strongly correlated electron physics. Moreover this is an area where high performance computing is likely to have an important role in the future. Although strongly correlated systems are a CMT focus area we are committed to hiring the strongest candidate, as we have done in the past. Due to the relative flexibility of theorists and the rapidly changing importance of the various sub-fields, we believe that a candidate's quality and potential can be more important than the particular area of interest at the time of the hire and all theory hires should be made in broad searches. This ensures the quality of candidates by relieving the pressure on a group to hire in a particular year when the search is authorized.

Faculty research activities

Anton Andreev

Andreev's research focuses on the theory of electron transport in mesoscopic and disordered systems, theory of speckles of coherent waves propagating through random media, and Coulomb blockade devices and other low-dimensional electron systems. Over the last ten years he published over 30 papers.

The main research achievements over the reporting period include: the development of the Schwinger-Keldysh formulation of the nonlinear sigma-model for disordered metals, development of the theory of thermoelectric phenomena in Coulomb blockade devices at strong tunneling, a development of the theory of nonequilibrium oscillations in cold Fermi gases in the narrow Feshbach resonance regime, development of phenomenological theory of the zero-resistance state observed in AC-driven two-dimensional electron gases, development of Langevin description of speckle statistics of directed waves.

Awards: Packard Fellowship, Sloan Fellowship, NSF CAREER award, undergraduate teaching award (UW Physics).

Marcel den Nijs

My research is centered in statistical mechanics and low dimensional quantum field theory, with applications to surface science, one dimensional quantum fluids/solids, and neuroscience. The most visible research achievements are: The discovery of disordered flat phases and preroughening phase transitions in crystal surfaces, and the topological off-diagonal long-range order of valence bond type quantum fluids in quantum spin chains (the "denNijs-Rommelse order parameter"). My study of roughening induced reconstruction transitions in crystal surfaces (as applied to Pt(110), *e.g.*). My role in the development of the theory of commensurate- incommensurate phase transitions in absorbed mono-layers; the discovery of the topological Chern number invariant in the integer quantum Hall effect (with David Thouless); and the development of the so-called Coulomb gas method, which provided the derivation of the exact scaling properties of most 2D equilibrium phase transitions (including the "den Nijs conjecture" for the thermal exponent Potts model and its descendants).

Since the mid nineties, my research has shifted to non-equilibrium driven stochastic processes. The central interests in such processes reside with the structure of non-equilibrium stationary (NES) states, the dynamical pathways to NES states, and the scaling properties of dynamic phase transitions. Driven stochastic processes often undergo dynamic phase transitions inside their NES states as function of control parameters, with intricate scaling properties both within the stationary state and in the time evolution towards it. Characterized by scaling dimensions, such as the dynamic scaling dimension z which specifies critical slowdown, the time required to reach the stationary state scales with system size, $t \sim L^z$. These properties tend to be universal. They can therefore be studied by models, using a mix of numerical simulations and exact analytic techniques, and the results can be directly compared to experimental data (*e.g.*, our slow bond ASEP results being directly applied to to flameless paper combustion experiments).

Specific recent research projects include: driven stochastic flow through channels (jamming phase transitions), directed percolation type population growth statistics, the solution of the even-visiting random walk, surface reconstruction in driven growing surfaces, relations between KPZ growth and self organized criticality (SOC) in the context of an unloading sand box model, and localization of polymers in quenched random media. Marcel maintains strong contacts and collaborations with the statistical physics community in South Korea (Korea Institute for Advanced Study and Seoul National University).

The research area of stochastic complex processes encompass the properties of so-called scale free networks, and SOC avalanche type processes. Right now, Marcel, together with Larry Sorensen, triggered by mentoring MD-PhD physics graduate student Kai Miller, is addressing such issues in the context of ECoG experiments in the brain (see independent neurophysics group report, 4.2).

John Rehr

Our research effort focuses on fundamental condensed matter theory, and aims at a quantitative understanding of electronic structure and many-body theory, using modern high performance computational techniques. Our effort is at the forefront in the emerging field of excited state electronic structure, which is central to the understanding of the interaction of electron radiation and matter, *e.g.*, in x-ray and electron spectroscopies. Over the past ten years our group has had a number of significant achievements. One major accomplishment was the solution of the XAFS problem based on the development of first principles x-ray and electron spectroscopy codes, which are now in use world wide. This theory required the practical implementation of a number of many-body techniques including inelastic losses and self-energy effects and excitonic effects (via time-dependent density functional theory and the Bethe-Salpeter Equation). Our accomplishments in this field were recognized by the International XAFS Society Outstanding Achievement Award in 2006. More recently we have extended our approach to treat x-ray magnetic circular dichroism, inelastic x-ray spectra, and optical spectra down to visible and UV energies including non-linear response, *e.g.*, for photonics applications. Our group was also the first to introduce high performance parallel computation into the Department and maintains two linux clusters. The combination of theory and computation has proved to be extremely effective and has generated many breakthroughs and significant support. Over the past ten years we have published over 100 papers in refereed journals and our works have over 10,000 citations. Our research is currently supported by a large grants from the DOE and additional grants from the NSF, NIST, and NIH/SSRL. I am also a Consulting Professor at the Stanford Synchrotron Radiation Laboratory, and I serve as co-Coordinator of the DOE Computational Materials Science Network.

Michael Schick

Refer to Section 4.2 for information regarding Michael Shick's work which is now focused on biological physics.

Boris Spivak

In the last ten years I was developing the following areas of the condensed matter theoretical physics.

1. Mesoscopic effects in metals

   (a) We showed that the resistance of mesoscopic metallic samples oscillates as a function of temperature. This effect has been observed experimentally.

   (b) We showed that Friedel oscillations of the electron density and spin density in disordered metals exhibit long range correlations.

   (c) We developed a theory of a mesoscopic mechanism of the adiabatic charge transport in disordered metals. This effect has been observed experimentally.

   (d) We developed a theory of the exchange interaction in ferromagnet-disordered metal-ferromagnet junctions. It has been shown that in the case when the thickness of the normal metal is larger than the elastic mean-free path the equilibrium relative orientation of the magnetization in ferromagnets is perpendicular to each other. The theory was done to explain experimental observations.

   (e) We predicted the existence of currents in conductors which are quadratic in voltage and linear in the external magnetic field. This effect has been observed experimentally.

2. Propagation of waves in disordered media

(a) We developed a theory of fluctuations wave speckles in the case of when a linear wave propagates in an elastically scattering disordered medium.

(b) We develop a theory of nonlinear coherent waves propagating in disordered samples and showed that at given incident wave on a sample a number of solutions of this problem increases exponentially as the sample size increases.

3. Theory of mesoscopic fluctuations in superconductors

   (a) We showed that the critical current of superconductor-insulator (normal metal)-superconductor junctions can be negative in the case when the electron-electron interaction in the insulator (metal) is repulsive and strong enough.

   (b) We showed that the zero temperature superconductor-metal transition as a function of the magnetic field is entirely determined by the mesoscopic effects.

   (c) We developed a theory of the zero-temperature quantum superconductor-metal transition as function of the disorder.

   (d) We developed a theory of the Hall effect in superconductor-normal metal junctions.

   (e) We developed a theory of mesoscopic effects in supercondictor-ferromegnet-supercondictor junctions. This theory has some experimental support.

4. Theory of phase separation in 2D electron system

   (a) We proved impossibility of of first order phase transitions in 2D transactionally invariant electronic systems with Coulomb and dipolar interaction and built a theory of micro-emulsion electronic phases.

5. Classical kinetics

   (a) We developed a theory of the magnetic-field dependence of the chemical reaction rates at room temperatures.

I am a member of the advisory board of the Pacific Institute of Theoretical Physics, Canada. I also serve on the Nanotechnology Advisory Panel to the Supreme Court of Canada.

In the last 10 years I received the following awards: 1997 Landau-Weizmann Prize for achievements in theory of disordered conductors (Israel). 2001 Kramers chair of theoretical physics, ITP (Utrecht, Holland).

David Thouless

The main component of my work over the past fifteen years has been on the dynamics of quantized vortices in superfluids, initially considered as semiclassical objects, although we had the ultimate aim of understanding their quantized motion. We (initially Ping Ao and myself, with considerable help from Qian Niu of the University of Texas) originally thought that most of the necessary understanding had been developed in the fifties and sixties, by such people as Hall and Vinen, Pitaevskii, Iordanskii, Fetter, Bardeen, De Gennes, and others. However we slowly came to realize that the consensus that had developed around 1970 was full of inconsistencies; these were brought home to us by a pair of referees, one of whom said that our paper was not worth publishing because the results were obvious and had been know for years, while the other said that it was not fit for publication because the results were known to be wrong.

We also went back to the old controversy between Bardeen and Stephen on one side, and De Gennes and Nozières and Vinen on the other, about the Magnus force in superconductors. By using methods similar to those we used for the neutral superfluid, Geller, Wexler and I got results that agree closely with those of Nozières and Vinen. However, like Nozières and Vinen, we assumed that the positive background was a uniform elastic medium, so the normal state resistivity would be zero. Rhee and I intended to follow this up for a more realistic positive background, and preliminary work on this was included in Rhee's dissertation. We later found that there were errors in this part of the dissertation, and both of us were too much committed to other things to pursue this work. It is my intention to pursue it fairly soon.

In 2003 James Anglin and I started discussing the question of whether one can usefully define a mass for a quantized vortex, and what its value is. There are statements in the literature that it is infinite for a neutral superfluid, and, in another well-known paper, that it is negligible. There is an important insight from our earlier work that seems to have been ignored in much of the literature, that one has to apply a force to counteract the Magnus force if one wishes to constrain the motion of a vortex. Various authors have pointed out that a moving vortex in unconstrained motion relative to the fluid moves in a spiral orbit and rapidly radiates its energy away as phonons. Anglin and I developed new methods and exploited some old ones to study this problem, and came out with some sharp conclusions, which were recently published. Our main conclusions were that, in agreement with earlier work, the finite bulk modulus of the superfluid leads to a logarithmic divergence of the vortex mass at low driving frequencies, and that, unexpectedly, the inertial mass is sensitive to the form of the driving force on the vortex, and diverges logarithmically as the range of the force goes to zero. Although we have published part of this work, we have actually only studies the low frequency limit of the driving force, but we think we know how to extend the study to nonzero frequency.

At the beginning of the period under review I completed and published my book on topological quantum numbers in nonrelativistic physics. I also published later and shorter reviews of this material in proceedings of Schools in Les Houches and in Lisbon at which I taught.

I have been quite deeply involved with two projects in areas in which my background knowledge is weak. The first was in plasma physics, and arose from Li-Jen Chen's unusually novel dissertation on solitons in plasmas. She had the main ideas right, but she needed to change some of the details before it was approved, and my expertise in classical self-consistent fields helped her to make these changes. We had great difficulty in getting this published, as one of the referees claimed, incorrectly, that the main ideas were already contained in one of his own papers, and wanted us to say so in the paper.

The other project was a key part of Ping Ao's work on dynamical systems subject to a steady state-dependent driving force and a time-dependent random force. Chulan Kwon and I argued that a much cleaner and more rigorous derivation was needed and available. It took us a long time to construct such a derivation, but it was eventually done.

Currently I am trying to apply my forty-five year old knowledge of quantum solids to the anomalous properties of solid helium first found by Eun-Ju Kim and Moses Chan three years ago. So far I neither have my own theory, nor believe the theoretical explanations of my colleagues such as Phil Anderson.

In the second half of next year I shall be at a Program at the Isaac Newton Institute in Cambridge on the Anderson model of localization in disordered solids, and one of my aims is to understand the influence of localization on the possible occurrence of supersolidity in quantum solids.

Two other problems that I want to work on are the effect of nonzero resistance on the transverse force on a vortex, and the mass of a vortex when it is subject to a driving force of nonzero frequency.

Relationships

A list of the collaborations of members of the Condensed Matter Theory group is given in Table 4.1.

Physics Faculty	Collaborator	Collaborator's Institute
Den Nijs	Hyunggyu Park	KIAS, South Korea
	Meesoon Ha	Kaist, South Korea
	Jussi Timonen	Jyvaskyla, Finland
	Jeff Ojemann, MD	UW Neuro Surgery
	Eberhard Fetz	UW Physiology and Biophysics
	Rajesh Rao	UW Computer Science and Electric Engineering
	Sara Keller	UW Chemistry
J. Rehr	R. C. Albers	Los Alamos
	E. Shirley	NIST
	Z. Levine	NIST
	H. Krappe	Hahn Meitner Institut
	B. Hedman	Stanford-SSRL
	K. Hodgson	Stanford-SSRL
	B. Robinson	UW Chemistry
	C. Luscombe	UW Materials Science
	A. Jen	UW Materials Science)
	G. Hug	ONERA, France
	M. Jaouen	U. Poitiers, France
	L. Campbell	PNNL

Table 4.1: Collaborations of Condensed Matter Theory group members.

Physics Faculty	Collaborator	Collaborator's Institute
M. Schick	D. Andelman	Tel Aviv
	S. Keller	UW Chemistry
	M. Mueller	Goettingen
	Igal Szleifer	Northwestern
	Yoav Tsori	Beer Sheva
B. Spivak	S. Kivelson	Stanford University
	B. Altshuler	Princeton University
	L. Levitov	MIT
	A. Zyuzin	Physics and Technics Institute, St. Petersburg, Russia
	O. Agam	Hebrew University, Israel
	E. Ivchenko	Physics and Technics Institute, St. Petersburg, Russia
	B.Pannetier	C.N.R.S. Laboratory, Universite Joseph Fourier, France
	D. Cobden	UW Physics
	A. Andreev	UW Physics
Thouless	Ping Ao	UW Department of Mechanical Engineering
	Qian Niu	University of Texas, Austin
	Michael Geller	University of Georgia
	Jean-Yves Fortin	CNRS, Lyon and Strasbourg
	Joe Vinen	Birmingham
	Moo-Young Choi	University in Seoul
	Chulan Kwon	University in Seoul
	James Anglin	Professor at Technische Universität, Kaiserslautern

Table 4.2: Collaborations of Condensed Matter Theory group members (continued from Table 4.1

A list of students is available in Appendix 9.6, p. 188.

4.5 Elementary Particle Experiment

The Large Hadron Collider (LHC), with its first collisions coming in 2008, will open unprecedented opportunities for unraveling the physics principles that govern nature at a distance scale of approximately 1 TeV^{-1}. Although continuing our strong involvement in the D0 experiment at the Tevatron, and planning for a possible Linear Collider, the focus of our Experimental Particle Physics group in the next ten years will clearly be the exploration of the discovery potential of the LHC data.

The group includes five teaching faculty, Burnett, Goussiou, Lubatti, Rothberg, and Watts; one research faculty, Zhao; four post-docs, Garcia-Bellido, Salamanna, Gaudio, Mal; two engineering staff members; four UW graduate students and students formerly from Anna's group. In addition several part time student employees and undergraduate assistants work with the group.

Due to the long lead time for many of the major efforts, the group has found it essential to participate simultaneously in two phases of typical high energy experiments: first, analysis of data from experiments in the "running" phase and second, preparation for the next major experiment involving detector development, construction, commissioning, and experimental design. This provides opportunities for students to participate in all phases of a modern high energy experiment without requiring that they spend an unusually long time to complete their research. The second component of our activities has taken advantage of the very high quality Machine shop and fabrication facilities at UW.

During the past decade the activities have centered on three experiments in different phases of operation: ALEPH at CERN/LEP, now completed; D0 at Fermilab, ongoing; ATLAS at CERN/LHC, construction and commissioning and about to run.

ALEPH at CERN

The 45 GeV electron-positron collider (LEP) at CERN allowed us to study the intermediate vector bosons Z^0 and the charged W boson. The Z^0 decays into all possible fermion-antifermion pairs including electron, muons, neutrinos, and quarks permitting a wide range of physics issues to be addressed with high precision. In a first result the number of neutrino types was established and many subsequent results confirmed the Standard Model of electroweak interactions. The UW group, together with three graduate students, produced a precision measurement of the tau lepton lifetime and studied several leptonic decay channels of the strange-carrying D meson, D_s. The collider (called LEP2 after the energy was increased above the W pair threshold) ran in a new energy regime never before accessible to electron-positron physics. Results were obtained on the W boson mass and limits on Higgs production and supersymmetry. Students were granted PhD's for work on the tau lepton lifetime and the decays of the D_s meson.

D0 at Fermilab

The physics activities were focused on the Single Top Analysis and the high $\tan\beta$ search for light Higgs produced with bottom quark pairs. Both were major analysis efforts, and both analyses resulted in published papers. The UW EPE group played a leading role in the single top analysis effort. The EPE group played a central role in D0's recent $3.6\,\sigma$ evidence for single top production at the Tevatron: Thomas Gadfort, a graduate student, lead the Matrix Element version of the analysis, Toby Burnett and Gordon Watts introduced one of the other analysis techniques (decision tree) to D0 and Aran Garcia-Bellido co-led the D0 working group through most of the grant period. The top quark was discovered in 1995 through pair production. It has been the subject of intense study since then: its high mass has led many to speculate that it is associated with the Higgs mechanism responsible for electro-weak symmetry breaking – one of the great open questions in particle physics. While the strong force produced the discovery signature, it has been known that the top quark could also be produced by the electro-weak force. This production mechanism is known as single-top production because only one top quark is produced in the final state. For the first time we have observed evidence for this production mechanism of the top quark. Single top production also allows us to make the first ever direct measurement of the V_{tb} matrix element of the CKM quark-coupling matrix. This measurement is just the beginning of an exciting top-quark research program. As we accumulate data we will be able to better probe top quark interactions for evidence of physics beyond the standard model and better constrain the as yet unobserved Standard Model Higgs. Observing single top production is also important because is it one of the last unmeasured backgrounds to the Standard Model Higgs.

While ATLAS and the LHC are the future of this group and collider physics, the Tevatron will continue to run for several more years. Our group has been involved in the D0 experiment at the Tevatron for over 8 years. D0 and the other Tevatron experiment, CDF, will continue to improve the world's best limits on W and top quark mass, various new phenomena model limits, and, of course, the Higgs search – all for the same reasons we are pursuing these topics in the ATLAS experiment. Our group's remaining effort on the Tevatron is focused on the last topic: the Higgs search. A. Goussiou has long been involved in Higgs searches at D0 and G. Watts has recently started working on Higgs searches after the evidence for single top quark work. At the very least we expect that the Tevatron will rule out low mass Higgs (below $120\,\mathrm{GeV/c^2}$) and also a region of high mass Higgs. Our significant investment and The Tevatron is most likely to shut down in 2009-2010, depending on the LHC's startup. Our involvement with the day-to-day activities of the D0 experiment will end shortly after that and our data analysis efforts as soon as our remaining students on D0 graduate.

The post-doc and students who have been part of A. Goussiou's group before coming to UW are being supported on start-up funds. They are becoming an integral part of our expanded D0 and LHC programs.

ATLAS at CERN (LHC)

ATLAS provides a unique opportunity to explore a new mass energy region with a center of mass energy of 14 TeV. It is generally believed that this energy region holds the key to understanding fundamental questions in particle physics: the mechanism for providing mass for the elementary particles and it is also a likely energy region to discover supersymmetric particles and other new physics.

The High Energy Physics group at UW fabricated 32,000 drift tubes for the precision muon chambers. The tube production facility (in the basement of the physics building) was designed by H. Lubatti and built under his direction. This design was adopted by the other US ATLAS muon tube fabrication sites (Michigan and the Boston Muon Consortium).

The UW group built 80 of the very large precision drift chambers (MDT chambers) for the endcap Muon system. The construction effort took place in the Physics building over an approximately three year period with heavy involvement of the machine shop. The construction and testing were carried out by engineers, students, and temporary employees under the supervision of Tianchi Zhao and Paul Mockett and Henry Lubatti. The group developed a very close working relationship with Prof. C. Daly of the University of Washington Mechanical Engineering Department who was an important member of the construction and installation team. Following completion of construction and preliminary tests at UW chambers were shipped to CERN. Mockett and the engineers spent over a year at CERN performing acceptance tests of the chambers and equipping the chambers with alignment devices, various services, sensors, and peripheral components. Beam tests of a set of chambers with muons (the H8 beam line at CERN) were carried out during 2002, 2003, 2004. Several of the UW chambers were permanently installed in the beam line and ran over many months. Tests were made on efficiency and tracking alignment. As a final step in the testing sequence the Muon chambers were run together with calorimeters and other components of the ATLAS detector in a so-called "combined run". Rothberg was a participant in all phases on the beam testing and took responsibility for readout, control, and monitoring of the optical alignment system.

For the past two years the major effort at CERN on the MDT chambers has been the assembly of the EM station chambers into sectors. Each of the 32 end cap sectors holds 5 chambers. The completed sectors, after final tests, were lowered into the experimental cavern and assembled into two wheels, one for each end of the cylindrical detector.

Several UW students who were in residence at CERN during summer 2006 participated in testing and assembly of the sectors. This phase was completed early in 2007 and work started on assembly of the smaller inner EI wheels. Participation by UW engineering personnel has been very important at all of these stages and is continuing. UW undergraduates have contributed to software development for the control of the optical alignment system and have also participated in assembly work. The software development work for control and monitoring of the alignment system is also ongoing.

During the past year several graduate students have begun work on physics analysis topics in preparation for data-taking. Three graduate students have been in residence at CERN since summer 2007 and are also participating in detector component testing and in the sequence of milestone cosmic ray runs. Two post-docs on ATLAS, Salamanna and Gaudio, are respectively, in residence at CERN or spending a considerable fraction of time there. Gaudio is heavily involved in performance monitoring (the GNAM project) and data quality while Salamanna is participating in the UW studies on the detection of highly displaced decays from BSM particles (Hidden Valley) and on muon tracking development.

Higgs Physics

A large part of our research interests consists of understanding the nature of the underlying mechanism of electroweak symmetry breaking, and the related issue of generation of mass. The prevailing theory that explains the above, both in the Standard Model as well as in the supersymmetric extensions of the model, is the Higgs mechanism. Thus, our research at the LHC will initially focus on the search for the signature particle(s) of the Higgs mechanism, the Higgs boson(s).

One of the most promising avenues for the Higgs searches at the LHC is exploring the $\tau^+\tau^-$ Higgs decay mode, thanks to the relatively clean signatures and small backgrounds of the $\tau^+\tau^-$ final states. Especially for the Higgs in the Minimal Supersymmetric Standard Model (MSSM), the $h/H/A \rightarrow \tau^+\tau^-$ decay mode offers the best discovery chances and covers the largest region of the MSSM parameter space. In particular, the Vector Boson Fusion (VBF) process ($qq \rightarrow qqh$) with $h \rightarrow \tau\tau$ offers the best chances for discovering the light MSSM Higgs (h), while the associated production of a Higgs with b-quarks ($gg \rightarrow b\bar{b}(H/A)$) with $H/A \rightarrow \tau\tau$ offers the best chances for discovering the heavy MSSM Higgs bosons (H/A). Our group brings in a lot of expertise with $h/H/A \rightarrow \tau\tau$ searches from the Tevatron, and will thus be in a good position to play a central role in the Higgs to $\tau\tau$ searches at the LHC.

Hidden Valley Physics

Our group has a very large effort also in searches for long lived particles at the LHC. A number of extensions of the Standard Model result in particles that have macroscopic decay lengths that can be comparable with detector dimensions. These long lived particles occur in many models: gauge-mediated supersymmetry extensions of the MSSM (addition of one singlet field), MSSM with R-parity violation and Hidden Valley Scenarios in which a new sector is weakly coupled to the Standard Model. The common feature of these beyond the Standard Model extensions is that they result in non standard Higgs decays to four jet final states with pairs of jets coming from vertices far from the pp collision point. In the Hidden Valley scenario there are also models where the LSP and a Z' can decay into long lived states that decay into pairs of b-jets or τ pairs.

The EPE group organized an ATLAS subgroup that works in the ATLAS Physics EXOTICS group. The group consists of the University of Rome (La Sapienza), University of Genova, SLAC group and the University of Pennsylvania has been working on optimizing the ability to detect such long lived particles in ATLAS. Recently the EXOTICS group was reorganized to include a Long Lived Particle group that Henry Lubatti co-leads with Philippe Mermod from Stockholm.

LHC Schedule

The present (October 2007) schedule for the LHC states that beam pipe closure ("T0") will take place in June 2008; beams are expected in LHC one month after that in July (ATLAS will start running), collisions after two months, and collisions at high energy after three months.

Center for Terascale Physics

Refer to Particle Theory, Section 4.10, for additional information.

One of the strengths of the UW physics department in the area of particle physics has always been the close collaboration of its experimental and theoretical groups. We plan to strengthen this collaboration even further in order to explore the discovery potential of the LHC and hopefully the Linear Collider. To this end, and in collaboration with the University of Oregon (UO), we have proposed to create a unique research facility, the Northwest Center for Terascale Physics (NWCTP). The proposed Center will foster collaboration between particle experimentalists and theorists from the UW and UO, as well as bring in visitors from other US and international institutions. Its aim will be to combine experimental and theoretical work in order to understand the experimental implications of the Standard Model at terascale energies, and to find and interpret indications of physics beyond. Besides the visitors mentioned above, the Center will involve theoretical and experimental post-docs working together, graduate and undergraduate students, and promote outreach to the general public in the northwest region. We have submitted the NWCTP proposal to the National Science Foundation as well as to the Department of Energy.

Gamma Ray Large Area Space Telescope (GLAST)

Introduction

GLAST is the current name for a joint DOE/NASA gamma ray observatory, scheduled to be launched in May 2008. It has two instruments: the LAT, a large area, large field of view gamma-ray telescope sensitive to energies from 30 MeV to beyond 300 GeV, and the GBM, a gamma ray burst detector sensitive from 8 keV to 30 MeV. Together, they will extend the energy range for gamma-ray bursts far beyond any current or past instrument.

Prof. T. Burnett is a member of the LAT team, responsible for the primary instrument. This will extend the sensitivity for observing astrophysical sources in this energy range by at least a factor of 50, and much for higher energies, 10 GeV to 300 GeV, which has never been observed before. The funding and students are described below.

There is collaboration with Scott Anderson of the Astronomy Department who has high energy astrophysics expertise and is a member of the SDSS collaboration.

Goals

There are several goals. We will contribute to the success of the mission by participating in development of the launch and early orbit procedures. We are particularly responsible for defining the alignment just after launch. This is because we have developed a special procedure to deal with finding and fitting point sources against an arbitrary background. Unlike telescopes operating at other wavelengths, we must be able to distinguish point sources against a diffuse background. This was designed for the basic astronomy that can be done with point sources, but is ideal for quick determination of the point spread function (PSF), and alignment of the LAT with respect to the orientation predicted by the star tracker device on the spacecraft.

We will certainly participate in data taking and data analysis; the LAT analysis and control center is at the Stanford Linear Accelerator Center; where we plan to spend a significant amount of time to during the early mission.

After the initial checkout is stable, with the energy and angle response understood, we plan to apply the UW-developed analysis procedures for detecting and cataloging point sources, mentioned above, to perform searches for new active galactic nuclei for population studies, and to help resolve point sources from the diffuse gamma-ray background. This would continue a study started by a former PhD student, Sean Robinson.

Another goal is to contribute to the discovery of dark matter and supersymmetry. This is a primary goal of the mission, which could help answer the basic physics/astrophysics question as to the origin of 25% or so of the energy density in the Universe. I note that this would complement the search for creation of supersymmetric particles at the new Large Hadron Collider at CERN.

Accomplishments

We designed and implemented much of the original Monte Carlo analysis that established the basic design of GLAST. Early in the process, THB was involved in a detector simulation project that was crucial for defining the original parameters, and which was heavily used in the successful proposal to NASA to justify the innovative design. Much of the code written for that period still survives.

We designed the scheme to define astrophysical sources, and cosmic ray background. Much of this was with the help of a former PhD student, Sean Robinson. It was a requirement to be able to simultaneously generate photons from multiple sources, with different rates and possible variability. We invented the "target sphere", a way to account for the shape of the instrument and surrounding material. We also instituted the now-standard "all-gamma" way to distribute incoming photon directions and energies to calibrate the instrument.

We established all details of the geometry and coordinate frames. We were responsible for all the code currently used to represent directions in space, with built-in conversion between equatorial and galactic reference frames. Also, we have packaged the representation of the celestial coordinates which is used in the science analysis part of the software, and included interfaces to standard code defining the many planar projections for creating images.

We designed, and manage the code to account for the exposure. We instituted, while THB was on sabbatical leave but supporting two students, the present scheme for performing the integral over an exposure time, taking into account the pointing direction as a function of time. This involved important contributions from a former master's degree student, Bruce Lesnick, who helped import code to interface to a novel new pixelization scheme, called HEALPix. Another master's degree student, Marshall Roth, who is now a PhD student, provided important contributions.

We defined the basic parameterization for describing the point spread function (PSF), and wrote the code to manage fits to create the parameters.

We have developed an efficient source localization and detection, using a novel way to represent photon data using the HEALPix pixelization mentioned above. Tue to multiple scattering, the angular resolution varies roughly inversely according to the energy. We used variable-sized pixels, the size determined by the resolution scale.

Prof. Burnett, while on sabbatical leave at the Goddard Space Flight Center, contributed to the definition of the code architecture for the "science tools" environment, fixing an unfortunate early wrong start. [These are simple executable programs addressing anticipated astronomical analysis scenarios.]

We established a Condor "flock" for general use by the Department, harnessing unused cycles of the 70 or so Windows machines used in the introductory labs and the study center. It was and is an invaluable for GLAST simulation studies.

Future Plans

ATLAS Muon Chamber Upgrade

We have joined a proposal to upgrade the inner region of the ATLAS forward muon tracking and trigger chambers for the high luminosity operation of the future super LHC. We are currently developing new detector technologies based on micropattern gas detectors that can perform high precision tracking, provide fast trigger signals, and can handle high rates.

The proposal was submitted to the ATLAS management in early July. The title of the proposal is "Development of muon chambers based on micromega technology"

ILC Detector Research and Development

The EPE Group is working on Detector R&D for the International Linear Collider. Two efforts are currently underway. One is to design the mechanical support structure for a vertex detector; this work is done in collaboration with W. Copper, M. Demarteau, et al at Fermilab. Henry Lubatti is working on this effort together with Colin Daly and William Kuykendall, with the Mechanical Engineering Department. Henry is funded by a subcontract from the University of Oregon as well as a Fermilab PO. The contribution of our group has been to design and fabricate test structures using carbon fiber composites. The group uses facilities in the Department of Mechanical Engineering and the Department of Material Sciences in order to prepare and lay up the carbon fiber samples, which are cured in autoclaves available in those departments. Group presentations at ILC meetings have been made; Henry Lubatti and Bill Cooper presented their work at the review of the ILC vertex detector R&D at Fermilab in October 2007.

The other effort is led by Tianchi Zhao involving the ILC Calorimeter. Tianchi Zhao works in collaboration with groups at Fermilab and Italy to study the concept of a total absorption calorimeter that can combine functions of EM and hadron calorimeters and achieve good energy resolution. He is also working with the University of Texas group to study the design of a digital calorimeter readout by the GEM detector. He is funded by two separate subcontracts from the University of Oregon. The concept of the total absorption calorimeter for ILC was proposed by him and a study group consisting physicists from Fermilab and Italy was formed to study the two options of this concept. The first option is to achieve the hadron energy compensation by a dual readout scheme that detects the scintillation light and Cherenkov light at the same time. The other option is to achieve the energy compensation by detecting signals from nuclear fragments, neutrons and gammas in the hadron showers. His current focus of the digital calorimeter of the GEM is to develop a thick GEM structure that can reach higher gain. The low gain has been one of the main drawbacks of the GEM detector. Tianchi Zhao is also working on methods to increase the gain and achieve two dimensional readout with the micromegas, which is another novel micropattern gas detector. Such a detector can be used for the digital calorimeter readout and also for the future ATLAS muon tracking detector upgrade.

A list of all students, past and present, can be found in Appendix 9.6, p. 188. Funding information is located in Appendix B, p. 253.

4.6 Gravity Tests

Eöt-Wash Gravity Group

Brief History of the Group

The Eöt-Wash Group, formed with NSF support in late 1987, uses the techniques of experimental gravity to address contemporary problems in basic physics. Our work now spans "fifth force" searches, Equivalence Principle tests, tests of the Inverse-Square Law at submillimeter length scales, searches for exotic spin-dependent interactions using polarized electrons, and we collaborate with UCSD and Harvard on the APOLLO next-generation lunar-laser-ranging effort. Each of these topics lies at the heart of contemporary theoretical speculations. To pursue our objectives, we have pioneered many innovations in torsion-balance technology: extremely high-quality rotation platforms, systems for maintaining platforms level to within a few nanoradians, techniques for measuring and canceling gravity gradients, detectors containing $\approx 10^{23}$ polarized electrons but negligible external magnetic fields, etc. We have developed uniquely sensitive instruments, and built up a powerful infrastructure that allows us to make rapid progress in new areas. Each of our undertakings – Equivalence-Principle tests, measurement of Newton's constant G, short-range tests of the inverse-square law, and Lorentz-symmetry tests) – has produced results that are substantial improvements over all previous work. Our high-precision results and our ability to respond rapidly to new developments in physics have made us a highly visible group and allowed us to attract outstanding postdocs and graduate students (in recent years several grad students have chosen to attend the UW specifically to work with us). Our graduate students receive an excellent education in experimental physics and more good students want to work with us than we can support financially. Our graduates have done very well; our first student, Christopher Stubbs, is now Professor of Physics and Astronomy at Harvard, and our most recent graduate, Dan Kapner, is a Kavli Fellow at the Kavli Institute for Cosmological Physics.

Eöt-Wash Faculty and Funding

The Group now has three faculty members, Professors Adelberger (Emeritus, but active), Gundlach and Heckel, and is primarily supported by the NSF with supplemental funding from the DOE (through CENPA) and NASA.

NSF support is currently over \$600,00 per year.

Current Research Thrusts

We are currently operating 6 different torsion balances, each optimized for a particular scientific issue.

1. Tests of the gravitational inverse-square law at the dark-energy length scale:

   The gravitational inverse square-law is a consequence of the existence of 3 spatial dimension, and tests of this law provide a direct probe of theoretical ideas about extra dimensions. We are almost completely ignorant about the behavior of gravity at length scales less than 100 μm. But there are compelling reasons for devising experimental techniques that can probe this regime. Recent cosmological observations energy of the Universe is a mysterious "dark energy" with a density $\rho_{\rm d} \approx 3.8$ keV/cm^3 and a repulsive gravitational effect. This dark-energy density corresponds to a distance $\lambda_{\rm d} = \sqrt[4]{\hbar c/\rho_{\rm d}} \approx 85$ μm that may represent a fundamental length scale of gravity. Some ideas for explaining the dark energy suggest that gravity will become weaker at short distances, while others, which postulate extra dimensions, predict that the strength should faster than $1/r^2$. We are operating two balances to test the $1/r^2$ law, and have already shown that the $1/r^2$ law holds down to length scales of 56 μm. We hope to extend this test down to 20 μm.

2. Equivalence-Principle tests:

   The discovery that roughly 2/3 of the mass-energy of the Universe is a mysterious "dark energy" adds to the interest in highly sensitive tests of the Einstein Equivalence Principle (EP) that constrain speculations about exactly what this dark energy can be. One currently popular notion is that the dark energy is a scalar field. In fact, proposed scalar fields permeate much modern thinking in particle physics. Recent results from our EP torsion balance, with a differential acceleration resolution of 2×10^{-13} cm/s^2, have sufficient precision to test for true quantum cosmological scalar fields that couple directly to the elementary constituents of matter, and by watching different materials fall toward the center of our galaxy, we have established that gravity is the dominant long-range force between dark and luminous matter. Our measured differential accelerations toward the sun, combined with the Laser Lunar Ranging EP test, provide the best unambiguous test of the Strong EP for gravitational self-energy. Differential accelerations in the field of the earth allow us to probe EP-violating interactions with ranges as short as 1 m (something that space-based experiments cannot do).

3. Spin-pendulum tests of Lorentz Invariance, Non-commutative geometry and other Spin-coupled Forces:

   Exotic scalar and vector fields produce forces between unpolarized objects that can be detected as apparent violations of the EP and the ISL. On the other hand, pseudo-scalar fields, which appear in many contexts, do not produce first-order forces between unpolarized bodies but instead lead to new spin-dependent forces. In addition, breakdown of Lorentz and CPT symmetries at Planck-scale energies leads to vector and axial-vector fields frozen in space that will also couple to quantum mechanical spins. In general, physics beyond the standard model can produce at least five new spin-dependent potentials that could generate torques on a polarized electron. We operate a torsion balance with a pendulum containing 10^{23} polarized electron (and negligible external magnetic fields). We have established an upper limit of $\sim 10^{-22}$ eV on the energy required to flip an electron's spin about an arbitrary direction fixed in space. This probes speculations about the non-commutativity of the space-time coordinates at a scale of 10^{13} GeV.

4. Torsion-balance search for axion-like particles:

   One of the best motivated candidates for a dark matter particle is the axion, which could have a mass anywhere between 1 μeV and 10 meV. We are operating a special torsion balance in which a highly non-magnetic pendulum sits in an alternating magnetic field to detect the CP-violating force induced by axion exchange. This experiment is sensitive to the very high end of the allowed mass range and complements

Prof. Rosenberg's RF cavity experiment which is most suitable for the low end of the allowed mass range.

5. Stray forces of gravitational-wave sensors:

   NASA supports our final balance that is used to study various phenomena that can produce stray forces on the inertial sensors of gravitational wave detectors such as in the proposed space-based LISA Mission.

Paul Boynton

This year I was again awarded a $240k/yr. competitive renewal of my group's 15-year NSF research program in experimental gravitation. An equal amount went to my collaborator, Prof. Riley Newman (UC Irvine) for the same set of experiments.

Tests of Newtonian gravity may play an important role in constraining possible extensions of the Standard Model. Over the past few decades a number of experiments have searched for inverse-square law violation (ISLV) and tested the Weak Equivalence Principle (WEP) on a wide range of distance scales. Significant deviations from Newtonian behavior have not yet been detected, but possibilities abound in the theoretical literature. In our view, much more sensitive searches are feasible, practical and scientifically essential.

During the past few years we have constructed instrumentation designed to carry out searches in both ISLV and WEP categories. In collaboration with UC Irvine, we have exploited new advances in the reduction of systematic effects, improved measurement precision using cryogenic techniques, and established with PNNL a laboratory facility on the DOE-Hanford site that provides an ultra-low vibration environment to make such work possible. We are now carrying out these experiments using this new instrumentation in this unique laboratory environment.

The Battelle Gravitation Physics Lab (BGPL), our remote, seismically quiet, underground lab several miles west of LIGO-Hanford in eastern Washington, was established by PNNL for our work in 1995. It provides a restricted access, extremely low vibration environment crucial to the conduct of these ultra-sensitive experiments. According to seismometric surveys, the ambient ground motion there is nearly two orders of magnitude lower than the basement labs in the Physics/Astronomy Building.

In the first set of experiments at BGPL, our measurement strategy involves a more sensitive, generalized version of the classic inverse-square-law test of gravity. Instead of attempting to measure the force between two bodies as a function of separation, we measure an observable directly related to the departure from zero of the source-free Laplacian of the interaction potential. Such a departure, if verified, would constitute a violation of the inverse square law, and suggest physics beyond the Standard Model.

The initial phase of the ISLV test involves an extensive setup and calibration process, which is currently near completion. At BGPL, the noise performance of this instrumentation is roughly two orders of magnitude better than when tested in our UW lab, as expected. This phase is followed by a still-lower-noise cryogenic apparatus able to detect an ISLV interaction with range of 10 cm and strength down to 10^{-5} of gravity – nearly two orders-of-magnitude below currently established upper limits at that range. Finally, with certain modifications to the instrumentation, we will be conducting a similarly deep search for violation of Einstein's weak equivalence principle.

In addition to facilities support from our institutional partner, Pacific Northwest National Laboratory, we are benefiting greatly from the indefinite loan of a $300k, 3-D, laser coordinate measuring machine by our corporate partner, the Boeing Company. This state-of-the-art device is essential to carrying out the precision metrology that underlies our experiments.

4.7 Nuclear Experiment

Recent significant accomplishments

- In 2007 we completed our precision ^{3}He + ^{4}He fusion measurements, with data from counting both the prompt and the activity gamma-rays over the energy range $E_{\text{c.m.}}$ = 330 - 1230 keV. A new beamline has been constructed for our experiment, in collaboration with TRIUMF, on the destruction of ^{22}Na by (p, γ) in hot astrophysical environments. The target chamber has been designed.

- In 2004 we completed our ^{7}Be(p,γ)^{8}B measurements, extending our earlier work to lower energy and reducing our systematic errors. Our measurements remain the most precise determination to date of this important solar *pp*-chain reaction rate.

- We developed a ^{8}B radioactive beam at the Tandem with a flux of half a dozen ^{8}B per second for an experiment searching for a branch to the ground state of ^{8}Be. We found an upper limit (at 90% confidence level) of 7.3×10^{-5} for the branching ratio to the ground state. This new limit rules out any significant contribution of this branch to the spectrum of solar neutrinos observed in the SNO and SuperKamiokande experiments.

- We finished an analysis of data that yields the branch for the $0^+ \to 0^+$ transition in ^{32}Ar, which allows an experimental determination of the isospin-breaking correction and a stringent test of the calculations that are used to make this correction in order to extract the size of the largest element of the CKM matrix.

- We have made significant improvements in our production of Ultra Cold Neutrons at Los Alamos, which has allowed us to measure the beta-decay spectrum from UCN at a rate of approximately 2 Hz. We expect to get a determination of the beta asymmetry to approximately 2% by the end of 2007. The beta asymmetry can be combined with other observables, such as the neutron lifetime, to derive the axial-vector coupling constant of the semileptonic weak interaction.

- We have completed a survey of minijet number and pt correlations on A-A collision energy and centrality, indicating that minijets form a strong contribution to RHIC A-A collisions although they are strongly altered in central collisions. We are now using the same analysis system to study elliptic flow on its own and relative to minijets, to reconsider its hydrodynamic interpretation and possible alternatives.

- We received DOE/NA22 funding for a large-channel-count TPC for indentification of special nuclear material. The readout electronics and software will be the responsibility of CENPA.

Recognition and awards

CENPA researchers have been honored with national awards: Jens Gundlach received the APS Francis M. Pipkin Award, Karsten Heeger and Kathryn Miknaitis both received the APS Dissertation Award in Nuclear Physics

(2002 and 2005, respectively). Dan Melconian received the CAP Dissertation Award. Peter Doe was elected a Fellow of the APS. Hamish Robertson was elected to the American Academy of Arts and Sciences and the National Academy of Sciences. The SNO Collaboration including 4 CENPA faculty members (Doe, Robertson, Tolich, and Wilkerson) was awarded Canada's Polanyi Prize.

CENPA, the INT, and the Nuclear Theory Group of the Department together form a powerful university research center in Nuclear Physics that is ranked second (after MIT) in the nation.

Future Plans

CENPA includes research work on gravity and associated weak, relatively long range fields and research on nuclear physics, including neutrino physics and relativistic heavy ion physics. We anticipate the installation of the Axion Dark Matter Experiment. The nuclear and neutrino physics research is supported primarily by the DOE. Plans for the other research will be provided by the proponents of it. A brief summary (in abbreviated draft form) of the nuclear and neutrino physics plans for the future follows.

We expect to continue our activity in neutrino physics, which is presently focused on the KATRIN experiment to directly measure a neutrino mass, and on the the Majorana experiment, which is in the planning stage. These are both large international collaborations. The KATRIN experiment is under construction at Karlsruhe. The Majorana experiment will search for neutrinoless double beta decay of ^{76}Ge in a multi-crystal array of isotopically enriched Ge counters. Other possibilities include work at the new SNO laboratory on, for example, geoneutrinos. We presently have 3 state supported and one research faculty members involved in this effort.

Nuclear physics has recently focused on nuclear astrophysics. We will have one state supported faculty member working in this area after the retirements of 2007 and 2008. Other nuclear physics involves precision measurements of neutron decay parameters. This field should be a fruitful in the near future, as there are several new sources and a lot of interest in the possibile research using them. Two state supported faculty members have part of their research effort in the neutron field at present, and we expect this may increase.

We have one state supported and one research faculty member working in relativistic heavy ion physics. It is likely that the state supported faculty member will retire in the next few years, and when that happens the continuing support of the effort in relativistic heavy ions by the DOE is problematical.

A list of funding sources is available in Appendix B, p. 253. A list of recent Ph. D. graduates and their theses is available in Appendix 9.6, p. 188.

4.8 Neutrino Physics

Recent significant accomplishments

- Data-taking on the Sudbury Neutrino Observatory project ended November 28, 2006, concluding six highly successful years in which the solar neutrino problem was resolved and new neutrino properties measured. As the heavy water is being returned to the owners, the data from the final phase, during which ^{3}He-filled proportional counters were deployed in SNO, are being analyzed. A clear neutron signal is seen and significantly improved precision on the mixing angle θ_{12} can be expected.

- KATRIN is a new, large-scale experiment to make a direct measurement of neutrino mass by studying the electron spectrum from tritium near its endpoint. The completion of the main KATRIN spectrometer, its very successful vacuum test and spectacular delivery to the Forschungszentrum Karlsruhe in Germany marked the achievement of a major KATRIN milestone. The UW is the lead US institution in KATRIN. We played a prominent role in the commissioning of the pre-spectrometer, which yielded valuable lessons on avoiding Penning traps, lessons that will be applied to the main spectrometer. Following a review in November 2006, the DOE announced its decision to fund the US-KATRIN proposal to build the focal-plane detector system for KATRIN. Forward funding assistance is being provided by the University of Washington to ease funding profiles.

- The Majorana experiment is being developed to look for neutrinoless double beta decay of ^{76}Ge. The process, if observed, would indicate that neutrinos and antineutrinos are identical particles. This violation of lepton number conservation would open an avenue by which nature could have produced a universe that contains matter but essentially no antimatter. The UW is playing a major role in Majorana, and has recently secured some R&D funding to begin development of a Demonstrator system, consisting of about 60 kg of Ge detectors, both natural and enriched. A detailed design is in an advanced stage.

4.9 Nuclear Theory

This document contains a summary of the physics research carried out by the Nuclear Theory Group at the University of Washington during the last ten years, and a vision for the future.

The last decade has seen remarkable progress and evolution in the research undertaken by the Nuclear Theory Group at the University of Washington. In addition to our efforts in nuclear theory, the group has broad interests in physics that include condensed matter theory, biological physics, particle theory, astrophysics and fundamental symmetries. Perhaps the most significant redirection of our research program is our embrace of high performance computing. Both Savage and Bulgac are now deeply involved in projects that require the use of the most powerful supercomputers available, to tackle problems central to nuclear theory, lattice QCD and the nuclear many-body problem, respectively. These efforts have brought new research directions and tools to the physics department and to the University of Washington. Our work continues to enjoy outside recognition, demonstrated by both Bulgac and Savage becoming Fellows of the American Physical Society (APS) in the last decade.

Aurel Bulgac's research is geared towards various aspects of strongly interacting many-body systems, mostly fermions and in particular nucleons in nuclei and neutron/nuclear matter. At the dawn of this decade Bulgac concluded a long study of dissipation and its origin in the large amplitude motion of nuclei based on a random matrix formalism of intrinsic nuclear motion. A quantum Fokker-Planck equation for large amplitude collective motion was derived within a Feynman-Vernon path integral formalism, a number of highly nontrivial exact and numerical solutions of this equation have been obtained. Further, in a very unexpected development a first derivation a quantum fractional Fokker-Planck equation was given, one of the few examples of genuine quantum dissipative equations and a very unique extension to the description of Lévy processes.

After many years of being involved in the study of atomic clusters and their relation with the properties of nuclei Bulgac performed a number of studies of their properties at finite temperatures and of their "phase transitions" (clusters being finite systems).

In collaboration with Vasily Shagynian, Bulgac investigated the unusual role played by the nuclear collective modes in the Coulomb interaction in nuclei and has shown how in particular a significant part of the celebrated Nolen-Schiffer anomaly could be accounted for in a very simple and natural manner.

Together with Yongle Yu, Bulgac has developed for the first time a mathematically and physical correct procedure to renormalize the zero range pairing interaction in fermionic systems. This allowed them to perform an extremely accurate study of entire isotope and isotone chains of more than 200 spherical nuclei with an unprecedented precision. All this formed the basis of what became to be known as Superfluid Local Density Approximation (SLDA), the first consistent extension of the DFT formalism to superfluid systems with local pairing fields. This scheme has been applied subsequently to the description of vortices in neutron matter and cold atomic gases. It was thus for the first time shown that the core of such vortices develop a hole in their core. In neutron stars that leads to a dramatic and totally unexpected change in the pinning properties of the vortices and in cold gases it was the key suggestion on how to make them visible and thus be put in evidence and prove that such systems are indeed superfluid. SLDA has been applied recently by Bulgac to a long series of atomic systems in traps, the properties of which have been independently computed essentially exactly in Monte Carlo approaches. The quality of the agreement obtained with the ab initio results within SLDA is simply spectacular.

In the last few years it was realized by many that the properties of cold atomic gases are very similar to those of atomic nuclei and that lots of techniques and results relevant to both fields, and others as well, could be obtained from their study. Together with Piotr Magierski and Joaquin E. Drut, Bulgac initiated a completely new program aimed at a numerical exact solution of the many fermion problem at finite temperatures within a Path Integral Monte Carlo description. Thus the thermodynamic properties of a unitary gas have been established for the first time and subsequently a full agreement with relevant cold atom experiments in trap has been demonstrated. Many other properties have been investigated using a variety of techniques: collective states, exotic pairing mechanisms, phase diagrams of spin imbalanced systems, the existence of a completely new class of selfbound universal dilute system.

During the last year Bulgac together with George Bertsch became respectively the co-PI and PI of a new national initiative on High Performance Computing in Low Energy Nuclear Physics under SciDAC, titled Universal Nuclear Energy Density Functional (UNEDF). This project funded at a level of 3 million dollars per year for five years, brings together researchers from eight universities and six national labs, both physicists and computer scientists and aims at achieving an order of magnitude improvement in the accuracy, reliability and theoretical consistency in the description of nuclear masses, energy spectra and low energy reactions for all known approximately 2500 nuclei and with the aim of providing a reliable extrapolation to the expected 6000 nuclei or so to be created at the radioactive beam facilities to come online in US and other countries in the immediate future. In the first two years Bulgac in collaboration with Piotr Magierski and the computer scientist Kenneth J. Roche (ORNL) are developing new codes for describing ground and excited state properties of nuclei on massively parallel computers.

The research work of Miller involves several topics including color transparency, nucleon structure, fundamental symmetries and relativistic heavy ion physics. Color transparency is a novel effect of Quantum Chromo-Dynamics (QCD) in which initial and final state interactions are suppressed and Miller has derived the quantum mechanical formulae needed to predict the nuclear consequences of this effect. Exciting experimental confirmation has recently appeared in two separate reactions suggested by Miller, one involving high energy pions incident on nuclei and the other pions produced in electron-nuclear interactions.

Miller's recent work on nucleon structure has focused on the electromagnetic form factors. He explained that the experimental discovery that the proton's electric form factor falls more rapidly with increasing momentum transfer than its magnetic form factor can be explained by considering the relativistic motion of the quarks within the proton. The consequence of this is that the matrix elements of a specific spin-dependent density operator exhibits a strongly non-spherical shape of the proton, wave function. This suggests one possible physics interpretation for the sculpture that appears in front of the physics building. An invited talk at the Philadelphia APS meeting led to publication of articles about the work in the New York Times, New Scientist, Discover, and many other popular scientific publications and web-sites. A model incorporating the relativistic features was extended by including the effects of the pion cloud so that the model respects both Lorentz invariance and chiral symmetry. This enabled an excellent description of all four of the nucleon electromagnetic form factors.

Most recently Miller used model independent techniques to show that: 1) that the charge density of the neutron is negative at is center and at its outskirts; 2) the proton magnetization density extends further than its charge density; and, 3) the angular dependence of pions produced in specific electron-proton scattering scattering experiments can directly measure the shapes shown above and verify that the shape of the proton is not spherical.

Work on fundamental symmetries focused on an approximate symmetry: the interchange of u and d quarks, known as charge symmetry. This symmetry is broken slightly by the mass difference between the light up and down quarks, as well as electromagnetic effects. Miller participated in an experiment that successfully measured a cross section for a reaction $DD \to \alpha\pi^0$ forbidden under charge symmetry. This cross section is a square of a "forbidden matrix element". Wide attention was received, with publication in Science News and mention in Scientific American because of the interest in constraining the light quark mass difference. This work appeared in Physics News 2003 and was judged by Discover Magazine to be the 49th top Science story of 2003. Miller and collaborators wrote a "popular" account that appeared in Physics World (the British version of Physics Today) and also published a series of papers on the analysis of this reaction.

Miller and Cramer originated a quantum mechanical treatment of opacity and refractive effects in two-pion (HBT) correlations produced in RHIC collisions. Our calculations reproduced the measured radii and single pion production spectrum with parameters showing that the RHIC data is consistent with the presence of a chiral phase transition. This work has received widespread popular attention including an appearance in the Wall Street Journal. Wilzcek, writing in Nature, stated that this work defines an important new direction in the field.

Savage entered the last decade focusing upon constructing an Effective Field Theory (EFT) description of the nucleon-nucleon interaction, and ultimately nuclei. With Kaplan and Wise, Savage had uncovered fundamental problems with Weinbergs power-counting (a chiral expansion of the NN potential) in 1996 and soon after developed what is now known as KSW (Kaplan-Savage-Wise) power-counting, in which pion-exchange is incorporated perturbatively into the scattering amplitude. While KSW power-counting provides the correct description in the spin-singlet channels, it was found to fail in the spin-triplet channels. Subsequently, along with Beane, Bedaque and van Kolck, Savage introduced what is now known as BBSvK power-counting which is an expansion about the chiral limit. This collection of work constitutes, and has lead to, significant advances in the field. On the way to understanding the chiral expansion, the pionless theory was explored in detail. Due to its simplicity as a EFT implementation of effective range theory along with gauge interactions and relativistic effects, calculations of simple two, three and four-body processes (including multi-nucleon interactions) have now been performed. The calculation of the cross-section for neutrino induced break-up of the deuteron is used by the SNO collaboration in their data analysis.

Savage's research evolved from the NN EFT explorations into understanding the EFT "needs" of future lattice QCD calculations of nucleon, and later nuclear, properties and processes. While chiral perturbation theory was still somewhat new to the mainstream lattice community, it was quickly embraced as the tool with which to make reliable extrapolations of the lattice QCD calculations from the relatively large pion masses that were available then, to those of nature. In contrast, the EFT calculations required to extrapolate lattice calculations in the single nucleon sector were quite primitive, and were plagued by questions of convergence, nothing existed in the multi-nucleon sector. In collaborations with Chen and Beane, Savage wrote a series of papers setting up and computing with the EFT describing partially-quenched lattice calculations of the simplest observables, including NN scattering. These works lead naturally to questioning "what it would take" to compute NN scattering and other simple nuclear processes with lattice QCD. Together with Beane, Bedaque and Parreno, Savage realized that the lattices that MILC had generated, and continues to generate with which they perform their precision calculations of meson observables, were big enough to compute NN scattering (at unphysical quark masses) even if the scattering lengths were much larger than the lattice volume. This observation was in contrast to the conventional wisdom at the time. It was at that point that Savage and his collaborators decided to re-tool and start performing lattice QCD calculations with a focus on multi-hadron physics.

During his first sabbatical leave (after 11 years as a faculty member) Savage took the opportunity while at MIT to learn the techniques of lattice QCD under the tutelage of John Negele and Kostas Orginos. It was there that the NPLQCD collaboration took shape. The goal of the NPLQCD collaboration is to use lattice QCD to compute the interactions and properties of nuclei. During the last two years, the collaboration has successfully performed the first QCD calculation of the simplest nuclear process, the low-energy scattering of two neutrons (at unphysical quark masses) .

Work is ongoing to refine this calculation by moving toward the physical quark masses and to progress to more complex nuclear reactions, such as those involving multiple neutrons and other processes that are difficult to isolate experimentally. During the last two years, we have published the first results for nucleon-nucleon, hyperon-nucleon scattering, kaon-kaon scattering, kaon-pion scattering, multiple pion interactions, and precision pion-pion scattering.

All of these results were obtained by computing domain-wall propagators on the MILC coarse ensemble of rooted-staggered lattices. In order to perform such calculation, huge amounts of computer time are required. After being awarded exploratory time by USQCD at during our first year, we have received increasing resources, and at this stage we have roughly 14 million core-hrs at our disposal this year, including a large fraction of the Athena cluster we are currently installing at NPL, allocations from USQCD, NCSA, Mare-Nostrum and others. Further we installed a small 32-core machine (Deuteronomy) in 2005.

The research of the members of the Institute for Nuclear Theory is discussed here. They work closely with the Nuclear Theory Group.

George Bertsch

My major goal is to develop a systematic theory of nuclear structure based on self-consistent mean field theory, also called density functional theory (DFT). The key word here is "systematic"; the theory should be well-justified by the known properties of the nuclear interaction and it should apply to all but the lightest nuclei. The goal is very broad in scope and there are many specific objectives. One objective that I am presently pursuing is to understand the performance of various theories and energy density functionals for calculating low-lying excited states. In recent years I have also devoted considerable effort to apply the techniques developed in nuclear physics to other areas of physics, an effort that is continuing but is decreasing due to the demands of the density functional work.

Wick Haxton

I work on problems involving nuclear and neutrino astrophysics, low-energy tests of symmetries, and many-body physics. An example of the first is a current project with Aldo Serenelli on the possibility of combining various laboratory astrophysics and neutrino flux measurements to constrain the C and N content of the primordial solar core. An example of the second is recent work with C.-P. Liu and M. Ramsey-Musolf on a more general derivation of the Schiff theorem – the response of an neutral atom with a nuclear electric dipole moment to an external electric field – that avoids a subtle "factorization" approximation. In many-body theory I am involved in a long-term project to understand the form of the effective theory appropriate to a basis of harmonic oscillator Slater determinants. I am also working on the fractional quantum Hall effect, relating the short-distance structure of this problem to a set of order parameters that uniquely define the incompressible states.

David Kaplan

I work at the interface between nuclear and particle theory, with a special interest in lattice field theory as an approach to strongly coupled systems. Over the past few years I have developed a lattice theory for studying supersymmetric gauge theories, in particular ones which are being studied by string theorists and nuclear physicists alike fr clues as to how the real strong interactions work. I have also been very interested in finding ways to use lattice field theory to study fermion systems at finite density, or to at least correctly identify the origin of the problems encountered in studying such theories. Most recently I have also been interested in the cosmological properties of axions, a promising candidate for the missing dark matter of the universe.

Paul Romatschke

The creation of the quark-gluon plasma, a state of matter described as the "perfect liquid" with very small viscosity at the Relativistic Heavy Ion Collider (RHIC) has been named the top physics story of 2005 by the American Institute of Physics. Strangely enough, most evidence for the notion of the "perfect liquid" came from modelling RHIC data using a theory that does not include viscosity, namely ideal hydrodynamics. In an article recently published in Physical Review Letters (Phys.Rev.Lett.99:172301,2007) my wife and I for the first time used viscous hydrodynamic simulations to describe the experimental data, obtaining estimates for the value of the viscosity at RHIC. We confirmed that this value, or more precisely the dimensionless ratio of viscosity over entropy density, is indeed very small, and close to the result for a plasma in the limit of infinite coupling, which had been conjectured to serve as a lower bound for all real relativistic fluids. The viscosity at RHIC may even be "too small", since our best fits to experimental data were achieved for a ratio of viscosity over entropy density which was less than the conjectured lower bound. Our results thus indicate that a complete understanding of the "perfect liquid at RHIC" is still lacking and either standard assumptions for heavy-ion collisions used in our hydrodynamic model or the validity of the conjectured viscosity bound need to be reviewed.

Dam Son

I have applied the techniques of gauge/gravity duality to the problem of computing transport coefficients in hot gauge plasmas. I have also developed a phenomenological model of hadron based on the idea of holography. In addition I have proposed an approached based on the epsilon expansion around four spatial dimensions understanding the fascinating properties of trapped fermionic atoms, tuned to a Feschbach resonance. Most recently, I have been studying the problem of impurity screening by interacting electrons in graphene.

During the last 10 years we have graduated 15 students (Arndt, Beck, Chen, Cooke, Drut, Hazelton, Karakowski, Rupak, Smith, Thompson, Tiburzi, Walden, Walker-Loud, Watrous, Yu) with PhD's. Further we have trained 10 postdocs (Beane, Carter, Detmold, Forbes, Griesshammer, Hanhart, Lahde, Lin, Sargsian, Strickland) and 4 Research Assistant Professors (RAPs) (Detmold, Kovchegov, Phillips, van Kolck). Most of our postdocs and RAPs now hold faculty positions and have gone on to receive Outstanding Junior Investigator awards (OJI)'s from the DOE (van Kolck, Phillips, Kovchegov), Sloan Foundation awards (van Kolck), Carreer Awards from the NSF (Beane, Griesshammer) and the Sackler Prize (Kovchegov). Three of our recent graduate students now hold faculty positions, Chen (Taiwan), Rupak (Research Assist Prof at NCSU)and Yu (China).

Nuclear theory at the University of Washington is very strong. We will continue the evolution of our research program to address the most important questions in the field at any given time. The last few years have been very exciting, and the future seems even more promising.

Bulgac will continue in the foreseeable future his studies of the properties of strongly interacting many fermion systems, in particular the description of their properties within the Quantum Monte Carlo approach, the description of nuclei and other related systems within the Density Functional Theory within the UNEDF and without, the study of various new forms of pairing mechanisms, and the study of the collective modes of these systems. A major part of his research would be performed on the largest supercomputers accessible, in the hope that the ability to use them efficiently for the study of all/large number of nuclei will amount to a quantum leap in our low energy nuclear physics. One can think of this as a new facility to perform theoretical nuclear physics, but not on isolated nuclei or a small number of them, but on a large number/all of them and thus producing hopefully a more reliable theory, which could have a great impact on other fields (nuclear engineering, nuclear astrophysics, and weapons). It is estimated that these new tools will also be of great use to other fields in physics.

Miller will continue to think of new ways to test Quantum Chromodynamics and its application to the physics of atomic nuclei. The new decade will begin with further studies of color transparency to follow up the discovery of color transparency in an experiment involving a high energy pion incident on a nuclear target, suggested by him and his colleagues. Predictions are being made for new measurements, that are just becoming feasible, in which pions or rho mesons are produced. Further work on charge symmetry breaking will be aimed at more precisely constraining the up-down quark mass difference using improved calculations and new experiments. Further tests of his theory of HBT correlations will be made by predicting effects for kaons and for elliptic flow. These efforts should enable the Group to continue its leadership in phenomenological nuclear theory related to experiment.

Savage will continue his efforts in lattice QCD with complete focus on computing nuclear reactions and properties. The NPLQCD collaboration are leading the world in this effort and with the vast computational power that will be available during the next 5 years, one should see dramatic progress within the near future. The Athena cluster, a joint facility of the INT, physics department and astronomy is a first step towards establishing eScience at the University of Washington and in the physics department. During the last decade numerical exploration of physics has developed into the third arm of research, accompanying theoretical and experimental exploration. We are positioning ourselves to be leading this effort locally.

It was eleven years ago that Savage was hired as an Assistant Professor at the age of 34, and he is now 45. In order for us to maintain our intellectual vitality, we must hire a junior faculty member within the next few years. We are the only group in the physics department that has not searched during the last ten years, and we will be focused on hiring in the near future
A list of faculty members, including group affiliations, is available in Appendix C.1.

For a list of students and post-docs, refer to Appendix 9.6, p. 188.

To maintain our vitality and our present ability to attract the very best young nuclear theorists, as only a truly outstanding group will appeal to truly outstanding candidates, we must hire in the near future. During the 2005-2006 academic year the staffng committee, after reviewing the quality of our group, informed us that we would be included in the Department's next search for a theoretical physicist. With this commitment from the department to our group, we used the interim period to identify a small number of excellent candidates to be interviewed during the next theory search. We are confident of their quality and it is clear that the department will benefit greatly from having them here as faculty members.

We look forward to interviewing these people during the next theory search.

4.10 Particle/Field/String Theory

Recent history

The previous decade has been a period of major renewal for the UW particle theory group. The retirements of Professors Brown and Baker, and the move into administration of Professor Boulware, created an opportunity to restructure the group in a unique fashion. Our goal was to build a group with an exceptionally broad range of activities covering all of theoretical particle physics from collider phenomenology, performed in close collaboration with our experimental colleagues, to string theory, involving joint activities with colleagues in the Mathematics department. At the same time, we wanted to ensure that there was sufficient overlap of interests among group members to stimulate novel and fruitful collaborations.

Thanks to the hires of Andreas Karch, Matt Strassler, and Mina Aganagič, we were remarkably successful in this rebuilding effort. In diverse areas such as the development of improved methods for recognizing evidence of new physics in collider data (Ellis and Strassler), innovative models of possible new physics beyond the standard model (Nelson and Strassler), applications of gauge/string duality to QCD-related physics (Karch and Yaffe), and improved techniques in lattice gauge theory (Sharpe), the contributions of the UW particle theory group are very well known and well regarded in the international community. For example, outside reviews of our 2004 DOE research grant proposal included comments such as:

> *The Univ. of Washington theory group has become over the past ten years one of the best and most productive centers of high energy theory. The only places that could be comparable are Harvard, Stanford and Berkeley (and in string theory also Princeton, UCSB, Caltech and Rutgers). However, I feel that none of these places have such a coherent program that nevertheless covers practically every aspect of high energy theory, from lattice QCD to collider phenomenology to model building and to less and more formal string theory.*

We strive to foster a stimulating, productive environment for students and postdocs which exposes them to a wide variety of forefront research and enhances their professional development. Our success at doing so is clearly evident in the track record of recent students and postdocs. Over the past dozen years, nearly all of our postdocs and two thirds of our fifteen PhD graduates have gone on to academic or research

Inevitably, hiring outstanding people leads to efforts by other universities to recruit those people. Our group is now faced with the consequences of having lost Mina Aganagič to UC Berkeley in 2004, and Matt Strassler to Rutgers University in 2007. In the case of Aganagič, there was a spousal situation and, although the UW attempted to hire Raphael Bousso away from Berkeley, in the end the presence of family in the Bay Area tipped the balance and UC Berkeley succeeded in hiring Aganagič away from us.

Matt Strassler came to the UW hoping to contribute to and help build strong efforts in both string theory and collider phenomenology. Thanks in no small part to the local environment here and the collaborative efforts of Steve Ellis, our high energy experimental colleagues, and several outstanding students, Matt was able to rapidly redirect most of his research effort toward collider physics in anticipation of the start-up of the Large Hadron Collider (LHC), which will begin taking data next year. This, he was convinced, will be the source of the most significant scientific progress likely to occur during his entire career. Unfortunately, a combination of factors induced Matt to move to Rutgers last summer.[3]

Particle theory in the next decade

Looking forward, the intellectual vitality of particle, field and string theory has rarely been greater. Data from the LHC will usher in a new era in fundamental physics which may well include discovery of supersymmetry, extra dimensions, the particle(s) responsible for dark matter, new interactions, and other complete surprises. Due to the complications of separating events with new physics from standard model backgrounds, maximizing the extraction of useful knowledge from LHC data will, almost certainly, require an unprecedented level of collaboration between experimentalists and theorists. So-called "astro-particle" physics has become an exciting area in which observations of the microwave background, structure formation in the early universe, gamma and cosmic ray astronomy, terrestrial neutrino physics experiments, high energy collider experiments, and dark matter experiments all come together to constrain possible new physics. Concurrently, progress in string theory has led to the development of entirely new methods for understanding the dynamics of strongly coupled gauge theories – including theories which share many similarities with QCD. Results from string theory are now being used to improve the modeling of quark-gluon plasma as produced in heavy ion collisions at RHIC (the relativistic heavy ion collider at Brookhaven Lab) and in the near future at the LHC. Insights from string theory are also leading to improved understanding of high energy diffractive scattering, new classes of technicolor models, and better phenomenological models for hadronic physics. Faster computers and improved algorithms have come together to change the nature of lattice gauge theory from an exploratory technique (with uncontrolled errors) to a precision tool in which all systematic errors can be controlled. This has advanced our understanding

[3]Issues included the failure of the UW to strengthen high energy experiment soon enough to have a healthy in-house experimental group at the time of LHC start-up, the failure to strengthen string theory after Aganagič's departure, a very nice offer from Rutgers involving reduced teaching and direct research support which the UW was unable to match, and the proximity of family on the East coast.

in many areas including B-physics and the extraction of CKM parameters. Continued, rapid progress in all these areas is virtually certain.

We expect to continue to play a major role in these areas, and others, as we have in recent years. But because of our recent departures, particle, field, and string theory at the UW has been significantly weakened. Adding to our concerns for the future is the foreseeable retirement of Steve Ellis. In the absence of new hires, in a few years time we may no longer have any activity in collider phenomenology – just when LHC physics is likely to be most exciting! Although the UW has been very prominent in applications of gauge/string duality, with only a single string theorist on our faculty successfully recruiting first rate postdocs in this area will be increasingly difficult.

We are doing everything we can to keep the UW particle theory group in the forefront of the entire field. Our most recent DOE proposal was reviewed very favorably and our DOE funding, as measured by $/faculty-member, has just gone up – which is remarkable in the current federal funding climate (even though the increase fails to cover escalating salary costs). Jointly with the University of Oregon, we have recently submitted to both NSF and DOE a novel proposal, whose fate is not yet known, for the creation of a Northwest Center for Terascale Physics which would be devoted to collaborative theoretical and experimental work related to LHC physics. Members of our group make numerous other highly visible professional contributions [4].

For more information, refer to Elementary Particle Experiment, Section 4.5.

But the prominence in particle theory which has been achieved by the UW will not be sustainable without new hires that rebuild our strength. Particularly valuable would be hires in some of the areas highlighted above: collider phenomenology, string theory, and astro-particle theory.

For a list of faculty members, including group affiliations, please refer to Appendix C.1.

[4] These include serving on the Particle Physics Project Prioritization Panel (P5) [Nelson], the Executive and Scientific Program Committees of the US Lattice QCD Collaboration [Sharpe], and the TeV4LHC Collaboration [Ellis], participating as a Microsoft Research Fellow at the Newton Institute for Mathematical Sciences in Cambridge [Yaffe], co-organizing the KITP program on Non-equilibrium Dynamics in Particle Physics and Cosmology [Yaffe], the KITP program on The First Year of the LHC [Nelson], and the INT summer school on Lattice QCD and its Applications [Sharpe], and lecturing at the Institute for Advanced Study Prospects in Theoretical Physics summer program on The Standard Model and Beyond [Ellis].

String Initiative

One of the more interesting areas of outreach and intellectual initiative within the Department of Physics in the last 10 years has been the effort to develop a joint Mathematics-Physics String Theory group. The idea for this initiative was developed in 1999 within the Particle Physics Theory Group. Facing the forthcoming retirement of 2 senior members of the group, and the commitment of a third to the Departmental Chair position, an opportunity presented itself for a targeted hiring effort. In considering the many exciting areas of research in theoretical physics, the latest developments and promise for future results seemed particularly strong in string theory. We had for some time observed the developments in formal string theory, including work in the realm normally inhabited by mathematicians. We were excited by the possibilities to study strongly coupled systems afforded by the rapidly developing area of the so-called AdS/CFT correspondence connecting a string theory (with gravity) in one space to a (conformal) quantum field theory in a lower dimensional space (without gravity). Finally the suggestions from string theory were behind many of the Beyond the Standard Model scenarios being probed at the proton collider at Fermilab in Chicago and sure to be explored at the planned higher energy Large Hadron Collider (LHC) at CERN in Geneva (and just now turning on in 2008). At the same time this seemed an ideal opportunity to build stronger intellectual ties with our Mathematical colleagues. Working with faculty in the Mathematics Department we developed a plan (at that time a UIF proposal) to perform coordinated recruiting in both Departments. (The original proposal carried the names of Ann Nelson, Steve Ellis, Martin Savage, Steve Sharpe, and Laurence Yaffe in Physics and Robin Graham Jack Lee, and Paul Smith in Mathematics). Indeed a period of recruitment something like this original proposal did occur over the next several years. Andreas Karch and Matthew Strassler joined the Department of Physics in 2002, as did Mina Aganagič a year later in 2003. (Unfortunately Mina departed for UC Berkeley in 2004.) Charles Doran and Amer Iqbal joined the Department of Mathematics in 2004.

The desired connections between the two Departments quickly developed with shared research workshops, joint seminars and working lunches, which continue to this day, with the participation of faculty, post docs and graduate students from both Departments. The AdS/CFT based research program in Physics now includes Physics Professors Karch, Son and Yaffe and their students. Prof. Strassler has not only maintained his research efforts in string theory proper, but has also collaborated with Prof. Ellis in Physics to establish his credentials as a Collider Physics phenomenologist. Unfortunately this success placed prof. Strassler in such a unique position at the interface of theoretical and phenomenological particle physics, that Rutgers recruited him away this last year to play a role in the joint initiatives at Princeton and Rutgers aimed at capitalizing on the forthcoming LHC results. While it would have been better for the UW if everyone recruited in the last 10 years had stayed here, recruiting and fostering outstanding scientists guarantees that some will eventually be lured away. At the same time there can be little doubt that the String Intiative served to stimulated the science in both the Physics and the Mathematics Departments, while strengthening the connections between the Departments.

4.11 Particle Astrophysics & Neutrino Physics

SuperK and T2K

This group's primary focus is on neutrino physics and astrophysics. We continue to work in the Super-Kamiokande Collaboration, a US-Japan-Korea joint project involving about 100 physicists, which has operated the Super-Kamiokande Neutrino Observatory in Japan since 1996. Super-K is a 50,000 ton water Cherenkov detector. We use Super-K to study the physics of neutrinos, in particular refining our understanding of the neutrino oscillation phenomenon, which allows us to investigate the fundamental properties of these particles. Super-K also will detect the precursor neutrino burst from a supernova within our galaxy with high statistics, which may allow us to give optical astronomers several hours advance warning before visible-light signals arrive at Earth, and learn more about the core-collapse process in supernovae. In addition, Super-K continues to set new limits on proton decay lifetime for many possible decay modes predicted by GUT theories.

We are starting intensive work on T2K (Tokai to Kamioka), a long-baseline neutrino oscillation experiment in which a new high energy particle accelerator (JPARC) located 100 km NE of Tokyo will generate a high intensity neutrino beam, and direct it through the earth to Super-K, 300 km to the west. This will allow us to study how the properties of the neutrinos change as time passes, while they are in flight from JPARC to Super-K. From 1998 to 2006, we worked on a predecessor experiment, K2K, which used the less powerful particle accelerator located at the KEK national lab in Japan. K2K data analysis was completed last year.

New detectors for T2K, used to sample the neutrino beam at its source, will be constructed in 2008 and begin data-taking in 2009. Our group is responsible for several critical detector elements. Our research engineer, Mr. Hans-Gerd Berns, is a major technical resource for both the Super-K and T2K collaborations, on call 24/7 to provide technical advice, designing and building custom electronics as required, and monitoring and maintaining equipment.

Another project is WALTA (Washington Area Large Time-coincidence Area), which combines outreach effort with basic physics research. WALTA provides local high schools with cosmic ray detector sets, and links the school sites to form an extensive air shower (EAS) array covering the Seattle metropolitan area. EAS's result when very high energy cosmic rays strike nuclei high in the Earth's atmosphere. Each summer we hold a week-long workshop to train new teachers to use the equipment supplied, and provide continuing education for teachers and students who are already members.

Information regarding Particle Astrophysics and Neutrino Physics' current funding and students can be found in Appendices B, p. 253 and 9.6, p. 188, respectively.

Accomplishments

During the past 10 years, the Super-K collaboration has published 38 papers in refereed journals, including our 1998 paper announcing the first of neutrino mass (and another 9 papers have been published presenting K2K results. Members of Our group has received international recognition for its expertise in neutrino physics research, and members of the grou have made numerous presentations at international conferences and workshops.

In September, 2006, we hosted the 7th International Workshop on Next-Generation Neutrino and Nucleon-decay detectors (NNN-06) here at the University of Washington, attended by over 100 scientists. NNN-06 proceedings are in press and will be published by AIP Conference Publications later this year.

To date we have about 12 high schools and 2 community colleges participating in WALTA. Within the NSF-funded Quarknet program, WALTA has repeatedly been acknowledged as one of their most successful programs.

One of our WALTA teachers (Mark Buchli, physics teacher at Liberty HS in Renton) won a Murdock Foundation Partners in Science grant, which allowed him to work with us for two summers, including a visit to Super-K where he helped supervise undergraduate summer workers during an upgrade of the experimental apparatus.

Axion Dark Matter eXperiment

Our group's research interests lie at the boundary of nuclear, particle and astrophysics. This research has three main areas: Searching for dark-matter axions, surveys of dark matter and dark energy, and developing advanced instrumentation.

At present I am heavily involved in the Axion Dark Matter eXperiment (ADMX). The Axion is a hypothetical elementary particle arising from a mechanism to cancel otherwise large CP violation in QCD. The properties of the axion make it a compelling dark-matter candidate. This goal of ADMX is to provide a definitive answer to the question of whether or not our Milky Way dark-matter halo is axionic. ADMX is the only dark matter search with such definitive sensitivity, and ADMX has been strongly endorsed by a string of national review panels. Since axions are so compelling and the experiment is definitive, the potential for a major discovery is therefore very real. The search technique involves threading a liquid-helium cooled RF cavity with a large static magnetic field, thereby inducing nearby halo axions to convert into microwave photons. The 10^{-25} watts of converted axion power is detected by our exquisitely

low-noise receivers. Prof. John Clarke (Berkeley), a member of our collaboration, fabricated SQUIDs (Superconducting Quantum Interference Devices $\cdots$ a quantum device that converts magnetic flux into voltage) with geometries suitable for microwave amplification. We then built microwave amplifiers and receivers around these SQUIDs and have demonstrated the world's most sensitive receivers by far of microwave radiation. Our current electromagnetic power sensitivity is at a fraction of a yactowatt. Since the sensitivity of the axion search improves rapidly as the system noise is reduced, the new SQUID amplifiers greatly improve the experiment sensitivity. This SQUID-amplifier and receiver chain is the heart of the ADMX upgrade. The other major component of the upgrade is

dilution-refrigerator cooling for the SQUIDs and cavity. The upgrade occurs in two phases: Phase I is installing the SQUID receiver chain and Phase

II is installing a dilution refrigerator to reduce the Johnson cavity noise and SQUID amplifier noise to near the minimum allowed by quantum mechanics (the "standard quantum limit"). The DOE Office of Science project start for ADMX Phase I came in 2004. Construction finished in January of this year and the experiment is now transitioning from commissioning into operations. I am the co-spokesperson and driving force of ADMX including program, technical and scientific leadership.

The Phase I Upgrade to ADMX will operate for about a year. At that point, Phase II construction of ADMX is scheduled to begin. Recall that the technical goal of Phase II is to retrofit ADMX with a dilution refrigerator, resulting in an axion search experiment that would be sensitive to the entire range of plausible axion masses and couplings to normal matter and radiation, even if axions were a minority fraction of our Milky Way dark-matter halo. This final phase is sometimes called the "definitive" experiment. Very importantly, at the end of Phase I operations, ADMX will move to CENPA at the University of Washington. The new site is ideal for the project, and the move has been enthusiastically endorsed by our program sponsors and ADMX collaborators. Having ADMX on-campus at the University of Washington will be a boon to our Department's activity and profile in particle astrophysics and will draw outstanding students and postdocs.

A related activity of our group is searching for the spontaneous decays of axions into photons in halos of astrophysical objects. These decays appear as a line superimposed on a long-exposure electromagnetic power spectrum recorded by a radio telescope pointed at an astrophysical object. This search is more sensitive to unusual axions of higher masses, where the decay rate is appreciably faster. Our radio telescope measurements are among the most sensitive at these higher axion masses. These data were originally taken some time ago on the large single-dish radio telescope at the Haystack Observatory, where the ultimate sensitivity of the analysis was limited by baseline variations of the power spectrum. We have since acquired data from interferometric dishes where the baseline variation is significantly less, and we are pursuing further measurements. This work, including preparing publications, has been accomplished almost entirely by undergraduate students under my direction.

I have a research role in the Large Synoptic Survey Telescope (LSST) project. LSST is a large, 8.4 meter, ground-based wide-field telescope designed for time-domain astronomy as well as mapping cosmic shear, and therefore dark matter and dark energy, out to cosmological distances. LSST will be the premier cosmology instrument of its decade. My LSST research focus is on what I consider the key issue: The sensitivity of LSST weak-lensing analysis of dark matter and dark energy depends ultimately on how well atmospheric optical distortions can be corrected, particularly since LSST has a huge aperture, wide field of view and long exposure time. This instrument presents new challenges in understanding the atmosphere, and this understanding is crucial for the LSST cosmology survey to be a success. I am on the LSST science team on this and we are responsible for, among other things, establishing the ultimate sensitivity of LSST for weak-lensing (cosmic shear) probes of dark matter and dark energy. The timetable for LSST is relatively fast by large project standards; it's now under limited construction from private and NSF R&D funds, and the initial contract for the primary mirror has been let. Assuming full LSST construction is approved, LSST will absorb an increasing fraction of my research time as first-light approaches sometime in 2015 to 2020. LSST is a flagship project of the Astronomy Department here at the University of Washington, so Physics Department research in LSST science is greatly leveraged by the large Astronomy role.

Our advanced-detector program has been crucial for our research success in that dramatic sensitivity improvements in our measurements come from products of our

detector-development program. One area of our development focuses on Time Projection Chambers for programmatic (weapons-treaty verification) and basic science (rare positronium decays and extra dimensions) applications. This is another activity where I have included undergraduate students in substantive roles. Another program area is developing the world's lowest noise receivers. These receivers, based on quantum-noise-limited SQUIDs, opened up an orders-of-magnitude improvement in our dark-matter axion search sensitivity and find utility across a broad range of basic science and low-power signal detection applications.

4.12 Physics Education Group

The Physics Education Group (PEG) currently consists of three tenured faculty, one research assistant professor, one post-doc, an experienced high school teacher on indefinite leave from her school, and graduate students working toward an M.S. or Ph.D. in physics for research in physics education. Members of the PEG have a shared mission: to improve student learning from

K to 20+. In pursuing this goal, the group conducts systematic research on the learning and teaching of physics and develops curriculum that is research-based and research-validated.

At the introductory university level, the group has produced and continues to expand Tutorials in Introductory Physics[5]. This supplementary curriculum has been adopted at about 165 institutions in the U.S. The PEG is also developing tutorials for upper division courses. The group prepares the Department's graduate students for their role as TAs and contributes to the professional development of post-docs and faculty as physics instructors. Impact on K-12 students is through the development of curriculum for the preparation of teachers of physics and physical science. The PEG has produced and continues to expand Physics by Inquiry[6] (PbI), a self-contained, laboratory-based set of modules that have been used at 50 institutions. Tutorials and PbI have each been translated into at least two other languages and are arguably the most widely distributed and most rigorously assessed research-based curricula in physics.

The PEG is one of very few physics education research groups that have active programs for undergraduates (introductory and advanced), graduate students, and K-12 teachers. The group can thus provide a broad background in research, curriculum development, and instruction that is not available elsewhere. Faculty who have visited the PEG have established several research groups in physics departments. [*e.g.*, University of Maryland (Joe Redish), University of Illinois, Champagne-Urbana (Gary Gladding), University of Colorado (Steve Pollock)]. Since 1997, the group has had more than 200 visitors, many of whom have stayed from one week to about one year.

Since 1997, 14 students have received Ph.D.s for their research with the Physics Education Group. Nearly all have obtained tenure-track positions at colleges and universities ranging from the University of Maryland and Hamburg University of Technology to smaller ones such as Cal-State Fullerton and Grand Valley State University. During this period, another 10 students received Masters degrees. Most are currently teaching in community colleges or in high schools. The group has also had 6 post-docs during this period. One is still a post-doc with the group. Three have since obtained tenure-

[5]L.C. McDermott, P.S. Shaffer, and the Physics Education Group, Tutorials in Introductory Physics, Prentice Hall. Preliminary Edition (1998); First Edition (2002)

[6]L.C. McDermott and the Physics Education Group, Physics by Inquiry, Wiley & Sons (1996)

track positions and one currently has a research Associate Professor position. The remaining former post-doc has a science position at Boeing.

In the last 10 years, the PEG has collaborated with faculty who have implemented our curricula at other institutions. Besides the three previously mentioned, the list includes: California State Polytechnic University (Pomona), Cascadia Community College, Harvard University, Montana State University, New Mexico State University, Peninsula College, Purdue University, University of Cincinnati, University of Maine, Western Washington University, University of Cyprus, Hamburg University of Technology, and the Monterrey Institute of Technology (Mexico).

Scholarship on the Learning and Teaching of Physics: Activities and Accomplishments

The primary focus of scholarship in the Physics Education Group is research on the learning and teaching of physics and development and assessment of curriculum based on that research. During the past 10 years, we have published our results in 24 papers in peer-reviewed journals, 17 Conference Proceedings and other articles, and 257 invited and 112 contributed talks. Our work has been cited in more than 357 articles. Tutorials in Introductory Physics and PbI have provided the basis for research by many other faculty, who have reported their results in 79 articles and in 128 talks. Our curricula have also formed the basis for 11 grants to faculty at other institutions. Findings from research inform the design of our instructional materials through an iterative, cyclical process. Progress in student learning is documented through comparisons of student responses on pretests (after standard instruction) and on post-tests (after research-based instruction). The results are supplemented by classroom observations and individual demonstration interviews.

Undergraduate Students and K-12 Teachers

1. **Introductory calculus- and algebra-based physics courses**

   In the past ten years, the PEG has conducted research on student understanding of many concepts covered in standard introductory university physics courses, including: vectors, friction, potential energy, conservation of energy, momentum, angular momentum, rigid body dynamics, simple harmonic motion, Galilean relativity, hydrostatics, EM waves, photoelectric effect, the particle nature of light, wave properties of matter, 2-d kinematics, Newton's laws, electrostatics, electric circuits, magnets and magnetic fields, waves, and physical and geometrical optics. Published results include a long-term study on 1- and 2-d motion involving 20,000 students at 8 universities.

Results of the research above has guided the development of Tutorials in Introductory Physics, which is designed to supplement instruction in standard algebra- and calculus-based introductory physics courses. Two editions have been published in the past 10 years: a Preliminary Edition, published in 1998, and a First Edition, published in 2002.

Since 1991, the tutorials have been used in the introductory calculus-based physics sequence at the UW. All students, including those in a special honors sequence, participate in weekly, small-group tutorial sessions. The PEG is responsible for all aspects of the tutorials including preparing pretest questions for students to take before the tutorials and writing examination questions to assess their effect. (About one quarter of each examination is based on the tutorials.) Group members regularly revise the tutorials, trying to improve them by drawing on assessments of student learning from previous quarters. The group also takes responsibility for many administrative aspects of the calculus-based sequence: managing the scheduling of TAs in tutorials, designing examination questions based on tutorials, organizing regular exam-writing sessions attended by faculty in the introductory course, assigning exam and homework grading to TAs, monitoring grading, and conducting classroom observations of all TAs in the tutorials.

The PEG has also collaborated with faculty teaching other introductory courses, including the introductory algebra-based sequence and algebra-based laboratories. The PEG also helped develop a laboratory-based component for the introductory liberal arts physics course (Phys 110).

2. **Upper division physics courses**

   Members of the PEG collaborate regularly with faculty teaching upper-division physics courses. In the last 10 years, the group has conducted research into student understanding of concepts covered in upper-division physics courses, such as hydrostatics, thermodynamics, special and general relativity, and quantum mechanics. The results have guided the development of tutorials for thermal physics (Phys 224), modern physics (Phys 225), relativity and gravitation (Phys 311) and quantum mechanics (Phys 324 and 325). Most of these tutorials have not yet been published but results at the UW are very promising. Most students rate the tutorials highly.

3. **Introductory and upper-division laboratory courses**

   Since 1998, the PEG has been collaborating with faculty teaching introductory laboratories. New experiments on the ideal gas law and buoyancy have been developed, assessed, and iteratively refined. Research has also provided insights into student understanding of more advanced topics. A study of student reasoning about DC circuits, rectifier diodes, and full-wave rectifiers is prompting modifications in upper-division laboratory courses (Physics 334 and 434).

4. **Courses to prepare K-12 teachers to teach physics and physical science by inquiry**

   The PEG has a major commitment to improve the subject-matter preparation of K-12 teachers. We are particularly interested in determining how best to help them develop the ability to interpret and apply scientific representations and reasoning skills, such as proportional reasoning and the control of variables. This effort complements and extends our work with undergraduates. In the last 10 years, the group has examined teacher understanding of kinematics, dynamics, electric circuits, electrostatics, mechanical waves, geometrical and physical optics, relativity, astronomy, thermodynamics and, more recently, the particulate nature of matter.

   Findings from this research are guiding the development and extension of Physics by Inquiry, which has been designed expressly for the subject-matter preparation of K-12 teachers. PbI also works well with liberal arts majors and with students who are under-prepared in science but interested in pursuing careers in science or engineering. The PbI modules consist of experiments and exercises that guide students through carefully sequenced questions in making observations, developing concepts, and constructing scientific models in an ongoing process of inductive and deductive reasoning. This type of guided inquiry helps teachers develop the depth of understanding required to teach physics and physical science as a process of inquiry.

PbI has been developed and assessed in courses, workshops, and institutes for K-12 teachers and in courses for students without a strong science and mathematics background. Pilot sites provide feedback from a variety of instructional settings. The First Edition was published in 1996, just prior to the period covered in this report. The relevant courses at the UW are described below.

(a) **NSF Summer Institute for Inservice K-12 Teachers**

Each year, the group conducts an intensive, all-day, six-week Summer Institute for Inservice Teachers. This NSF-funded program provides the primary environment in which research on conceptual understanding is conducted and curriculum for Physics by Inquiry is developed, implemented, and tested. Teachers from the local area and across the nation are admitted on a competitive basis. Participants may attend for up to three years. The Institute also helps teachers develop the leadership ability needed to influence the teaching of science, not only in their classes but also in their schools and school districts.

(b) **NSF Academic-year Continuation Course for Inservice K-12 Teachers**

The group teaches an academic-year Continuation Course for Inservice Teachers that provides a follow-up for the Summer Institute. The course meets for 2-3 hours one night/week, during which teachers work through curriculum, receive guidance in applying what they learned during the summer to their own classes, and consult with us and with one another on science topics that they are teaching.

(c) **Courses for Preservice K-12 Teachers**

Members of the PEG teach an academic-year sequence (Phys 407 - 409) for preservice middle and high school teachers. PbI forms the basis for instruction. This environment provides an opportunity for prospective teachers to learn (or relearn) physics as a process of inquiry. A corresponding course for elementary school teachers

(Phys 101A – 103A) is not currently offered because of insufficient instructional resources.

5. **Tutorial sections for underprepared students**

   For many years, the group taught courses for students under-represented and under-prepared in the sciences. Physics 101B – 104B were designed to provide these students with the background needed to succeed in the calculus-based sequence that is the gateway to science and engineering majors. Although this sequence has not been offered for several years, the group has worked with the College of Engineering by offering special tutorial sections for under-represented students.

6. **Undergraduate Independent Study**

   In the past 10 years, 15 undergraduates have completed independent study projects with the PEG.

Outreach and K-12 inservice professional development since 1997

A broad spectrum of inter-related and inter-dependent activities extends the environment in which research takes place. The PEG has an extensive program of outreach to K-12 teachers and school districts in the Seattle area and nationwide.We consult with faculty in physics and other sciences on how to conduct discipline-based education research and use the results to inform instruction.

Annual Workshop for New Physics and Astronomy Faculty: For the past 11 years, the PEG has been invited to present at a national AAPT and APS workshop for about 100 new physics faculty (sponsored by AAPT and APS). The purpose is to introduce new faculty to resources available to them in their role as instructors. Each year, the PEG has opened the Workshop by conducting the first scheduled session, which consists of a talk on physics education research and a tutorial.

International Workshops for Physics Faculty and Teachers: During the past 10 years, the PEG has conducted about 25 workshops on Physics by Inquiry and the Tutorials in Europe, Asia, and South and Central America. The group has had a particularly significant impact in Singapore, where, for the last three years, the Ministry of Education has invited senior members of the group to give talks and conduct workshops for teachers, university faculty, and administrators.

Seminars for other Departments at UW: The group has a long-standing tradition of working with colleagues at the UW in other sciences, mathematics, and education. The group has offered courses and workshops for faculty, scientists, K-12 teachers, and graduate and undergraduate students in other units, such as the Mathematics Department, the College of Education Teaching and Learning Partnership, and the College of Education Masters in Teaching (MIT) program.

Workshops for local Seattle teacher preparation programs: The PEG works regularly with various Seattle-area projects. A major project during the last 10 years was the development of week-long workshops for the NSF-funded Seattle K-5 Local Systemic Change (LSC) Partnership. Other current and recent collaborations include: the Fred Hutchinson Cancer Research Science Education Partnership, the Washington State LASER (Leadership and Assistance for Science Education Reform) project, and the Seattle Middle School Science Systemic Change Project.

Knowles Foundation: Since 2005, the PEG has provided annual workshops for preservice and inservice science teachers who have been awarded teaching fellowships from the Janet and Harry Knowles Science Teaching Foundation (KSTF). One PEG member (resident teacher Donna Messina) has served on the selection committee that awards Knowles Fellowships.

Overview of Accomplishments

The UW PEG leads in the production of Ph.D's in physics for research in physics education and has prepared the most post-docs in this specialty. Evidence of the influence of the PEG can be found in the emergence of groups at other universities in the U.S. that conduct research in physics education. Virtually all of these were formed after the PEG was well established. The PEG has contributed more than any other group in the U.S. to the literature in physics education research. Ours are also the only widely distributed curricula that are both research-based and research-validated. The group has been active in disseminating results from research in refereed journals, colloquia, seminars, and workshops at national meetings of APS, AAPT, other professional organizations, and at colleges and universities. Group members also regularly give talks and conduct faculty workshops for scientists in other disciplines.

The PEG has had a strong impact not only on the physics education research community, but also on the broader one of physics instructors. Our influence on instruction is evident in the way in which physics is taught at many colleges, universities, and K-12 classrooms. The teacher preparation program by the PEG is widely regarded as a model for how to help K-12 teachers develop subject-matter competence. Physics by Inquiry has been adopted by several large teacher preparation programs (*e.g.*, Project Discovery in Ohio State and UTeach at the University of Texas Austin). Implementation of the tutorials has had a direct effect at many institutions. Moreover, the work of the group has influenced the development of other curricula. Workshop Physics (Wiley) and Real Time Physics (Wiley) are but two examples that have incorporated results from research by the PEG. Lecture-Tutorials for Introductory Astronomy (Addison-Wesley) have also been developed using Tutorials in Introductory Physics as a model.

The PEG has also helped bring about recognition by physics departments (and by APS, AAPT, and AIP) that physics education research is an appropriate field for scholarly inquiry by physicists. The accomplishments of the PEG contributed significantly to the decision in 1999 of the APS, AAPT, AIP and other societies to endorse two resolutions. The first formally recognizes physics education research as an appropriate field for scholarly inquiry in physics departments and the second urges physics departments to take an active role in improving the preservice training of physics teachers.

The APS recently recognized the contributions of the PEG by awarding the 2008 Excellence in Education Prize to L.C. McDermott, P.R.L. Heron, and P.S. Shaffer. It was the second time that this award, which is intended for a group, has been given. (PSSC was the first recipient.) During the last ten years, members of the PEG have received other national and international awards[7].

[7] First LTSN (Learning and Teaching Support Network) Lecturer in UK, 2003, L.C. McDermott; Medal of the International Commission of Physics Education, 2002, L, C. McDermott; Jones Distinguished Lecturer. Emporia State University, KS, 2002, L. C. McDermott; 2002 Medal of the International Commission on Physics Education, L.C. McDermott; Sigma Xi Distinguished Lectureship, 2002-2003, L. C. McDermott; American Association of Physics Teachers, Oersted Medal, 2001, L.C. McDermott; Council of Scientific Society Presidents, Education Research Achievement Award, 2000, L. C. McDermott; Optical Society of America, Archie Mahan Prize, 2000, L. C. McDermott and P. R.L. Heron

For a list of the funding sources, please refer to Appendix B, p. 253.

Future Vision of the Physics Education Group

For more than three decades, the PEG has conducted research on student understanding over a wide span of educational levels with a broad range of populations. Our findings have guided the development of curriculum that has brought about marked improvement in student understanding. Evidence is accumulating that there is strong retention three years later. Moreover, we have shown that our procedure for developing research-based supplementary curriculum at the introductory level can also be effective in more advanced courses (*e.g.*, thermal physics, special relativity, and quantum mechanics). We have recently extended our research to upper-division laboratory courses (Physics 334 and 434), in which we plan to help the assigned faculty make modifications. We intend to strengthen our research and research-based curriculum development at the introductory level and beyond, as well as to continue our work in K-12 teacher preparation. Much has been accomplished, but much remains to be done at all levels of instruction.

A course-by-course or topic-by-topic approach, however, is not sufficient for overcoming the problems in physics education. Findings from research indicate that many of these are interdependent and cannot be effectively addressed in isolation. Our experience has shown that a set of coherent, multifaceted projects can contribute significantly to improvement in the effectiveness of physics instruction. We have found that identifying and addressing difficulties in physics in a vertical manner is more likely to have a broader impact than a horizontally confined effort (i.e., grade-by-grade). What we believe is required is a vertically integrated approach that addresses related problems over a span of educational levels. This type of intensive program, however, requires a strong, stable, organizational structure that can support a variety of interrelated projects.

For the past ten years (and longer), the PEG has been a *de facto* center for research in physics education, for research-based curriculum development, and for direct involvement of physics faculty in the preparation of K-12 teachers. Designation as a formal K-20 Center in Physics Education would enable us to increase the level of our current activities and start new programs. Our chances of being able to obtain support from NSF for a Center, either through an RFP or (more likely) through an unsolicited proposal, depends to a large extent on demonstrated substantial support by the Department and University. As is true in other areas of physics, a Center can also provide strong leadership throughout a sub-discipline.

We have done our share in bringing external funding to the Department. Moreover, we have engaged intensively not only in the intellectual activities in which we are intensely interested but also in strengthening the Department's instructional program by service that extends beyond our assigned responsibilities. We have promoted the goals, stature, and reputation of the Department and the University at local, national, and international levels. However, even if we continue to be as successful as we have been, external funding alone cannot provide a reliable base for maintaining national leadership. Although it has taken more than 30 years to build a group as prominent as ours, it could be quickly destroyed. Because it takes time to develop the necessary expertise, a replacement for Lillian is needed before she retires. We cannot possibly maintain our current level of productivity with fewer than three state-supported faculty positions.

4.13 Science and Society

Professor Vladimir Chaloupka, originally an Elementary Particle experimentalist, gradually switched during the last decade the emphasis of his research and teaching to interdisciplinary studies in Physics of Music and to transdisciplinary studies of issues in Science and Society. His activity in these fields has been recognized by his appointments as Adjunct Professor in the School of Music as well as in the Henry M. Jackson School of International Studies. He is also an Affiliate of the Virginia Merrill Bloedel Hearing Research Center at UW.

The main accomplishment at the boundary between physics, medicine and music has been the publication of the first observation of a reversible, medication-induced shift in the absolute pitch perception. This represents a valuable non-intrusive method of studying human hearing. Work on this will continue in the next decade.

In the general field of Science and Society, Chaloupka's interest lies in improving our understanding of the interactions between Society and modern Science, with its breathtaking promises and accompanying dangers, and in teaching students about these issues. The centerpiece of his teaching effort has been the development of a novel course on Science and Society (PHYS216/SIS216) offered jointly by the Physics Department and by the

Jackson School, in order to encourage a rich enrollment pattern of science- as well as non-science majors in the same classroom. This goal has been fully achieved, and it results in students learning not just from the Instructor, but from each other as well.

On the research side of this effort, the major development has been an invitation to deliver a talk on "Science and Human Security" at the recent conference at the Center for Governance and International Affairs, University of Bristol (UK). Chaloupka's proposal to establish an international working group involving scientists as well as representatives of the Humanities has been accepted, and he was invited to play a leading role in organizing the research group.

In addition to regular courses, there has been extensive student participation in this work, both at the undergraduate (PHYS400) as well as graduate (PHYS600) level. Professor Chaloupka is convinced that the importance of such profoundly interdisciplinary studies will increase in the coming decade, and that there will be significant demand for graduates skilled in this emerging field.

Chapter 5

Relationships With Other Units

5.1 Visiting Committee

The Department of Physics has an advisory committee known as the Visiting Committee. It consists of nine members from the larger community who meet semi-annually to hear about the Department and its developments. In addition to providing advice to the Chair and the Department it has been the source of most of the donations to the Department enabling the Department to more effectively recruit graduate students. The current membership is:

Member	Employer
Cairns, Bryan	Boeing (retired)
Edelheit, Lonnie	General Electric, CTO (retired)
Hadley, Dave	retired
Lindsey, Lex	retired
Mottler, Fred	Universal Avionics
Myhrvold, Nathan	Intellectual Ventures
Rao, Shanti	Jet Propulsion Laboratory
Schmid, Charles	Acoustical Society of America
Wiborg, Jim	retired

5.2 Collaboration with Other Units

Collaboration with other units is on an individual basis. The Department has a large number of adjunct faculty who advise Physics graduate students and, in many cases, collaborate with Physics faculty. The full list of adjunct faculty is given in Appendix C.1, page 262. The Department not only encourages such relationships but would like to strengthen them to provide a broader base of activities in which is engaged.

Faculty	Project	Department
Rehr	NSF-STC	Chemistry (L. Dalton, B. Robinson *et al)*
	NIH-SSRL	Stanform SSRL (K. Hodgson, B. Hedman *et al)*
	DOE-Solar Energy	Material Sciences (C. Luscombe, A. Jen *et al)*

Table 5.1: Joint grants

5.3 Research Experience for Undergraduates

The Physics Department hosted an NSF-funded Research Experience for Undergraduates (REU) program for many years, Summer 1995 through the Summer of 2006. During this time period, the program achieved a high enrollment of women students and had a specific focus on providing students with research opportunities which were not available on their home campuses. This led to some emphasis on admissions from four-year colleges and smaller state universities. The program size ranged from 12-14 participants, who were each matched with a research group for the 10 weeks of the program. One to two students per year who participated in the REU program later became UW Physics graduate students. The program drew over 300 applicants each year, and the acceptance rate for first offers averaged 90%. Thus the program drew many talented undergraduates to the UW, some of whom returned in later years as graduate students and postdoctoral researchers.

The department's grant for this program was not renewed for Summer 2007. Instead, alternative funding was found to bring in one student from

Grambling State University for a summer research experience with essentially the same format at the prior REU program. The subsequent reapplication to NSF has been successful, and the larger program will resume in summer 2008. Among the more significant changes in the reborn REU program is a stronger emphasis on recruiting students from underrepresented groups, with a target of 20% participation by 2010. This effort will be assisted by a coordinated outreach program to minority-serving institutions which will include both the REU program and the graduate program.

5.4 Center for Nanotechnology

Several members of the Department were founding members of the Center for Nanotechnoloy and Marjorie Olmstead now serves as the head of the Integrated Graduate Education, Research, and Training (IGERT) program. The program spans the several Departments including Chemistry, Materials Sciences, and Bioengineering and is an important resource for our students. It is more fully discussed in Section 9.5, page 187.

Chapter 6

Diversity

Diversity in physics has several overlapping meanings. These include not only issues related to gender and ethnicity, but also to international educational background, family responsibilities, political and religious outlooks, career goals, and research areas and approaches. Below, the statistical considerations focus on gender and ethnicity, but the general activities to enhance the departmental atmosphere are aimed more broadly.

6.1 Inclusion of Underrepresented Groups

Undergraduate Majors

The number of undergraduate physics majors has increased by 50% in the past 10 years, reflecting a national trend of a 40% increase since a low in 1998[1]. The number of male, female and UW-identified EOP registered physics majors is plotted in Figures 6.1 and 6.2 both as an absolute number (Figure 6.1) and as a fraction of the total (Figure 6.2) for the past 10 years (spring data). The percentage of women majors mirrors the national data for bachelor's degrees (shown as open symbols on lower graph), which has been around 20% for the past 10 years. The percentage women in a sampling of calculus-based introductory classes over the past few years averages 22% (range 15% to 29%). The number of EOP physics majors at UW has tripled over the past 10 years, from an average of 7 declared majors in 1998-2000

[1] All national data referred to here are from the American Institute of Physics Statistical Research Center, http://www.aip.org/statistics

to an average of 22 in 2005 – 2007, increasing from about 3.5% to 8.5% of the total major population. The national percentages in 2005 (relative to US citizens obtaining bachelor's degrees in physics) were 3% black, 4% Hispanic and 5% Asian Americans; since EOP does not include Asian Americans, our numbers are comparable to the national averages.

Graduate Students

At the graduate level, the statistics available from the graduate division (http://www.grad.washington.edu/stats) are difficult to interpret for our department since they merge the evening masters and Ph.D. program for first year enrollment figures. Also, terminal masters degrees are not reported separately from those awarded en route to the Ph.D., which some, but not all, of our Ph.D. students go through the paperwork to obtain. Plotted in Figures 6.3 – 6.5 show the yearly total of UW physics Ph.D.'s awarded to male, female, US-citizen minority, and foreign students. The average is 16 Ph.D.'s awarded per year. The female, minority and foreign numbers are shown on an expanded scale, with the average enrollment figures (total enrollment/6.5 to get an approximate per year number). The number of minority Ph.D. graduates fluctuates around 1 each year, while the number of women graduating fluctuates around 2 (10 and 21 in 10 years, respectively). The fraction of women enrolled in the program (around 20%) mirrors the national data for first year graduate enrollments (open diamonds); the female fraction of female Ph.D. graduates (13% of 10 year total) are below those for the total enrollment, a trend mirrored in the national data. This indicates that women are dropping out at a higher rate and/or taking a longer time to graduate than are their male peers. If the entire difference is attributed to relative attrition rates, approximately one more female is dropping out of the UW Physics Ph.D. program every two years relative to the rate for male students.

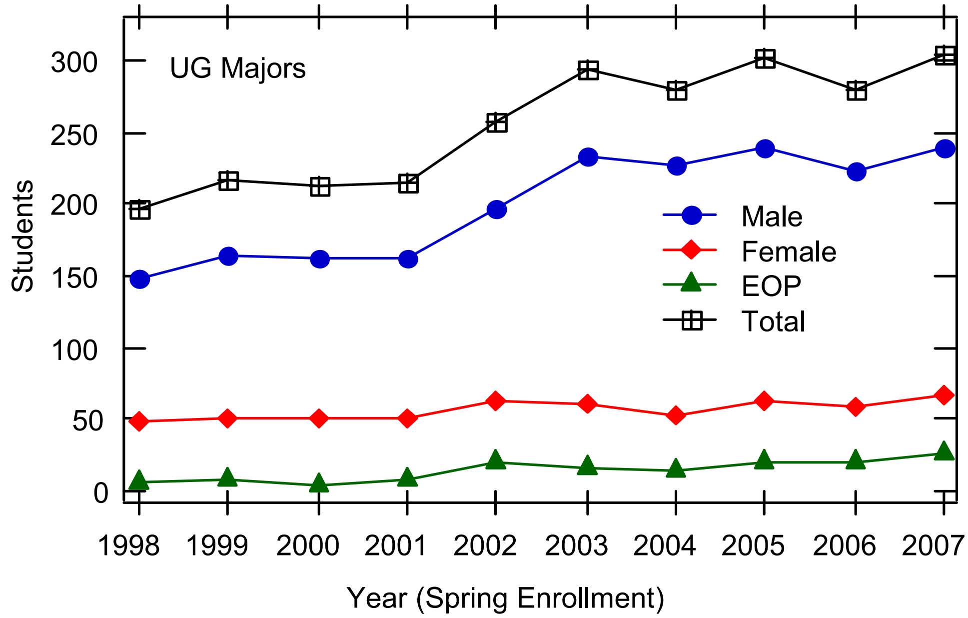

Figure 6.1: Student Gender by year

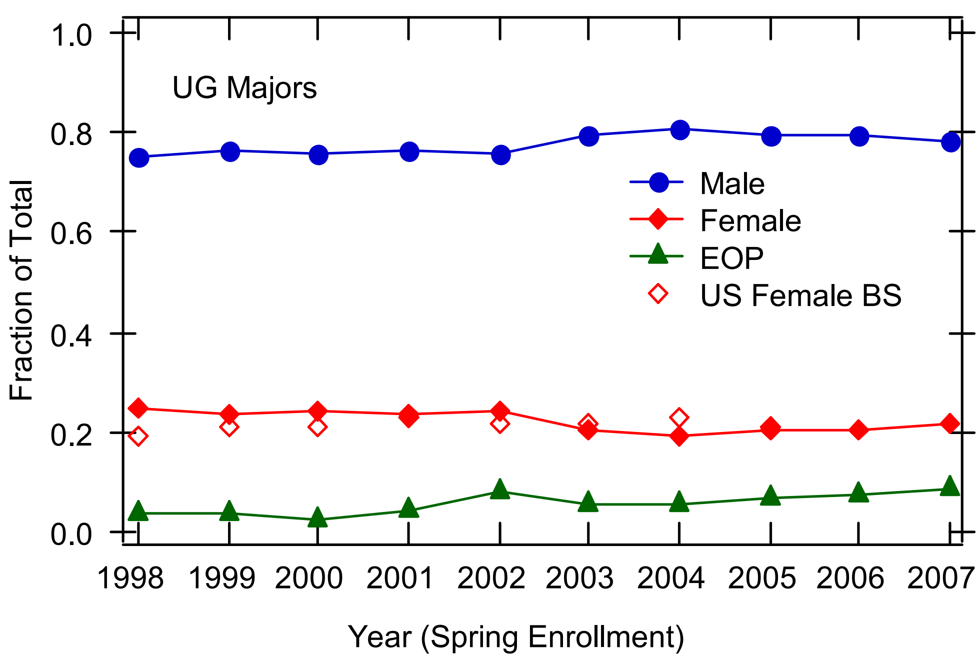

Figure 6.2: Fraction of Total Student Gender

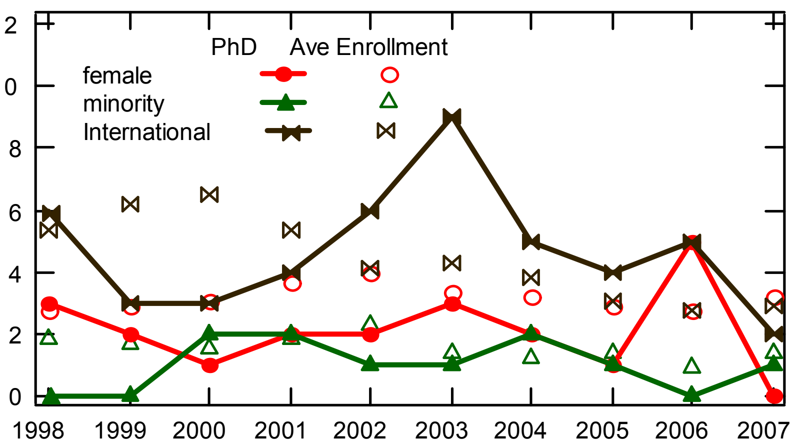

Figure 6.3: PhDs Awarded (by Gender)

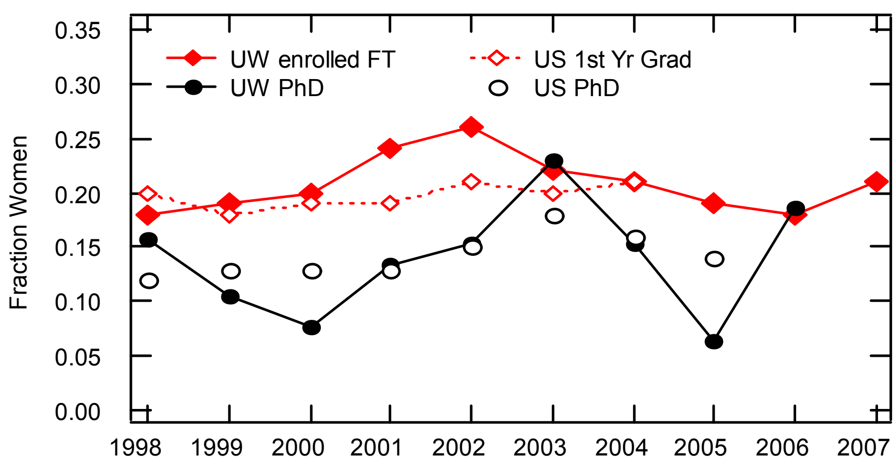

Figure 6.4 Average PhD Enrollment (by Gender)

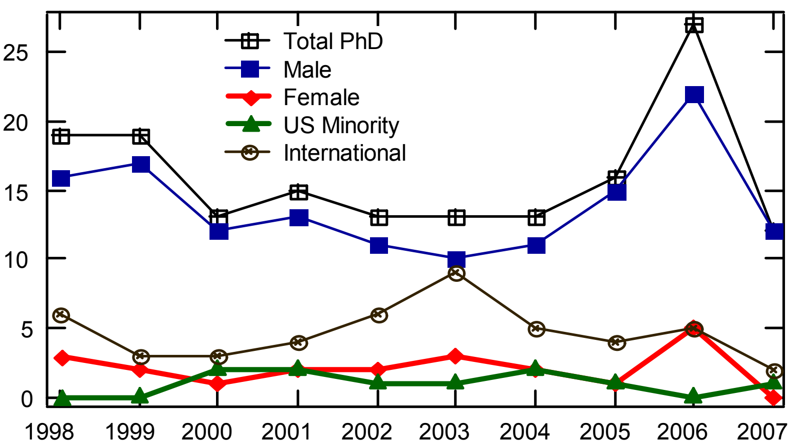

Figure 6.5: Fraction of Women Enrolled

Faculty

At the faculty level, change happens more slowly. Of the 45 members of the ladder faculty listed in the 1996-98 University Catalog, 29 are still on the faculty (all 3 women, plus 26 white males); 13 men have retired (including the only Hispanic), 1 white male moved to Harvard, and 2 men are deceased (including the only Asian). Three faculty (2 male, 1 female, all Caucasian) were hired and then hired away by other institutions in the past decade. The current ladder faculty has five female and 43 male members. All five women are Caucasian. Of the men, 2 are Asian-American, 1 is African-American and 1 current, 1 recently retired (and still teaching), and 1 recently hired (postponed initial appointment one year) faculty members are Hispanic-American.

	Date				
	1996 catalog	Winter 08	Top 50 2006[2]	Top 50 2006 Percent[2]	Projected
White Male	40	38	1579	79%	37.7
White Female	3	5	128	6.4%	3.1
Asian Male	1	2	226	11.2%	5.4
Asian Female	0	0	23	1.1%	0.5
Hispanic Male	1	1+1[3]	30	1.5%	0.7

[2]See http://cheminfo.ou.edu/∼djn/Science_and_Society/index.html

[3]Accepted offer in Sp07 to arrive in Au08

Table 6.1: Number and percentage of women and ethnic minorities.

	Date				
	1996 catalog	Winter 08	Top 50 2006[4]	Top 50 2006 Percent [4]	Projected
Hispanic Female	0	0	7	0.3%	0.2
Black Male	0	0	14	0.7%	0.3
Black Female	0	0	0	0%	0

[4]See http://cheminfo.ou.edu/∼djn/Science_and_Society/index.html

Table 6.2: Number and percentages of blacks and Hispanics.

On a national scale, UW physics is doing well in terms of female faculty. In 2005, only 20 physics departments in the country (including UW) had four or more women on their faculty. In 2006, of the 2,009 faculty members in the top 50 physics departments (ranked by '05 federal funding), 158 were women; UW's "share" is 3.8 (=158*48/2009)[5]. UW Physics made offers to 6 female faculty candidates in the past 10 years; 2 are now on the faculty, 3 chose to accept offers elsewhere (including an Asian American), and one came as an assistant professor for two years and then transferred to UC Berkeley, where her partner is on the faculty.

UW physics has had good recent success in increasing our minority representation on the faculty. Warren Buck, the African-American former chancellor of UW Bothell, temporarily joined our department last year[6], and the search in 2007 resulted in our hiring one woman (Caucasian) and one Hispanic-American. Assistant Professor Morales is the first US-born minority faculty member in our department.

6.2 Comparisons of Work Load

A typical faculty member is assigned to 2 or 3 standing committees in a given year. The amount of work associated with each committee varies, as does

[5]See http://cheminfo.ou.edu/∼djn/Science_and_Society/index.html

[6]Adjunct Professor Buck will return to Bothell next year.

the level of responsibility. The average number of committee assignments per year for the female ladder faculty over the period 00-01 through 07-08 is 2.6, compared to a value of 2.4 for male ladder faculty. For most of this period, there were two Hispanic ladder faculty and one Asian. The Asian faculty member is in the Institute for Nuclear Theory and is entitled to a lower committee load; his average is 1.8. One of the Hispanic faculty members was Associate Chair for a significant portion of this period, resulting in his higher than average 3.5 committees; the other Hispanic faculty member had an average of 3 committees/year.

Teaching loads in our department are typically one course in each of the three main academic quarters. This year, two of the women are on leave, and one just arrived Winter quarter (she will teach an upper division course in her specialty in Spring 08). One chooses to oversee our teacher and teaching assistant training courses for which there are multiple course numbers and extensive involvement of research staff (post-docs, graduate students and research assistant professor). The remaining female professor is teaching one introductory course (W08) and two upper division majors courses (A07 and Sp08). She is also overseeing the core course in nanotechnology, where much of the lecturing is done by other faculty; last year it was her only teaching assignment in the spring. Of the minority teaching faculty, one is a new assistant professor, teaching the senior level course (W08) and lab (Sp08) in his specialty this year; the two full professors are teaching the introductory sequence (one honors). The retired member's single quarter assignment is to oversee one of the introductory laboratory courses. The Asian male in the INT taught one course this year, which is typical for INT faculty.

6.3 Environment

The physics department has increased its efforts over the past several years to enhance the climate for all students through increased communications and several structural changes. In Spring 2002, the graduate students organized a report to the faculty inspired by a realization that in a given year 5 women (24% of total female enrollment) and 7 men (6% of total male enrollment) were leaving the Ph.D. program without a degree. The students reached the conclusion that the issues leading to student dissatisfaction were not specifically gender related, but that the women acted on these issues at a higher rate than the men. The students made a number of suggestions, which the faculty carefully considered; several of these suggestions were enacted, including a site visit from the American Physical Society Committee on the Status of Women in Physics, which we were able to schedule in April 2004. The CSWP report echoed many of the students' concerns and highlighted areas for improvement. The department held an open meeting to discuss the CSWP report, and created a diversity committee to deal with the many good suggestions arising from these discussions. Over the past five years, the department has acted on many of the issues brought up by the CSWP report as well as suggestions from students, faculty and staff. A Diversity Committee was created with the charge of coordinating efforts to improve diversity; with strong support from the Department and the faculty at large the activities have included:

- Increasing the number of students (both graduate and undergraduate) serving on important committees in the department;
- Encouraging development of the Society of Physics Students (undergraduates) and the Graduate Student Council, including pizza lunches with colloquium speakers and regular meetings between the chair and the officers of the student organizations;
- Holding informal teas for female students and professors following colloquia by female speakers;
- Instituting more interactive lecture techniques (*e.g.*, 'clickers'[7]) in the introductory classes, and staffed as many of those classes as feasible with dynamic instructors who are sensitive to the needs of students from underrepresented groups;
- Instituting tutorial sections in the junior level classes;
- Changing graduate admissions criteria to de-emphasize graduate record exams and increase consideration of research experience and personal statement;
- Changing the qualifying examination to make each sitting of the exam less stressful by allowing students to pass the exam in segments rather than requiring that they pass it all at once;

[7]See Section 3.4, p. 27

- Moving the yearly picnic to campus at lunchtime instead of holding it offsite on a weekend (attendance was greatly improved);
- Holding regular monthly informal get-togethers ("Final Friday Flings");
- Encouraging the Career Development Organization[8], including sponsoring its annual Networking Day where students meet potential employers and learn about non-academic career options;
- Revamping its mentoring program for incoming graduate students to ensure quarterly advising meetings individually and as small groups, and to have first year advisors keep track of students until they find a research home;
- Including diversity related issues in the orientation activities for new graduate students;
- Holding two department-wide meetings to discuss issues related to diversity (a third is planned for spring quarter);
- Surveying faculty, staff and students about departmental climate,;
- Adopting a policy of sending representatives to the National Society of Black Physicists and National Society of Hispanic Physicists meeting for recruiting graduate students (one current student, from Cameroon, was recruited at such a meeting, and is traveling there this month as a recruiter);
- Using our NSF Research Experiences for Undergraduates program as a means to bring students from traditionally underrepresented groups to campus, and then encouraging them to apply for graduate school (both at UW and elsewhere).;
- Developing, with approval of the faculty, a "diversity plan" for the graduate school;
- Sponsoring a group of interested faculty, staff and students to perform outreach in local high schools with high populations of students from traditionally underrepresented groups;

[8] See Section 9.1, p. 182

- Encouraging quarterly community outreach projects, coordinated by graduate students; and
- Installing baby-changing stations in 5^{th} floor restrooms.

The departmental efforts toward improving climate are slowly moving from the concern of a few dedicated faculty to a general concern of the entire department. The above changes have been accepted by members of the department, and are regarded by most to be positive improvements. It is too early to assess whether the recent increases in hiring faculty and recruiting both undergraduate majors and graduate students from traditionally underrepresented groups are statistical fluctuations or long term changes. However, the department remains committed to continuing these efforts.

6.4 Collaborative efforts to increase diversity

The graduate coordinator and admissions committees are coordinating with Sibrina Collins of the graduate school in developing contacts at schools with large minority populations. We have utilized the GO-MAP fellowship program for recruiting. We partnered with Astronomy on an NSF proposal for recruiting at the undergraduate level, but it was not funded. In her role as director of the Nanotechnology Ph.D. Program and chair of the Physics Diversity Committee, Prof. Olmstead has represented both physics and nanotechnology at meetings of the Science and Engineering Diversity Group and also at meetings discussing issues in interdisciplinary education.

6.5 Curricular and Climate Changes

The physics curriculum, *per se*, is largely independent of issues related to diversity. New courses related to diversity include Issues for Minorities and Women in Science and Engineering (Phys 451), which is taught every 2-3 years (first taught in 1999). A special topics class on Scientific Ethics was also taught once during the past ten years.

More generally, changes in pedagogy and curriculum can have differential impact on various student populations. Our department is unusual in encouraging majors who are not grad-school bound, and is one of the three largest producers of physics bachelors degrees in the country. A significant number of majors deviate from the "standard path" to a physics degree; accommodating these different paths aids all students, but especially those with family obligations. The department started teaching the core majors courses (advanced sophomore and junior level courses) twice each year to enhance opportunities for students, especially those transferring from community colleges.

Overall, the department is evolving into a more diverse environment. For example, last year all the officers of the SPS were "non-traditional" students – re-entry, first-generation college, Hispanic, female; all three new faculty are also from traditionally underrepresented groups; the new graduate admissions criteria led to a larger fraction of non-traditional students in the first year class.

Chapter 7

Bachelor's Program

7.1 General Discussion

Objectives

In broad terms, the objectives of the physics bachelor's degree program are a natural outgrowth of the central role played by physics in modern society. Our dramatic technological progress is rooted in the answers found by physicists who ask the most fundamental questions about the physical world: what are its basic constituents, what general laws describe the behavior of these constituents, and how do these laws manifest themselves in the organization of the constituents into larger entities from nucleons to galaxies? Basic physics establishes the underlying structure for many practical arenas of intellectual activity and helps provide an understanding of a very diverse range of phenomena, from the microscopic to the largest scales in the universe.

The goal of the physics bachelor's degree is to provide instruction, guidance, and learning opportunities for University of Washington students to have productive careers in our increasingly complex world. The criteria that underlies the bachelor's degree program is consonant with the findings of the AAAS *Project 2061*[1] for the effective use of scientific knowledge:

- To put scientific training effectively to work, a student must have the knowledge, the quantitative, communicative, manual and critical-

[1] *Project 2061: Benchmarks of Scientific Literacy* (Oxford University Press, New York, 1993).

thinking skills, and the attitudes and inclinations necessary for effective problem-solving.

- To develop intuitive feelings for what is reasonable and to recognize the use of vague and poorly substantiated arguments, a student must be able to link quantitative competence and estimation skills with learning about the real world.
- To use scientific knowledge productively, a student must have the ability to communicate clearly, convincingly, and accurately.

As scientific educators we strive to train young minds to ask questions, finds ways to define answers, recognize when adequate answers have been obtained, and apply those answers where needed. At the simplest level, our goal is to train *problem-solvers*. In an ever increasingly technological world and a state whose future relies upon advanced technology, such individuals are essential both directly in technical enterprises and as informed citizens.

Learning Goals for the Bachelor of Science Degree Program

In accordance with the university goal of setting learning objectives for all of its students, the Physics Department lists the learning objectives for its majors program as follows.

A student graduating from the University of Washington with a BS degree in physics should possess:

Knowledge of Physics. The student should:

- know the basic laws of physics (e.g. Newtons laws, Maxwells equations, conservation of energy and momentum, etc) and where they are relevant;
- have a qualitative understanding of the way the laws of physics govern how things work (e.g. un-balanced forces determine acceleration, time-varying electric fields produce magnetic fields, when and how things are quantized, etc);
- understand experimental evidence that supports the basic laws and the role that measurements play in science;
- be able to integrate disconnected bits of knowledge learned in the classroom into a coherent picture of the way the real world works;

- have a general awareness of current research in the fields of physics;
- know career paths that are available for a BS degree in physics.

Problem solving skills. The student should be able to:

- identify important concepts and ignore irrelevant data;
- use simple techniques (e.g. dimensional analysis, limiting cases, symmetry, order of magnitude estimates) for guidance toward and tests of more detailed solutions;
- incorporate physical intuition into an expectation for the character of a solution;
- translate physical concepts into symbolic mathematical language;
- use self-consistent reasoning and detect flaws in logic;
- use computer skills to solve problems numerically, to appreciate when such computational approaches are appropriate, and to know the limitations of the results;
- carry out detailed solutions (e.g. solving algebraic, differential, and integral equations).

Experimental skills. The student should be able to:

- take measurements of physical phenomena and understand the role of measurement uncertainties;
- use simple laboratory equipment (e.g. multimeters, oscilloscopes) and have a working knowledge of electronics.
- document experimental results and write accurate, clear and concise lab reports;
- analyze data using relevant curve fitting and error analysis techniques;
- participate in local and /or national research projects.

Communication skills. The student should be able to:

- present physics to technical and non-technical audiences;
- locate, evaluate, and use appropriate electronic and print resources;
- convey information using graphs, drawings, and pictures;

– give physically sound arguments to justify a stand on relevant issues.

Curriculum of the Bachelor of Science Degree Program

The University of Washington, being one of the larger research universities, has a Physics Department with a faculty of diverse interests. It offers one of the most varied physics programs in the nation as it attempts to graduate students who are competitive nationwide.

Our program is tailored to both those students who will pursue graduate studies in physics or a related science, and to those who will seek technical employment. While there are no "degree options", a multitude of paths are possible to meet the requirements for the BS degree. The curriculum for a BS degree is summarized in Table 7.1. A more detailed description of the curriculum is given in Section 7.2 and alternate paths to achieve the degree are presented in Section 7.3 in addition to the physics requirements in Table 7.1, 21 credits of mathematics (calculus, linear algebra, and differential equations) are required as are 9 credits of "related science" in Physical or Biological Sciences other than Physics or Mathematics. The minimum number of credits to earn a BS degree in physics is 87.

In general terms, we recommend that those students interested in graduate study in physics take a full year of electricity and magnetism and two quarters of quantum mechanics as juniors, three quarters of mathematical physics and as many survey courses as possible in atomic, nuclear, particle, and solid state physics, as well as a full complement of advanced labs. For those students interested in entering the job market immediately after graduation, we recommend that they take as many laboratory courses as possible (electronics, computer interfacing, optics, and atomic, solid state, and particle physics labs are offered).

Since the Department believes that knowing how to solve real world problems in a research environment is a valuable asset, it requires for graduation that all students do at least one quarter of independent study with a faculty member, or otherwise participate in a research seminar. We also encourage our strongest students to learn the art of teaching by signing up for parttime teaching duties. Some of these students take the same teacher training course that first year graduate students take, and are full TAs in instructional labs and tutorials.

Course	Title	Credits	Requirement
121	Mechanics	5	required
122	Elec. and Mag.	5	required
123	Waves	5	required
224	Thermal Physics	3	required
225	Modem Physics	3	required
227	Elem. Math. Physics I	3	required
228	Elem. Math. Physics II	3	required
229	Classical Mech.	3	optional
231	Modern Physics Lab.	3	optional
232	Computational Phys.	3	optional
321	Electromagnetism I	4	required
322	Electromagnetism II	4	required
323	Electromagnetism III	4	1/2 of acr[2]
315	Applied Quant. Mech.	3	315 or 324 required
324	Quantum Mech. I	4	315 or 324 required
325	Quantum Mech. II	4	1/2 of acr
334	Electronics Lab	3	required
335	Microprocessor Lab	3	1/2 of alr[3]
331	Optics Lab	3	”
311	Special Relativity	3	optional
328	Statistical Mech.	3	”
421	Atomic Physics	3	”
422	Particle Physics	3	”
423	Solid State Physics	3	”
424	Math. Physics	3	”
431,2,3	Modern Physics Lab	3	alr
434	Computer Lab	3	”
401,2,3	Independent Study	3	”
484,6,7	Honors Seminar	3	isr[4]
491,2,3	Seminar on Current Prob.	3	”

[2]Advanced Course Requirement
[3]Advanced Laboratory Requirement
[4]Meets Independent Study Requirement

Table 7.1: Present Curriculum for a BS degree in Physics

Curriculum Reform

In 2004, the physics department established a faculty committee (with student representatives) to review the curricula of our programs. As described in the "Assessment Standards" section below, feedback from physics majors along with faculty desire to strengthen the BS degree program has lead to a proposal that will modify significantly the BS program. The goals of the reform were to strengthen the second year of instruction to better prepare students for the challenges of the third year, to include more topics of current interest in the curriculum to show physics as *living* subject, and to ensure that all physics BS degree recipients have had exposure to a balanced palette of physics courses.

To meet these goals, a subsequent committee has proposed essentially five changes to the BS curriculum. First, two weeks of thermal physics will be added to Phys. 122 in the first year to allow Phys. 224, Thermal Physics, in the second year to introduce statistical mechanics. Second, Phys. 225, Modern Physics, in the second year will be split into two required courses: Introduction to Quantum Mechanics and a second course Particles and Symmetry. To make room for the additional required course, Phys. 229, Classical Mechanics, will be moved to the third year where it can be taught at a higher level appropriate for students who wish to take the Physics Graduate Record Exam. Fourth, Phys. 227 and 228, Elementary Mathematical Physics, will become 4 credit courses (rather than the current 3). The extra hour per week will be used to introduce numerical techniques for the solution of problems. Finally, fourth year courses in modern optics, biological physics, and general relativity will be added to the curriculum. A reduction in the requirement for courses in mathematics keeps the total number of credits required for a physics BS degree unchanged. If approved by the faculty, these proposed changes can take effect as early as Autumn, 2008.

Standards of Measuring Success

There are four measures by which we monitor and assess the BS degree program. First, enrollment data is compiled and evaluated. Second, yearly advising meetings between physics majors and faculty provide important feedback about the BS program. Third, graduating students fill out an exit survey that addresses the effectiveness of the program. Finally, the University Office of Educational Assessment performs biannual surveys of recent graduates to track their careers.

Consistent with trends nationwide[5], enrollment in our BS program has increased 50% over the past ten years, making our program one of the largest in the nation. Recently, our department was awarded the " 2007 AAPT Special Presidential Citation for achieving an exemplary increase in its number of physics majors".

Figure 7.1 shows the number of majors in the physics department over the past ten years. The figure shows that a significant fraction of our majors are enrolled in another major (about 1/3). This has an impact in the population of our fourth year courses since many students complete the minimum physics requirements and move on to complete their other major(s). The increased enrollment has caused the class size of some of our third year required courses to exceed the room capacity (*eg.* 90 students enrolled in an class with a capacity for 85). In response, we have added a second offering of the required courses in a different academic quarter. Another consequence of the enrollment growth is increased pressure on research groups to provide research opportunities for the students.

Figure 7.2 shows the enrollment of physics majors by gender. The fraction of women in the BS degree program is roughly stable at around 21%, comparable with the national average of 23%[6]. The pipeline for students who consider a major in physics is our calculus-based introductory physics sequence (Physics 121-123), for which the fraction of women was 28% in 2007.

Figure 7.3 shows the number of BS degrees in physics that our department has awarded in the past twenty years. Because we do not know all of the reasons for the increase in the number of physics majors over the past ten years, it is difficult to predict the demand for a physics degree in the next decade. In the near term, we expect that increased enrollment in the University of Washington, especially in the STEM disciplines, will translate to a moderate growth in the size of our BS program.

We interpret the enrollment data as evidence that our BS program is accessible to students and allows students to complete their undergraduate education in a timely manner.

There are no specific admissions requirements for a student to enter the Physics BS program. In 2007, the department instituted a policy that before

[5]*AIP Pub. Number R-151.42, p.5* August 2007).

[6]*AIP Pub. Number R-151.42, p.18* August 2007).

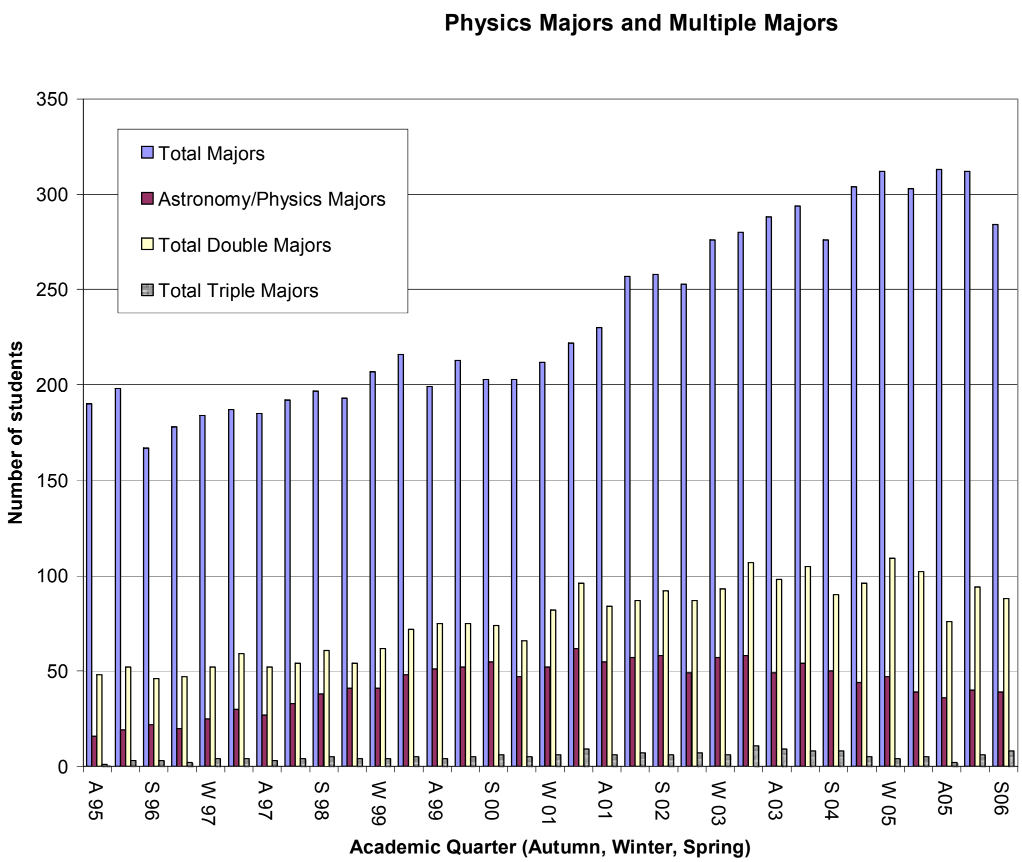

Figure 7.1: Enrollment Data for the Bachelor of Science Degree Program

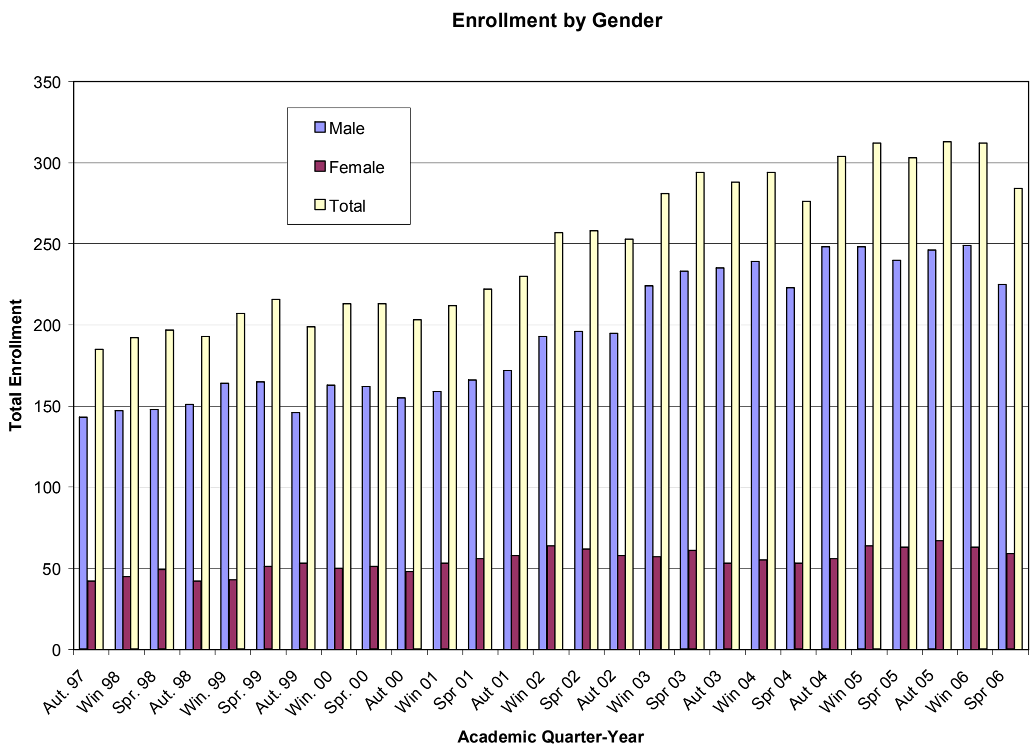

Table 7.2: Enrollment of Physics Majors by Gender

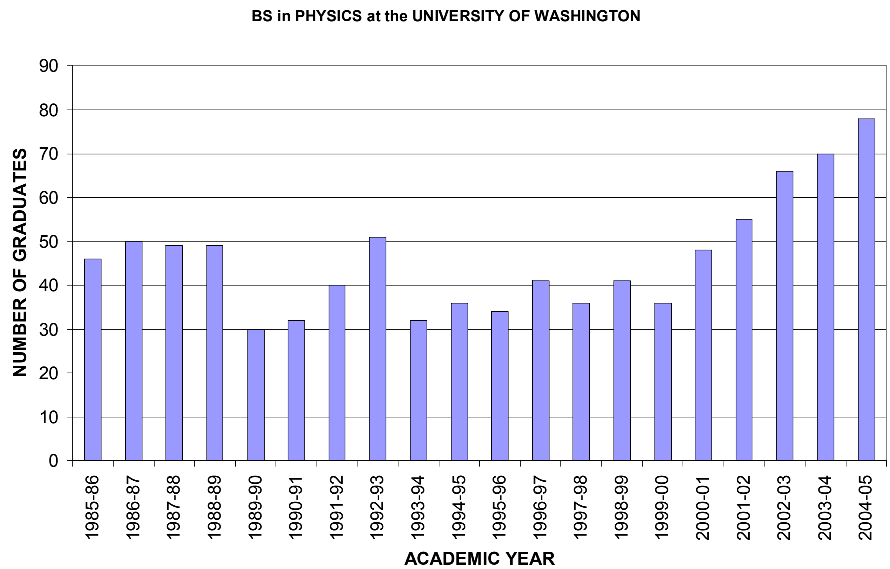

Table 7.3: Number of BS Degrees in Physics Awarded in Past 20 Years

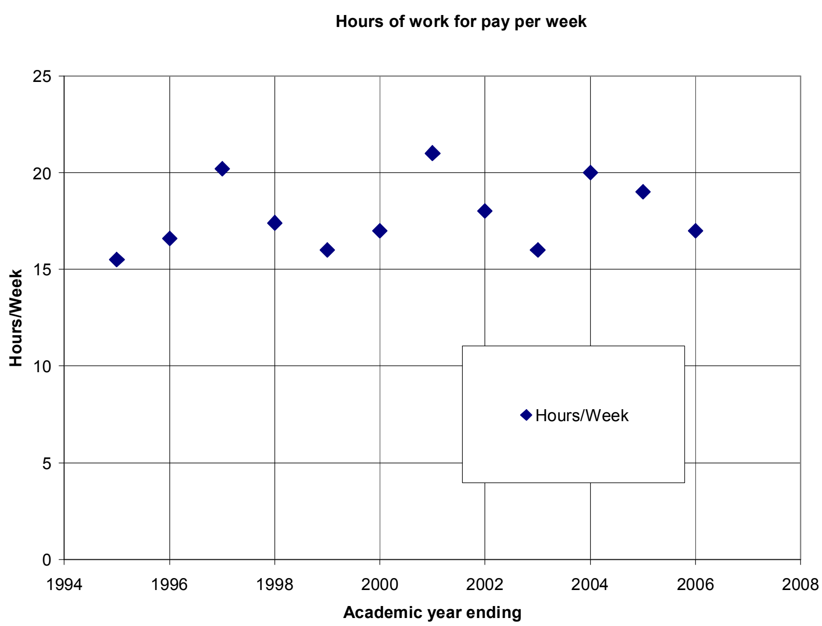

Table 7.4: Yearly Advising for the Bachelor of Science Degree Program

a student could declare a major in physics, the student would meet with the physics department undergraduate program coordinator. The purpose of this policy is to help ensure that new students understand the requirements of the BS program and have a sensible program of study. It is too soon to know whether this new policy is effective. The undergraduate program coordinator and faculty undergraduate advisor are available for advising throughout the year.

Once a year, usually in the spring, each physics major is required to go through formal advising. The advising is handled primarily by members of the Undergraduate Majors Committee. Students sign up for 20 minute interviews with faculty members. The faculty advisors are provided with the academic records of the student, and the students are requested to provide a plan for the completion of their BS degree. The plan of study is discussed with particular attention paid to signs of poor grades that may impede the progress of the student. This advising procedure has proven effective as a means to guide students to the courses that best match the educational goals of the student.

The advising sessions also provide important feedback about the problems students encounter in their BS studies. Four examples illustrate the feedback that the advising sessions have provided. First, we learned that many graduate school bound students had insufficient background in classical mechanics at the level needed for the Physics GRE exam. The course we offered in classical mechanics was taught in the autumn of the fourth year which was concurrent with or later than the time the students took the GRE exam. In response, we created a new course in classical mechanics, Physics 229, which is taught in the spring quarter of the second year. A second example was a consensus among students that the third year courses in electromagnetism and quantum mechanics required work in excess of that expected for a three credit class and that the homework sets were so challenging that students needed help to learn the techniques for solving the problems. In response, we changed the courses to four credits and used the extra hour per week as recitation sessions focused on problem solving. A related example is that we learned that offering the required third year courses only once per year created challenges in the schedules of double majors, transfer students, and students who needed to retake the courses. In response, we added a second offering each year of the required third year courses. A final example is a work still in progress. We learned from the students that the second year course offerings did not always adequately prepare students for the rigorous courses required in the third year. A Curriculum Revision Committee studied this problem and proposed changes to the first and second year curriculum to modernize and strengthen the curriculum of the second year. An Implementation Committee has developed a detailed proposal that will be brought to the faculty for a vote in the spring of 2008.

Graduating students are asked to fill an exit survey where we ask questions about whether they had jobs for pay, their satisfaction with physics as a major, their satisfaction with our program, quality of instruction, concern of faculty about their well being, comments about different classes, math preparation and future plans. We ask for written positive and negative comments. Data for the last 12 years is shown in Figures 7.4 and 7.5.

About 2/3 of our undergraduate majors work regularly for pay during the academic year. Some work as little as 5 hours/week while others report up to over 30 hours/week. It is obvious that long working hours leave little time to study or participate in university or departmental activities, and may be a major cause for mediocre academic performance. The number of hours worked/week has remained essentially constant for the last decade.

Praise from graduating seniors is centered on quality of most instructors, the undergraduate program advisor (Margot Nims), the quality of most of the courses, a broad and rigorous program, tutorials in Quantum Mechanics, the opportunity to do research projects, several individual instructors, the SPS room, and laboratory courses. Criticism ranges from individual experiences to more general topics: poor instructors and/or some of the instructors not being interested in undergraduates (reflected in consistently lower ratings in Fig. 7.7), too much mathematical rigor, lack of central place to find out about research opportunities, not enough practical or current topics, and weak sophomore courses. Students report that they are satisfied with the physics advising program, but that efforts should be made to catch students earlier. Section 7.4 provides a depersonalized (except for praise) list of comments is attached from the 2005-06 exit survey.

The exit surveys inform us that our BS program is viewed positively by the students, but there remains room for continued improvement.

University Surveys for the Bachelor of Science Degree Program

The University Office of Educational Assessment provides program and course evaluations. At least once per year, each faculty instructor must have a student evaluation of her/his course conducted by the Assessment Office. In addition, the physics department regularly conducts "peer reviews" of instructors to identify ways to improve the instruction.

The physics department has not been able to track the careers of its graduates. Instead, we rely upon the Office of Educational Assessment to conduct biannual surveys of recent University graduates. The most recent results can be found at http://www.washington.edu/oea/pdfs/grad1year/G5239.PDF. The responses on the most recent survey were consistent with those of previous surveys. For example, it appears that graduates of the physics BS program have little difficulty finding employment, most often in the local area. While the positions taken are not generally directly related to physics, they are generally highly paying. The survey results clearly suggests that holders of BS degrees in physics find positions with larger salaries than their colleagues who came from either rest of the physical sciences or from all of Arts and Sciences.

Challenges for the Bachelor of Science Degree Program

There are two major challenges for fulfillment of the physics majors learning goals while complying with state-mandated measures to reduce time-to-degree. The first challenge is to minimize the obstacles that students encounter while completing their degrees. The second challenge is to ensure that students who elect to graduate with the minimum number of required courses receive an education consistent with the learning goals.

In accordance with goals set forth by the state of Washington and the University, the physics department strives to provide a BS program that efficiently prepares students for a variety of career paths with minimal obstacles that are not under the control of the students. The major impediment to the completion of a physics BS degree are obstacles that prevent students from being able to take required physics courses at the time they are offered. These obstacles arise for students whose jobs prevent a full-time academic load, transfer students who arrive "off-sequence", double majors with course schedule conflicts, and students who need to re-take a course in which they failed to meet the minimum standards set forth by the department (a minimum grade of 2.0 in selected courses that are prerequisites for other required courses).

To overcome the course "bottleneck" impediment, the department has provided a menu of course offerings whereby each required physics course for a BS degree is offered in at least two academic quarters every year. The timing of the second offering of required courses is such that a student transferring into our program during the Winter Quarter can "catch up" so that by the following year, the student will be "on-sequence". Such duplicate offerings also make it easier for double majors to schedule required courses in more than one department and for students who need to re-take a course to do so without having to wait a full year. Multiple offerings of required courses limits the number of general education and special topic courses that the department can provide.

Two additional measures have been taken recently to reduce the number of students who fail to meet the minimum standards in our courses. Our advising program now attempts to interview students before they enter the physics BS program to ensure that the students do not enroll in courses for which they are not prepared. And a new second year curriculum has been proposed whose intent is to better prepare students for the challenges of the required third year courses.

Our large undergraduate program includes students who take very different paths towards their degrees. A study was conducted by the Curriculum Committee of our department in 2005. The study tracked the academic careers of 360 physics majors who received their degrees between 1997 and 2005. It was found that nearly 1/3 of our physics majors take the bare minimum of courses required for a degree, consistent with the fact that 34% of our majors graduate within 4 quarters of passing Physics 228 (the second quarter of the mathematical physics requirement). The remaining 2/3 of the majors take varying numbers of upper division (300 and 400 level) electives, graduate 2 or more years after having taken Physics 228, and includes those students who are graduate school bound. The "minimum course work" group of students had an average grade of 2.8 in Physics 228 while the remaining 2/3 had an average grade of 3.2. In fact, many instructors of the courses required for a physics BS degree report observing a "double-humped" grade distributions, which suggests that the undergraduate physics program now serves two relatively distinct cohorts of students with differing skills and interests. In particular, one of the humps is populated by a group of students who struggle in our courses.

There has been concern and significant discussion about how well our BS program fulfills the needs of both groups of students. There are faculty members who believe that neither group is well served: the level of courses is often pitched somewhere between the abilities of the two groups and is optimized for neither. Other faculty members point to the success of our graduate school bound students and the fact that the group of students who graduate with the minimum number of credits report satisfaction with our program and seem to find stable employment as evidence that our program is reasonably balanced. These discussions are sure to continue, especially in light of the proposed changes to the BS curriculum. There is consensus that our department should consider offering different degree options (perhaps a BS and a BA, or a BS and Applied Physics BS) to better serve our different student populations.

Involvement in Research Programs

The opportunity for students to study and work in a research environment is a vital component of the educational experience at the University of Washington. In addition to gaining research experience, students become better known to faculty who often are asked to write letters of recommendation for the students. The physics BS degree requires a minimum of 3 credits of independent study. This requirement can be met in two ways: independent study with a research group (usually working in a laboratory) through enrollment in Physics 401, 402, or 403, or independent study in a research seminar course, Physics 494, 495, or 496 (Physics 485, 486, 487 are the honors sections of the research seminar). Figure 7.6 shows the enrollment in both the laboratory and seminar courses for the past 10 years. Approximately 80% of physics majors are able to arrange independent study with a research group.

The spring advising of physics majors plays an important role in helping students arrange independent study with a research group. In the advising sessions, the students' interests, existing research programs, and potential faculty contacts are all discussed. Ultimately, each student must contact a faculty member to arrange the independent study. The undergraduate program coordinator provides advice and a "blue sheet" that must be filled in that describes the work to be done and the method for evaluation of the work. The blue sheets from the previous year are posted so that students can learn what opportunities exist and who to contact. The Society of Physics Students provides encouragement and advice to new physics majors who have questions about undergraduate research.

There are two major impediments to effectively involving undergraduates in research. The first arises from external constraints on the time that students have available for research. Exit surveys reveal that physics majors have external jobs and work for pay on average 15-20 hours/week. The most rewarding research experiences arise when students have enough time to become deeply engaged in a project. Students who have time for only 1 research credit (3 hours/week) are often not able to keep pace with the developments of a project and will miss opportunities to witness the thrills of discovery. The Mary Gates Scholarship program provides money for students to do independent research. Physics majors are encouraged to apply for Mary Gates Scholarships to allow them to have more time for research.

The second impediment to undergraduate research is the demand on faculty, post-doc, and graduate student time to create projects appropriate for undergraduates and to mentor the young students. As the physics BS degree program enrollment has increased, there was concern that we would be unable to provide research opportunities for the extra students. As shown in Figure 7.6, our research opportunities have kept pace with the increased enrollment, but the growing scarcity of research money and shrinking faculty size raise concerns about whether we will be able to continue to provide enough research opportunities for all our students. There is also a sentiment among faculty that insufficient recognition is given to the time and effort required to involve undergraduates in research; raise and promotion criteria emphasize classroom reaching and graduate student supervision.

The exit surveys of graduating physics majors provide an assessment of our undergraduate research program. Motivated by student comments, we provide advice at an earlier stage in the physics major to encourage students to begin to arrange their independent study and we post a list of all recent undergraduate research projects. Once placed in a lab, students comments about their research experiences are overwhelmingly positive. Additional positive feedback is provided by those students who enroll in graduate school and are able to compete with the best students nationwide.

Other Teaching Innovations in Bachelor of Science Degree Program

In the past 10 years, the Physics BS degree has added a recitation section to the junior level Electromagnetism (Physics 321, 322, 323) and Quantum Mechanics (Physics 324, 325) courses. These courses are the most demanding courses required for a major in physics. The Physics Education Research Group (PEG) in our department has developed tutorials for the Quantum Mechanics recitation sections to address specific conceptual problems that students encounter in this topic. Student response to the tutorials and role of the recitation section in the Quantum Mechanics courses has been very positive. The sections in the Electromagnetism courses are used for problem solving and suffer from uneven success, based primarily upon the training that we can offer the TA's who teach the sections. Our plan is to develop tutorials for the Electromagnetism courses, similar to what has been done in Quantum Mechanics.

A second innovation has been the modernization of Physics 434, "Application of Computers to Physical Measurement". The original course used a Z80 microprocessor breadboard to teach the principles of interfacing measurements to computers. The current course in based upon the LabView software package running on a PC that is an industry standard.

A final innovation that will be implemented in 2008 is the introduction of numerical computational techniques in the second year Physics courses (Phys. 227, 228, 321). There is a strong sentiment among the physics faculty that physics majors should have the ability to use computer techniques to solve problems. At the December 2007 faculty meeting, it was voted that an hour per week (one credit) be added to Phys. 227 and 228 to be devoted to introducing numerical computational techniques. It is also proposed that the first course in Electromagnetism, Phys. 321 be moved to the second year to immediately follow the mathematical physics sequence. The recitation section in Phys. 321 would also be devoted to numerical computation. In this way, the computational skills become part of the required physics curriculum and the skills will be developed as the students encounter the mathematical problems that require these techniques. The Physics Visiting Committee (primarily friends of the department from industry) recommends that we use MatLab software for teaching computation as this software is widespread in industry.

Society of Physics Students and Sigma Pi Sigma

Ten years ago, the Society of Physics Students was moribund. Since then, the Society, under a succession of dedicated undergraduate officers and its faculty advisor, Michael Schick, has been completely revitalized. A weekly activity consists of a pizza lunch on Monday with the speaker who will give the Colloquium later that day. The guest gives an informal talk to the SPS on the subject of the Colloquium or on any other topic of mutual interest. Typically there are about fifteen students at these lunches, which are subsidized in part by the Department. We have invited Seattle high school students to join us when they are able to do so.

The SPS has offered tours of many of the physics laboratories to show the undergraduates what sort of work is carried out here and to acquaint them with research opportunities. We have sponsored a day trip to LIGO near Hanford Washington as well as to other observatories. Members of the SPS have participated in professional meetings, such as the AAP meeting in Seattle in 2007, and have made many presentations at the Undergraduate Science Research Day at the UW. The SPS has also participated in "Dawg Days", an event designed to acquaint incoming freshman with the Department of Physics. It has also begun to display the photographs of all physics majors, an ongoing project. The local chapter of the physics honor society, Sigma Pi Sigma, which had been dormant since 1934, was resurrected last year at the students request. A class of fourteen which met the rigorous admission standards, a grade point average in Physics of at least a 3.8, was inducted.

More information about the local chapter is provided on its web site, http://ermine.phys.washington.edu/users/sps/Welcome.html.

Since the year 2000, the chapter has six times been designated an "Outstanding Chapter" by the National Society.

Compliance with State-Mandated Accountability Measures

The physics BS program is designed to comply with state-mandated accountability measures, specifically reduced time to degree and increased graduate efficiency index (GEI). Two department policies have been essential to meet the state-mandated requirements. The first is a decision to offer each course required for a physics BS degree at least twice during the academic year.

As already described, the timing of the second "off-sequence" offering is designed to accommodate transfer students who arrive in the Winter Quarter. The off-sequence offering is also essential for students who need to repeat a required course and for those students having course conflicts with other university requirements. The second department policy is the decision to require only 87 credits for the physics BS degree and to allow many of those credits to be met by elective physics courses and courses in other science departments. The flexible BS requirements are essential for students pursuing double or triple majors (33% of physics majors) and for students who decide to pursue physics only after their first year at the university. (Engineering majors are often advised to take introductory physics in their second year. Many of these students decide at that time to pursue a BS degree in physics. The courses required for a BS degree in physics can be met in three years).

Figure 7.7 shows the average time to a Physics BS degree from first enrollment at the UW over the past 10 years. (This data and the GEI data may be found at
http://www.washington.edu/admin/factbook/OisAcrobat-
/OisPDF.html#anchor3).

The physics department has made significant progress in reducing the time required for students to earn a BS degree.

Figure 7.8 shows the graduate efficiency index of the physics BS program compared to the average GEI of the natural science departments at the University of Washington. The GEI is comparable to that of other science departments, but on average slightly lower. We believe that the slightly lower average is a result of the large number physics majors who pursue double and triple degrees, leading to more total credits earned than the average science major. (GEI = 100× (Minimum Required Credits for Degree - Transfer Credits)/(Total UW Credits))

The steps taken to comply with state-mandated accountability measures come at a cost. Multiple offerings of required courses limits the number of optional courses that the department can offer in the BS program. Many topics of current interest such as Biological Physics and Cosmology cannot be offered on a yearly basis. The quality of student learning is not compromised, but the breadth of the material that is taught is reduced. Having a BS degree requirement that can be met in three years means that fourth year courses are not part of the required curriculum. We strongly advise students who are interested in graduate study to take a number of courses beyond the minimum requirement. These extra courses are needed for the students to have seen all of the subjects tested on the Physics Graduate Records Exam. Part of the motivation for the BS degree curriculum reform described elsewhere in this document is an attempt to ensure that even the minimum physics BS requirements teach students to the ideas, skills, and analytic thinking that is expected of graduates from a major research institution.

Undergraduate Placement

About 25% of our undergraduates go on Graduate School in Physics; 25% go on to graduate school in non-physics studies (*i.e.* MBA, Electrical Engineering, Mechanical Engineering, Oceanography, Earth & Space Studies); 50% go on to jobs in varied areas (Microsoft, other computer companies, National Labs (*i.e.* Lincoln Lab, JPL,), FBI, CIA, Boeing, small private companies, while some start their own businesses (usually software-oriented).

7.2 B.S. Requirements

Minimum Requirement in UW Courses

At least 12 credits of the physics courses presented to satisfy the major requirement must be in physics courses numbered 300 or above taken at the University of Washington.

(Note: These fall far short of what is desirable. Almost all physics majors will find that they need to complete considerably more than a minimum program to achieve their personal goals. Suggestions for electives beyond this minimum are given in later sections)

Language Skills

English Composition (5 cr) and Foreign Language (0-15 depending on the placement)

Reasoning & Writing in Context

Quantitative/symbolic reasoning (QSR; 5 credits; may be fulfilled by Math/Physics courses) and additional writing courses (10 credits)

Areas of Knowledge

General-education courses to include at least 20 credits in each of the following three areas: Visual, Literary & Performing Arts (VLPA); Individuals and Societies (I&S); The Natural World (NW; may be fulfilled by Math/Physics courses)

Electives

Free choice; as many credits as necessary to bring the total to 180 (including the Major credits)

(Note: To be awarded a baccalaureate degree from the College of Arts & Sciences, a student must fulfill requirements in the following areas: Language Skills, Reasoning and Writing in Context, Areas of Knowledge, and a Major. All required courses must be taken for a numerical grade. In addition, the student must present at least 90 credits outside the major department and must meet minimum GPA requirements of 2.0)

Description of Requirements

Core Physics Courses

All physics majors are required to complete 48 credits in basic physics courses with grades of 2.0 or better. This requirement forms a "core" which includes an introduction to all the principal areas of physics. It provides an essential foundation for later work in all areas of physics as well as in other sciences and technologies.

The required core courses are:

Physics 121 Mechanics (5)

Physics 122 Electromagnetism and Oscillatory Motion (5)

Physics 123 Waves (5)

Physics 224 Thermal Physics (3)

Physics 225 Modern Physics (3)

These five courses are the basic physics sequence for students majoring in physical sciences and engineering, and for many biological science majors. They treat all the principal fields of physics at a relatively sophisticated level. They use the student's concurrently developing skills in differential and integral calculus.

An "honors" section of Physics 121 is available in Autumn Quarter with "honors" sections of 122 and 123 following in Winter and Spring Quarters. Physics majors are encouraged to enroll in this section. It provides a deeper, enriched background in physics for those with a deeper interest in the subject.

Physics 227, 228 Elementary Mathematical Physics (3, 3)

> These courses introduce a variety of important applications of mathematics to physics. They are a very important preparation for later courses such as Physics 321 and Physics 324. They are a part of the second year physics program. It is very difficult to graduate in four years if they are postponed.

Physics 321, 322 Electromagnetism (4, 4)

> Intermediate work in the theory of the electromagnetic field. These are the first physics courses to make full use of the student's now sophisticated background in mathematics. In addition to the study of electricity, magnetism and relativity, they introduce the student to advanced mathematical techniques in physics. The field theory treated here is the model for most other physical theories.

Physics 334 Electric Circuits Laboratory (3)

> This course provides a solid background in the analog and digital electronics used throughout physics. (Though it carries a 300-numbers, it is intended to accompany the 200-level physics courses and to be completed in the sophomore year. Postponing it a year may cause severe scheduling problems, and often leads to a diminished program.) This course is usually offered in Summer Quarter as well as during the academic year.

Advanced Modern Physics

All physics majors are required to complete at least one 300- or 400-level lecture course in modern physics with a grade of 2.0 or better. This requirement is to ensure that all majors have at least minimum contact at a professional level with those areas of physics which are of greatest current interest.

Possible choices include:

Physics 324 Quantum Mechanics (4)

Physics 315 Applied Modern Physics (3)

The following courses have prerequisites Physics 323 and 325 (or permission):

Physics 421 Atomic and Molecular Physics (3)

Physics 422 Elementary Particle Physics (3)

Physics 423 Solid State Physics (3)

Advanced Laboratory Work

All physics majors are required, in addition to Physics 334, to complete at least two 300- or 400-level physics laboratory courses with a grade of 2.0 or better. This requirement is to ensure that all majors have a minimum contact with professional-level experimental physics. The importance of this requirement is illustrated by the fact that most physics majors spend a large part of their careers in experimental work.

Possible choices include:

Physics 331 Optics Laboratory (3)

Physics 335 Electrical Circuits II (3)

Physics 431 Modern Physics Laboratory (3) (Condensed Matter)

Physics 432 Modern Physics Laboratory (3) (Atomic & Molecular)

Physics 433 Modern Physics Laboratory (3) (Nuclear & Particle)

Physics 434 Application of Computers to Physical Measurement (3)

In unusual circumstances, and with approval prior to enrollment, Physics 401, 402, 403 Special Problems, may be accepted as fulfilling this requirement. This is most often in cases where the work includes three or more credits of independent experimental work in physics research laboratories. The student's role must be more than just that of an aide about a laboratory.

Research and Seminar Courses

All physics majors are required to complete at least three credits of physics research or seminar.

Possible choices include:

Physics 401, 402, 403 Special Problems (1-30)

Physics 485, 486, 487 Senior Honors Seminar (1, 1, 1)

Physics 491, 492, 493 Independent Research (1-3, 1-3, 1-3)

Physics 494, 495, 496 Seminar on Current Problems in Physics (1, 1, 1)

Any of these courses may satisfy the writing requirement provided they involve both written and oral presentation, with the work done according to the conditions specified by the College of Arts and Sciences for writing course credit. When this is done the student ordinarily should enroll for three credits, not one.

Courses in Calculus

All physics majors are required to complete courses in integral and differential calculus to the minimum level essential for advanced work in physics. This includes work in the calculus of single and multiple variable functions, vector analysis, and differential equations.

The following mathematics courses are sufficient to fulfill this requirement:

Math 124, 125, 126 Calculus with Analytical Geometry or Math 127, 128, 129 Calculus for Mathematical Sciences (5, 5, 5)

Math 308 Linear Algebra with Applications (3)

Math 324 Advanced Multivariable Calculus I (3)

Alternative ways of fulfilling this requirement are described in the Required and Recommended Mathematics Chapter.)

Students who contemplate advanced study in physics, other sciences, or engineering are advised to take, in addition to the above:

AMath 401, 402, 403 Introduction to Methods of Applied Mathematics (4, 4, 4) or similar courses in applied analysis such as Math 427, 428, 429 Topics in Applied Analysis (3, 3, 3)

Electives in Physics and Cognate Subjects

The Department of Physics requires that every student complete a major requirement consisting of at least 54 credits in a single field or in approved cognate subjects. The four requirements already listed add up to only 48 credits. Hence, the student must complete at least 6 more approved credits with grades of 2.0 or better in upper division courses in Physics or cognate subjects. (The requirement of 2.0 or better grades applies only to the minimum of 54 credits, not to courses elected beyond this requirement.)

So that students may have maximum freedom to plan programs suitable to their personal goals, these remaining credits may be selected from the list of **Approved Electives in Physics and Cognate Subjects**. This list includes advanced courses in physics plus nearly 200 courses in other sciences and engineering which are related very closely to physics. Although only 6 credits in elective courses are required, most students will want to complete considerably more to fulfill their personal goals. Physics graduates, in fact, have completed an average of 18 more credits in physics plus 41 credits in other sciences and in engineering.

The exact choice of electives always will depend on personal interests and career plans. Physics Advisers can be of assistance in many cases, but every student will need to devote substantial personal effort to working out a satisfactory plan.

Approved Electives in Physics and Cognate Subject

(A minimum of 6 credits are required)

In many cases, courses included in this list are open to students who have completed the specified physics and mathematics courses required for a bachelor's degree even though they may not completed the prerequisites listed for the courses. This is possible because the physics and mathematics courses have been judged to be roughly equivalent to the specified prerequisites. In case of doubt, the instructor of the course should be consulted (courses in brackets are prerequisites).

Additional courses may be approved in some cases on an individual basis. Students who seek approval of a course not listed should consult with Professor Van Dyck in the Physics Department.

Aeronautics and Astronautics

AA	300, 301, 302	Aerodynamics (4, 4, 4)
AA	310	Orbital and Space Flight Mechanics (4)
AA	311	Atmospheric Flight Mechanics (3)
AA	321, 322	Junior Lab (2, 2)
AA	330, 331, 332	Structural Analysis (4, 4, 4)
AA	400	Gas Dynamics (3) [302]
AA	402	Fluid Mechanics (3) [302]
AA	430	Finite Elemental Structural Analysis (3) [332]
AA	480	Systems Dynamics (3)

Astronomy

ASTR	321	The Solar System (3)
ASTR	322	The Contents of Our Galaxy (3)
ASTR	323	Extragalactic Astronomy and Cosmology (3)
ASTR	422	Interstellar Material (3)was 423
ASTR	497	Topics in Current Astronomy (13)

Atmospheric Sciences

ATM S	301	Introduction to Atmospheric Sciences (5)
ATM S	340	Introduction to Thermodynamics and Cloud Processes (5)
ATM S	431	Atmospheric Physics (5) [301]
ATM S	441, 442	Atmospheric Motions I, II (3, 5) [301]
ATM S	511	Formation of Snow and Ice Masses (3)

Ceramic Engineering

CER E	411	Vitreous State (4)
CER E	420	Colloidal Ceramics (3)
CER E	470	Refractories (3)

Chemistry

CHEM	335, 336, 337	Honors Organic Chemistry (4, 4, 4) [155, 160, or 162]
CHEM	455, 456, 457	Physical Chemistry (3, 3, 3)
CHEM	460	Spectroscopic Molecular Identification (3)
CHEM	461	Physical Chemistry Lab (23) [455]
CHEM	463	Spectroscopic Techniques for Structural Identification

Chemical Engineering

CH E	310	Material and Energy Balances (4)
CH E	326	Chemical Engineering Thermodynamics (4) [310, Chem 456]
CH E	330, 340, 435	Transport Processes (4, 4, 4)

Civil Engineering

CIVE	342	Fluid Mechanics (4)
CIVE	379, 380	Elementary Structures (3, 3) [Engr 320]

Earth & Space Sciences (previously Geophysics

ESS	413 (old GPHYS 403)	Geophysics: The Earth (3)
ESS	414 (old GPHYS 404)	Geophysics: Fluids (3)
ESS	415 (old GPHYS 405)	Space and Plasmas (3) [Phys 321]
ESS	416 (old GPHYS 406)	Geophysics: The Atmosphere (3) [404]
ESS	411/511	Geophysical Continuum Mechanics (3)
ESS	532	Formation of Snow and Ice Masses (3)
ESS	551	Mineral Physics (3)

Electrical Engineering

EE	436	Medical Instrumentation (4)
EE	445	Nonlinear Systems Analysis (4)
EE	467	Antennas: Analysis and Design (4))
EE	481	Microwave Electronic Design (4)
EE	482	Semiconductor Devices (4)
EE	488	Laser Electronics (4)

Engineering

ENGR	343	Environmental Radioactivity (3) was 305
ENGR	360	Introductory Acoustics (3)

Geological Sciences

GEOL	474	Introduction to XRay Crystallography (3)
GEOL	476	Isotope Geology (3)

Materials Science and Engineering

MSE	314	XRay Diffraction and Crystallography (4)
MSE	351	Electron Theory of Engineering Materials (3)
MSE	456	Experimental Techniques in Materials Sciences (3)

Mechanical Engineering

ME	323	Thermodynamics II (4)
ME	331	Introduction to Heat Transfer (4)
ME	333	Introduction to Fluid Mechanics (4)
ME	352	Mechanics of Solids (3)
ME	373	Introduction to System Dynamics (5)
ME	431	Advanced Fluid Mechanics (3)
ME	469	Applications of Dynamics in Engineering (4)
ME	470	Mechanical Vibrations (3)
ME	473	Instrumentation (3) [373]

Metallurgical Engineering

MET E	421	Metallurgical Processing (4)
MET E	462	Mechanical Behavior of Metals (3)

Oceanography

OCEAN	401, 402	General Physical Oceanography (3, 3)

Physics

PHYS	315	Applications of Modern Physics (3)
PHYS	323	Electromagnetism (4)
PHYS	324, 325	Quantum Mechanics (4, 4)
PHYS	328	Statistical Physics (3)
PHYS	331	Optics Lab (3)
PHYS	407, 408, 409	Physics by Inquiry (5, 5, 5)
PHYS	421	Atomic and Molecular Physics (3)
PHYS	422	Nuclear and Elementary Particle Physics (3)
PHYS	423	Solid State Physics (3)
PHYS	424, 425, 426	Mathematical Physics (3, 3, 3)
PHYS	427	Applications of Physics (13, max 12)
PHYS	428	Selected Topics in Physics (13, max 12)
PHYS	431, 432, 433	Modern Physics Lab (3, 3, 3)
PHYS	434	Application of Computers to Physical Measurement (3)
PHYS	441	Quantum Physics (4)
PHYS	500-599	[Any Graduate Course]

Related Sciences

In addition to the work in physics, mathematics, and cognate subjects already described, all physics majors are required to complete at least 9 credits in physical or biological sciences (excluding physics and mathematics), history of science, or individually-approved engineering courses. This requirement is to ensure that all who receive the B. S. degree in physics have at least an introduction to some other branch of science at the college level.

Courses taken to fulfill this requirement may include introductory courses in any of the approved areas (unlike courses taken to satisfy the electives requirement). Courses from the list of Approved Electives in Physics and Cognate Subjects also may be applied to this requirement if they fall into the categories listed above. However, courses used to fulfill this requirement may not also be used to fulfill the elective requirement.

Courses taken to fulfill the “related science” requirement may be used to satisfy the College of Arts and Sciences natural science distribution requirement if they appear in the appropriate list of Distribution Courses. That is, the same course may satisfy both requirements at the same time.

Engineering courses are approved for fulfilling this requirement only on an individual basis. Approved engineering courses must not have significant overlap with courses in physics or mathematics, nor may they be courses in computer programming.

Progress

In each academic year every undergraduate physics major who either has completed the required 200-level courses in physics or who has begun physics courses beyond the 200-level must:

A. Complete at least 15 credits of course work in fulfillment of the departmental degree requirements exclusive of credits earned by repeating courses in which acceptable credit has been earned previously.

or

B. Complete satisfactorily an approved part-time program of study. Students who do not satisfy this requirement will be dropped as physics majors unless exempted explicitly by the Physics Undergraduate Committee. Students dropped for this reason may petition this committee for readmission to the major.

7.3 Paths to Bachelor of Science

The various paths to the Bachelors of Science are presented in Tables 7.2 -7.5, pages, 161 - 164.

Standard Path to B.S.	
1st year	**Credits**
Mathematics 124, 125, 126 or 127, 128, 129 *Calculus* (15) Physics 121, 122, 123 *Introductory Physics* (15)	30
2nd year	**Credits**
Physics 224 *Thermal Physics* (3) Mathematics 307[1] *Introduction to Differential Equations* (3) Mathematics 324 *Advanced Calculus* (3) Physics 227[2] *Elementary Mathematical Physics* (3) Physics 225 *Modern Physics* (3) Mathematics 308 *Matrix Algebra* (3) Physics 228 *Mathematical Phys* (3) Physics 334[2] *Electric Circuits Laboratory* (3)	24
Recommended:	
Physics 231[1] *Introductory Experimental Physics*, 232[1] *Introduction to Computational Physics*(6) Physics 229[1] *Mathematical Methods and Classical Mechanics*(3) Physics 335 *Electronics II* (3)	
3rd year	**Credits**
Physics 321, 322 *Electromagnetism* (9) Physics 324[2] *Quantum Mechanics* (4) or Physics 315 *Applications of Modern Physics* (3) (either will satisfy modern physics requirement)	12 or 13
Recommended:	
Physics 311 *Relativity and Gravitation* (3) Physics 323[1] *Electromagnetism* (3) Physics 325[1] *Quantum Mechanics* (3) Physics 328[1] *Statistical Physics* (3) Physics 331 *Optics Laboratory* (3) Physics 434 *Application of Computers to Physical Measurement* (3)	

Note: Courses are required except where otherwise stated
Note: (#) indicate number of credits
[1]Courses recommended for further Physics work
[2]Physics 227, 324, 334 are usually offered during Summer Quarter

Table 7.2: Four year plan for a Bachelor of Science degree

Standard Path to B.S. (continued)	
4^{th} year	**Credits**
Physics 401, 402, 403 *Special Problems* or Physics 485, 486, 487 *Senior Honors Seminar* (required for Honors program) or Physics 491, 492, 493 *Independent Research* (to total 3 credits combined from 401/402/403, 485/486/487 or 491/492/493 - see Adviser for details) Recommended: Physics 407[3], 408[3], 409[3] *Physics by Inquiry II* (15) Physics 421[4] *Atomic and Molecular Physics* (3) Physics 422[4] *Nuclear and Elementary-Particle Physics* (3) Physics 423[4] *Solid-State Physics* (3) Physics 424[4] *Mathematical Physics* (3) Applied Mathematics 402[4], 403[4] (8) Physics 431, 432, 433 *Modern Physics Laboratory* (9)	3
Other	**Credits**
Approved course(s) in Physics or Cognate subject (5) Science courses other than Physics or Mathematics (9) Two labs above 300 level in addition to Phys 334[5] (6)	20
Total required Physics credits	**85 or 86**

Note: Courses are required except where otherwise stated

Note: (#) indicate number of credits

[3]Courses recommended for those interested in teaching physics

[4]Courses recommended for further Physics work

[5]Physics 227, 324, 334 are usually offered during Summer Quarter

Table 7.3: Continuation of Table 7.2

Alternate Path to B.S.	
1st year (taken elsewhere)	**Credits**
Mathematics 124, 125, 126 *Calculus* (15) Physics 121, 122, 123 *Introductory Physics* (15)	30
2nd year	**Credits**
Mathematics 308 *Linear Algebra* (3) Mathematics 324 *Advanced Calculus* (3) Physics 227[6] *Elementary Mathematical Physics* (3) Physics 225 *Modern Physics* (3) Physics 224 *Thermal Physics* (3) Physics 334[6] *Electric Circuits Laboratory* (3) Optional: Physics 335 *Electric Circuits Laboratory* (3)	18
3rd year	**Credits**
Physics 228 *Elementary Mathematical Physics*(3) Physics 321, 322 *Electromagnetism* (8) Physics 315 *Applications of Modern Physics*(3) or Physics 324[6] *Quantum Mechanics* in **Summer** (either will satisfy modern physics requirement) Optional: Physics 311 *Relativity and Gravitation* (3) Physics 331 *Optics Laboratory* (3) Physics 434 *Application of Computers to Physical Measurements* (3)	14

Note: Courses are required except where otherwise stated

Note: (#) indicate number of credits

[6]Physics 227, 324, 334 are usually offered during Summer Quarter

Table 7.4: Four year plan for transfer students that start in Winter Quarter (3 years at the UW) - Summer attendance needed

Alternate Path to B.S. (continued)	
4th year	**Credits**
Physics 401, 402, 403 *Special Problems* or Physics 485, 486, 487 *Senior Honors Seminar* (required for Honors program) or Physics 491, 492, 493 *Independent Research* (to total 3 credits combined from 401/402/403, 485/486/487 or 491/492/493 - see Adviser for details) Optional: Physics 407, 408, 409 *Physics by Inquiry II* (15) Physics 423 *Solid-State Physics* (3) Physics 421 *Atomic and Molecular Physics* (3) Physics 422 *Nuclear and Elementary-Particle Physics* (3) Physics 424 *Mathematical Physics* (3) Applied Mathematics 402, 403 (8) Physics 431, 432, 433 *Modern Physics Laboratory* (9) Physics 325 *Quantum Mechanics*	3
Other	**Credits**
Approved course(s) in Physics or Cognate subject (5) Science courses other than Physics or Mathematics (9) Two labs above 300 level in addition to Phys 334[7] (6)	20
Total required Physics credits	**56**

Note: Courses are required except where otherwise stated

Note: (#) indicate number of credits

[7]Physics 227, 324, 334 are usually offered during Summer Quarter

Table 7.5: Continuation of Table 7.4.

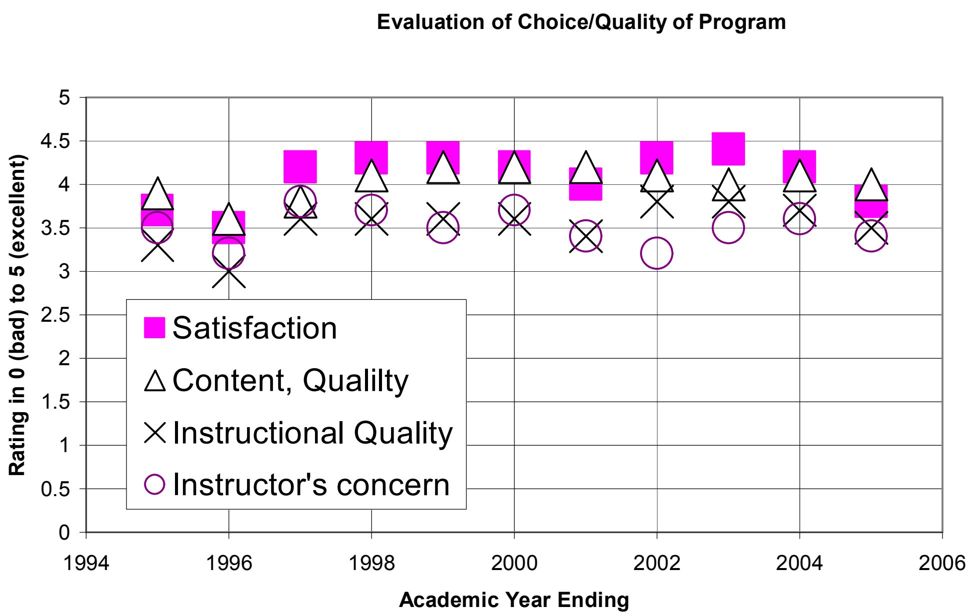

Figure 7.5: Exit Surveys for the Bachelor of Science Degree Program

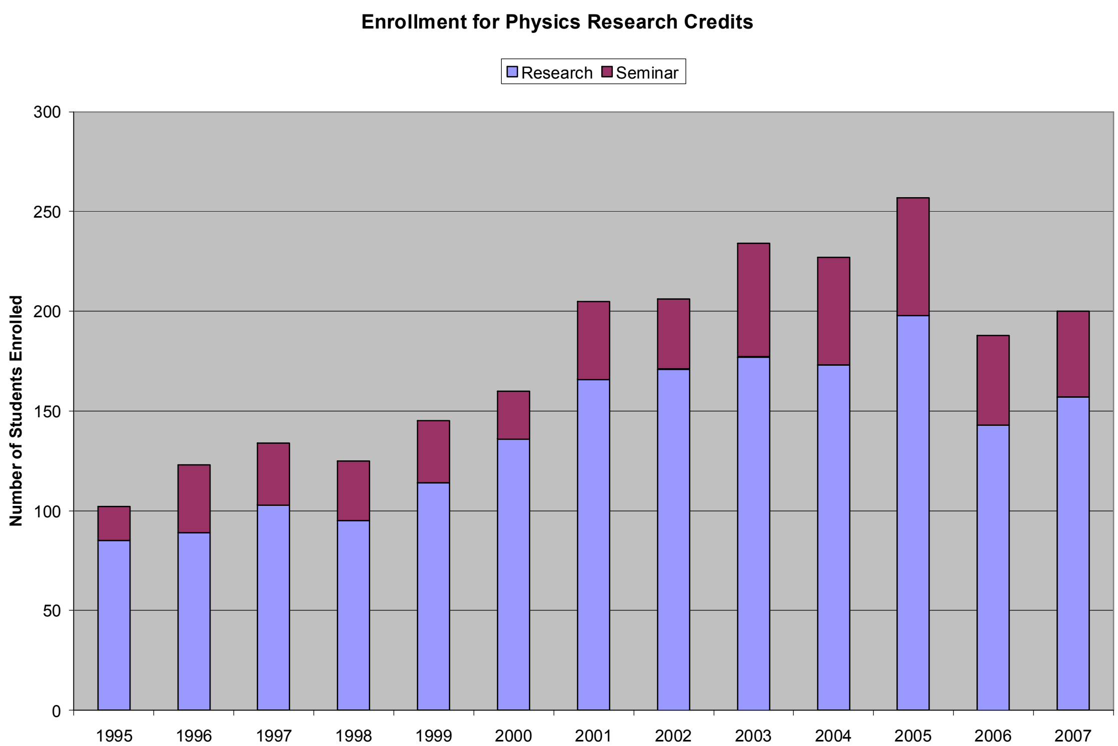

Figure 7.6: Enrollment by year for undergraduate physics research credits (Physics 401,402,403) and for credits in the undergraduate seminar courses (Physics 485,486,487,494,495,496).

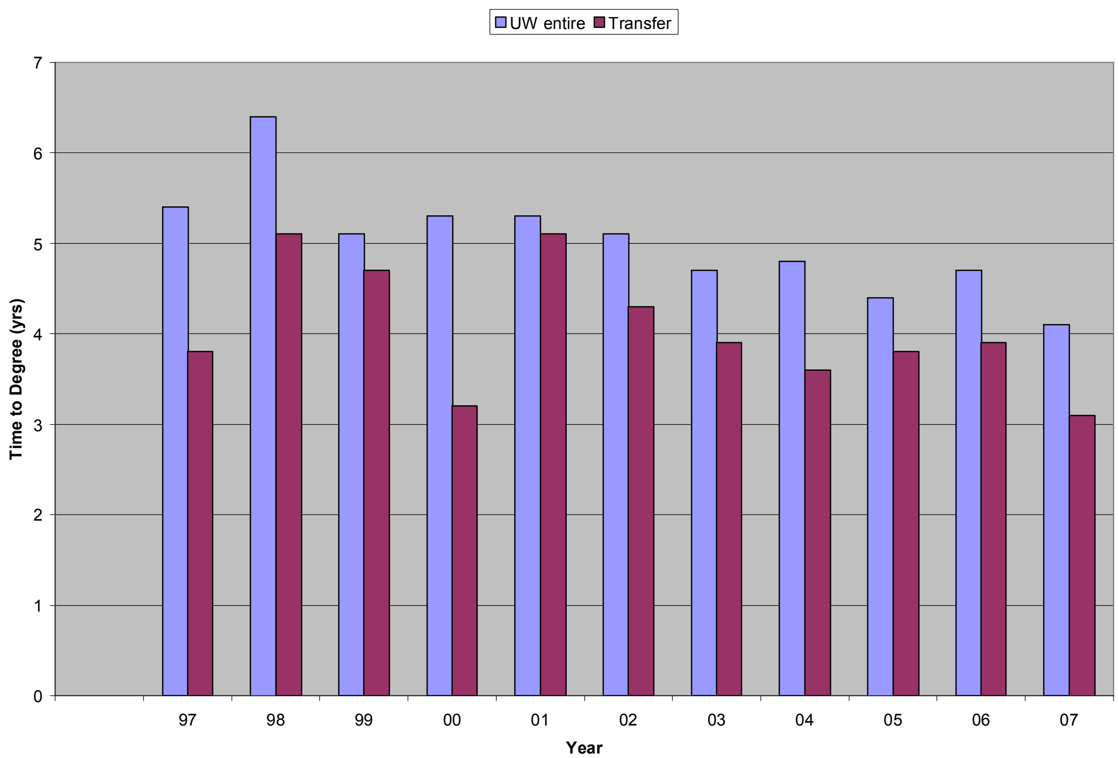

Figure 7.7: Average time from first enrollment to Physics BS degree in calendar years for undergraduates who enrolled at UW as freshmen (UW entire) and for transfer students. During the same period, the average time to degree for all students in the College of Arts and Sciences was 4.9 yrs (3.5 yrs) in 1997 and 4.4 yrs (3.1 yrs) in 2007 for UW entire (Transfer) students.

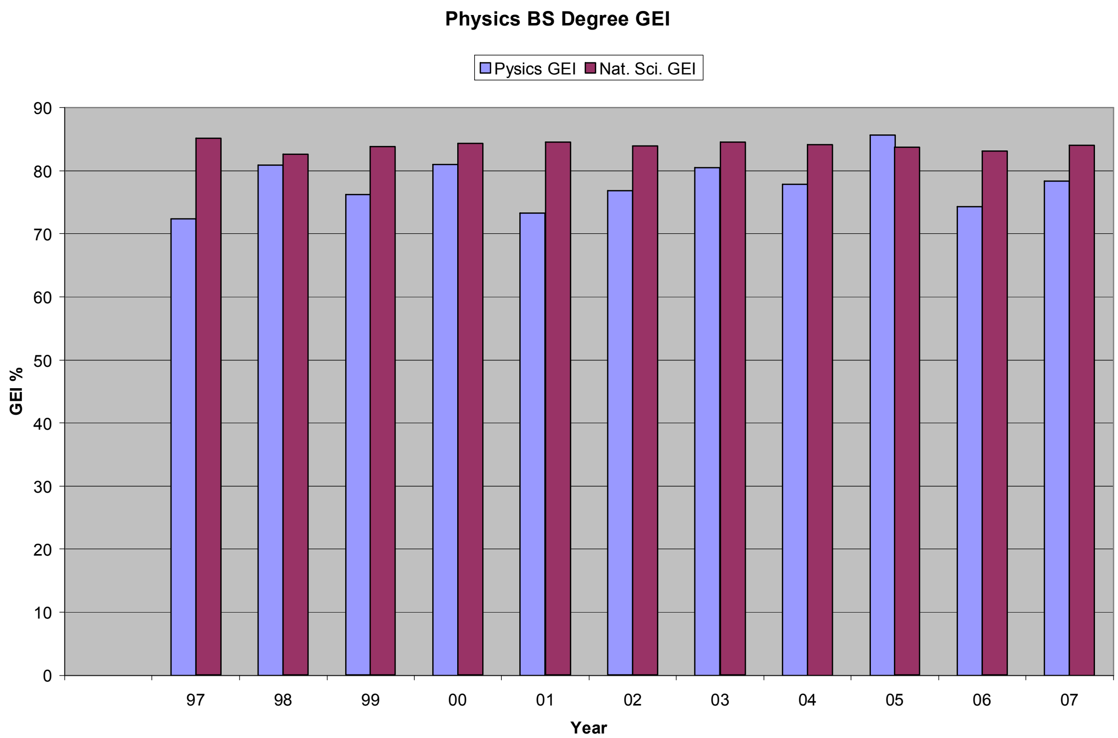

Figure 8.8: Physics BS graduate efficiency index (GEI) compared to the average GEI for natural science departments at the University of Washington.

7.4 Comments from BS Major Exit Surveys, 2005-06

Graduating seniors have been asked regularly for written positive experience in our program, and point out its shortcomings. For 2005-06, we added another line to the survey about departmental advising to learn about how students feel specifically about what we do. Numbers in parenthesis refer to the number of times a topic (roughly) was mentioned. There were 36 exit surveys returned, 35 of those had comments. Comments have been synthesized and essentially depersonalized by Oscar Vilches, except where praise to specific faculty was given. Some comments are obvious gripes, but for "truth in reporting" and to be fair to writers they have not been omitted although only the essence of the complain is reported.

Positive

Mostly knowledgeable, good faculty (11)

Office hours (4)

Attitude of most faculty and/or staff (2)

High quality, rigorous program (5)

Series courses taught by the same faculty member

Would like to have taken all the classes offered!

Physics project courses (Phys 335)

Independent research (Phys 401, etc) (4)

Quiz/tutorial sections for Quantum Mechanics (5)

Classes with tutorials (4)

Availability of most instructors to answer questions (2)

Great open ended education, applicable to many fields (5)

Great hands-on courses (6), Phys 331 (2), 334 (2), 431

Fun mathematical courses, Phys 227-228 (2)

Study Center (2)

Some TAs

SPS room, lunch box seminar (2)

Flexible program (4)

Great building, library, facilities (2)

Collegial faculty, avoids getting students involved in their disputes

Shop classes

Colloquium great for broadening education, will attend them after graduation

Praise for individual faculty/TA: Fain, Andreev, Efimov, Sharpe, Heckel, Kaplan, Olmstead, Vilches, Lubatti, Crouse

Physics Education group superb

Needs Improvement

Not all professors are good teachers, need more passion, dynamics, caring for all student,

even those struggling, professors not prepared and/or unclear (11)

Faculty should be more supportive of students (3)

Faculty put fear of asking questions into students

Hit and miss instructors (25% very poor)

Scheduling of courses makes it difficult to catch up

Not enough emphasis working on real life problems (radar, magnetic memory···) (3)

Too many mathematical proofs

No use of technology, lectures could have been delivered 100 years ago

Phys 12X series seems like “going through the motions”

Useless 12X labs (2)

Poor 12X tutorials

Add tutorial quizzes to E and M course (2) and other classes

Lack of sampling physics specialties, especially for graduate school bound students

Better coordination with Math, especially prerequisites

TAs poor at helping (2)

Many TAs dont know the subject matter, can not answer questions about class

Classmates not attending quiz sections

Organized social events so students get to know more of the faculty

Need more minority and women in program and faculty

One course out of 21 taken taught by a woman, unacceptable!

Chair and faculty need to make more effort in making students feel welcome

No 8:30 lectures! (2)

Organized seminar for undergraduates on what is going on in theory and experiment within the

Department, lab tours here and at other institutions (2)

Improve communication of, and organization of the independent study requirement (2)

Some very poor instructors assigned to the off-sequence major courses

Appoint a faculty sponsor for every entering major

Too much "overview" in 400-level classes

Better thermodynamics (Phys 224) (4), modern (Phys 225) and classical mechanics (3) courses

No courses where student can be creative: projects, presentations, doing what physicist do

Too many 3 credit classes, comparable to 5 credits classes in other departments (2)

Hard to take senior classes when they are 3-credit/too many classes for full time status (2)

Too many topics in and/or improve Phys 228 (2)

Students repeating a course should not be discouraged by the faculty teaching course

Selection should be done before entering major, not while already in the major and taking courses

Advising

Margot is "awesome"

Awesome advising for majors when needed, no bureaucracy

Two great advisors

Good departmental advising, and poor advising in Mary Gates Hall

Spring and other advising was good (2), always available

Post "tips" for majors to help those not pointed in the right direction

Improve on helping students with independent study

Tell students to stop complaining and do their homework on advising!

Vilches and Margot answered all questions

Provide more info on Graduate School preparation (2)

Make sure to advise students to take Math 308 and 324 ahead of Phys 321 and 324

Superb advising, only students fault when they run into problems

Chapter 8

Master's Program

8.1 General Discussion

The Department's Evening Master's Program in Applications of Physics (EMS) was started thirty years ago as a program for employees in local industry, mostly Boeing, who were interested in improving their knowledge of physics. Now we have a trickle of applicants from industry and a few K-12 teachers. There is a declining pool of faculty interested in teaching in the program. The Department has requested inclusion of the Evening Master's Program in the University's Educational Outreach program so that it could become completely self-sustaining and have access to the Educational Outreach resources for recruiting students. The University has not approved the transfer and the program is likely to die if the transfer is not approved.

Standards of Measuring Success

Students who have not yet chosen a faculty adviser are assigned a member of the EMS Committee as their temporary adviser. Students are encouraged to identify as early as possible a faculty member whom they hope to work with for their final independent study project. The project supervisor becomes the student's faculty adviser thereafter.

Students whose project supervisor is in another department are advised by the EMS Committee chair.

All students are required to do a significant independent study project as the final step in their degree program. Usually the project involves working with a Physics faculty member in his/her research program or laboratory, or with a faculty member in another STEM department.

In cases where the student has defined a project topic unrelated to the faculty supervisor's normal research, the faculty member will nonetheless take care to ensure the student's work follows normal standards of independent research and scholarship, and help the student learn any techniques or background material required.

Faculty teaching EMS classes obtain student evaluations each term, and peer evaluations at appropriate intervals, in the usual way. We do not have an explicit method of evaluating supervision of independent study, other than the exit questionnaire given every student completing the MS degree requirements. However, students are encouraged to contact the graduate advisor and/or the EMS committee chair if they have any concerns about the quality of supervision given by their faculty supervisor while doing Physics 600 (independent research). In fact, we have had only one case in the past 10 years of a student taking significant issue with the performance of a faculty member; in that case (involving one of our most respected and otherwise overwhelmingly highly-rated faculty), the student's claims were reviewed by a College investigation committee and rejected.

We depend upon individual faculty to analyze their own evaluations and adapt their teaching methods accordingly. As far as we know (presuming the department chair would notify the EMS committee chair if an EMS instructor got evaluation ratings poor enough to require action), all our EMS classes receive excellent ratings with no indications of significant issues.

We would be delighted to have junior faculty teach in our program, but none have recently been willing to do so. Teaching Assistants are used only for grading for EMS classes and have no specific teaching role.

We track and promote innovations and best practices in undergraduate and graduate student learning mainly by word of mouth and discussion with other students. With 20 students taking classes at any given time, and the rest doing independent study with a faculty member, our relations with our student group are more directly personal than is possible in either the undergraduate program or in the PhD program.

In recent years, the Evening Masters Program has been helpful to K-12 teachers who enroll in the Department's special courses for K-12 teachers taught by the Physics Education Group. These courses help teachers meet the requirements for an endorsement to teach physics and/or physical science and are also useful to students and teachers in Master's and PhD programs in Science Education in the College of Education.

Chapter 9

Doctoral Program

9.1 General Discussion

The Department has a strong PhD program which is currently in the top 20 nationally ranked Physics Departments. This stature combined with improved recruiting resources has enabled the Department to attract students of increased quality. Steps have also been taken to reduce the average time to degree, and to help students explore a variety of job opportunities (via the Career Development Organization). Almost all of our graduating PhD students find postdoctoral research positions or employment in academia, national laboratories, or industry.

Graduate students are usually supported by teaching assistantships for the first couple of years and by research grants thereafter. In recent years we have always had sufficient funding to provide this support for all of our students, despite the usual vicissitudes in grant support.

A major continuing concern for the PhD program is the availability of funding in various research groups. Many groups can not fully support as many graduate students as they and the students would wish. This is seen *e.g.*, in Particle Theory, where there is a large interest but few positions, and in Condensed Matter Experiment, where a shrinking faculty has reduced the number of available Research Assistantships. This is offset by a large number of our students working with Adjunct faculty in other Departments.

Another concern is the progressive thinning of our graduate curriculum. For example, mid-level courses in Nuclear Theory and Condensed Matter Theory are offered only irregularly. Sufficient manpower to offer a good variety of special topics classes is only rarely available. On a positive note, the student-run particle theory and condensed matter journal clubs have become very successful and partly compensate for some of these deficiencies. Nevertheless, it will be important to make efforts during the coming years to increase both grant support and teaching faculty manpower in certain areas, as well to improve and update the Graduate curriculum.

In the last 10 year report, one of the major concerns was the limited availability of recruitment funds for our entering graduate students, which are needed to compensate for the relatively low UW salary scale compared with our peer institutions. Fortunately, significant efforts have been made in development and improved recruiting strategies have reduced the magnitude of this problem. Currently, the Department uses its recruitment funds to provide supplemental funding to all entering students. As a result, our compensation is now comparable with the mean of our peer institutions. We also have a substantial number of large supplements, plus one to two full fellowships from the K. Young and Baumgartner endowment funds, in addition to ARCS[1] fellowships. We have also instituted a recruitment weekend supported in part by the Grad School, which has proven to be a cost effective means for attracting excellent graduate students to our program.

The PhD Program in Physics at the University of Washington aims to prepare graduate students for positions in a broad range of occupations including teaching, research, or administration in colleges and universities, government and private research laboratories and industry, especially in fields where analytical and computational skills are important. Students are required to complete specified graduate level course work or demonstrate equivalent proficiency, consistent with Graduate School requirements, and pass a written Qualifying examination. Admission to PhD candidacy requires passing an oral General examination focusing on their field of specialization. The award of the PhD also requires independent research in collaboration with one or more faculty members, a written dissertation, and an oral PhD defense. During their graduate program, students are also required to acquire experience in teaching.

[1] Achievement Rewards for College Students

PhD Program Data

The data below detail the number of students admitted to the overall graduate program each year since 2000 along with their average Graduate Record Examination (GRE) scores and a "predicted academic success" (PAS) index based on their normalized undergraduate grade point average (GPA) and GRE scores.

Recent Admission Statistics are as follows:

Year	Phys GRE	Avg PAS	No entered	PhD's granted
2006-07	815	14.01	18	12
2005-06	822	14.11	23	15
2004-05	776	13.00	28	20
2003-04	816	13.58	22	20
2002-03	730	12.26	28	11
2001-02	748	12.60	24	12
2000-01	728	12.10	29	13

Table 9.1: Recent GRE's

Currently our graduate enrollment in the PhD program is about 135 which has been fairly steady for the past 15 years. In the previous 10 year study the number was about 130. The total enrollment including about 40 in the Evening MS program is 175, compared to 170 in the previous 10 years report. Note that the overall quality as measured by the PAS strongly depends on the enrollment target.

PhD Program Demand

The Physics Department continues to experience a strong demand for its PhD program from both North American and International applicants. Students almost always receive full financial support and engage in their studies full-time. Hence they are not as constrained as to their geographical location as are students in many fields or at some other Universities. We typically receive over 1000 inquiries per year which result in about 350 completed applications per year, of which about 225 are North American and 125 International. Typically we make about 100 offers to fill about 25 positions in each entering class. Typically about 75-80% of the class is North American and 20% international. The admissions target is adjusted each year based on the expected number PhD's granted and the expected number of Research Assistant and Teaching Assistant positions.

PhD Production 1997-2007

It is of interest to analyze the total number of Ph Ds in terms of the various groups in the Department and affiliated groups. The table below contains two totals, one for the number of Ph Ds done with a given Group and a second for those done either with adjuncts or with other groups. For example of the 28 Ph Ds in CME, 22 are with CME faculty and 6 with affiliates or adjuncts. This illustrates the importance of our affiliates and adjuncts in our Graduate program, and gives a better picture of the relative contributions of various fields to PhD production in the Department.

Group	**Physics**	**Adjunct**	**RAs**
Astophysics/Gravity	5	4	3
Atomic Physics	9	0	7
Biophysics	1	4	0
Center for Experimental Nuclear Physics and Astrophysics	16	0	16
Condensed Matter Experiment	22	4	23
Condensed Matter Theory	18	6	9
Elementary Particle Experiment	8	11	3
Institute for Nuclear Theory	11	0	5
Nuclear Theory	11	0	5
Particle Astrophysics	2	0	0
Particle Theory	11	0	10
Physics Education	10	3	3
ADJ	33	0	16
Total	166	32	90

Table 9.2: Number of students working with each group.

Objectives

Our primary objective is to train PhD level physicists for employment in academia, research laboratories and industry. Our Program benefits the Department and the University by providing qualified Teaching and Research Assistants for our Undergraduate and Graduate Teaching Programs.

Curriculum: Detailed requirements are given in the attached document on graduate student policies and requirements (Section 9.7).

Standard Courses (required)

- Phys 505 Mechanics
- Phys 513, 514, 515 Electromagnetism and Relativity
- Phys 517, 518, 519 Quantum Mechanics
- Phys 501, 510, 513 Tutorials in Teaching Physics (For Teaching Assistants)
- Phys 524 Thermodynamics and Stat. Mechanics
- Phys 528 Current Problems in Physics
- Phys 511 Topics in Contemporary Physics
- Phys 600 Independent Study/Research

Advanced Courses (a prescribed subset of these courses is required)

- Phys 506 Numerical Methods
- Phys 550 Atomic Physics
- Phys 554 Nuclear Astrophysics
- Phys 555 Cosmology, Particle Astrophysics
- Phys 557 High Energy Physics
- Phys 560 Nuclear Physics
- Phys 564 General Relativity
- Phys 567 Solid State Physics

Our courses are similar to those of other comparably ranked large Physics Departments, *e.g.*, U. Michigan, U. Pennsylvania, U.C. San Diego, etc.

Standards of Measuring Success

The median time for a PhD is about 6 years and almost all of our PhD's find immediate employment.

Informing Students of Opportunities and Career Alternatives

The Career Development Organization (CDO), an organization created and run by the graduate students, organizes a Networking Day with the support ot the Department. At this event students present talks about their research to representatives of local industry and national labs. The event is largely self-supported by donations from the industry participants.

Also, the Graduate Coordinator posts all announcements that are received. In addition students learn of opportunities through various Seminars and Colloquia from visitors to the Department.

Students are informed of career options through regular advising sessions, colloquia by a broad range of scientists, participation at national meetings, and opportunities to interact with Adjunct and Affiliate faculty doing interdisciplinary research. We also ask students to complete a Future Plans form when they take their final PhD exam, and the Graduate Program Coordinator does exit interviews.

9.2 Recruitment and Retention

The department has a graduate program admission committee that was chaired by John Rehr from 1998 to 2005, then Ann Nelson 2006-2007, and currently by Jens Gundlach 2007-2008. The committee consists of 6 faculty members from various research groups in the department and one graduate student. Added to the group is the administrative assistant, currently Jen Lehner.

The recruitment target (number of new graduate students) for the department is set every year and is usually between 20 and 26 students. The target number is based on the number of graduations, the availability of funds in the research groups, the number of available Teaching Assistant positions and the number of the previous years acceptances.

The department receives between 250 to 400 applications every year. The applications are pre sorted by the PAQS number, which is computed based on the applicants advance/physics GRE score, the GPA, and classification of the recommendations. Applications with a high PAQS score are considered first. The file for each applicant is reviewed by up to three members of the admission committee who form a numeric score based on the recommendation letters, the applicant's statement and the applicant's research experience. The admissions committee is advised to pay particular attention to underrepresented groups in physics, in particular women and racial minorities.

Acceptance offer letters are sent to roughly four times as many applicants as the target number.

There are three major efforts to convince admitted students to come to join the department:

Visiting Weekend

40 students are invited (expenses paid) to come to an open house style event. During this 2 day visit students are shown research efforts in the department, are put in contact with faculty and graduates students and attend a dinner. Discussions during the visiting weekend are very effective for applicants and faculty. Usually this weekend results in follow-ups from students and faculty.

Signing Bonuses

The department has approx $75,000 in cash bonuses or fellowships. The usual signing bonus is $2,500 per student or $5,000 for a named scholarship/fellowship.

The distribution of these funds is at the discretion of the admissions committee. The committee strives to recruit underrepresented groups and minorities. Practically all students are offered a 3 quarter Teaching Assistantship.

Follow-up telephone call/emails

Each admitted student is assigned a contact faculty member. This faculty member is asked to make contact with the prospective graduate student.

Person-to-person contact is perhaps the single most efficient tool to recruit a student and to assess the likelihood of a student's accepting the offer.

9.3 Inclusion in Governance and Decisions

Inclusion of Grads

The department appoints graduate students to most of its department committees (Admissions, Diversity, Events, Examination, Graduate, Tutorial Coordinating, Safety). Additionally, the students meet annually with both the department Chair and Graduate Program Coordinator (GPC) to provide feedback on current policies and suggest changes.

Grievance Process

No grievances have been filed by graduate students in the past three years. The grievance process is as follows:

Students may report grievances to the Department Chair or the Graduate Program Coordinator; however, the Department recognizes that students also need a less formal environment where t hey may speak openly and easily about their concerns. The policy and procedure is intended to encourage students to report complaints to the Graduate Program Assistant (Graduate Advisor) who will provide sympathetic counsel in a supportive environment. Students should still speak with the Department Chair or the Graduate Program Coordinator about serious complaints, which warrant immediate action.

Policy The Graduate Advisor will respect confidences. While she will occasionally report to the Chair on graduate student concerns, these reports will not contain any details making it possible to identify individual students unless the students give their consent. Although the Graduate Advisor will not normally take action without the graduate student's explicit consent when specific instances of sexual harassment are reported any office of the University is required to report it to the Ombudsman for Sexual Harassment.

Procedure Graduate students wishing to lodge a grievance should make an appointment to speak with the Graduate Advisor. The Graduate Advisor will listen, discuss options and offer advice, and ask the student which of the following three proceedures they would like the Graduate Advisor to follow:

1. Take no action (simply provide a sympathetic ear);
2. Report the complaint to the Department Chair or Graduate Program Coordinator if a pattern of similar complaints is heard which, in the judgment of the Graduate Advisor, merits action; or
3. Report the complaint to the Department Chair or Graduate Program Coordinator (action requested or required).

9.4 Graduate Student Service Appointees

Appointment Process

Teaching Assistant appointments are made by the Teaching Assistant Coordinator (presently Senior Lecturer Daryl Pedigo), in consultation with the GPC, based upon the following criteria: experience and expertise as a Teaching Assistant, performance as a Teaching Assistant, extent of previous support and progress toward PhD

Research Assistant appointments are processed at the request of faculty who have made arrangements with a particular graduate student to serve under the supervision of that faculty member. Faculty contact the Graduate Program Assistant to request the Research Assistant appointment and provide a relevant budget number (from their grant), after which the Graduate Program Assistant prepares the appointment and offer letter. The offer letter states the terms and conditions of the appointment as outlined by the union contract.

Both Teaching Assistants and Research Assistants are contacted by email with a copy of the offer letter and deadline to respond, and additionally receive a hard copy of the offer letter in their department mailbox.

Duration of appointment

Mix of funding

Appendix B, Table B.3 provides information regarding funding sources for Graduate Student Service Appointments.

Research Assistants:	AU'06 – SP'07(annual) appointments	19
	AU'06 only appointments	39
	WI'07 only appointments	43
	SP'07 only appointments	41
Teaching Assistants:	AU'06 – SP'07 (annual) appointments	47
	AU'06 only appointments	40
	WI'06 only appointments	41
	SP'07 only appointments	42

Table 9.3: Appointment duration

Criteria for Promotions and Salary Increases

Promotions and salary increases are based upon student progress towards degree. Student who have not yet passed the Qualifying Exam are paid at the Teaching Assistant/Research Assistant level 0, students who have passed the Qualifying exam but not yet the General Exam are paid at the Teaching Assistant/Research Assistant level I, and students who have passed their General Exam (and thus classified as doctoral candidates) are paid at the Teaching Assistant/Research Assistant level II.

Supervision

Incoming first year student (who most often serve as Teaching Assistants) are required to take the Department's year-long training sequence; Phys 501, 502, and 50. Additionally, Teaching Assistants are observed in the classroom and then evaluated by their faculty during the first two quarters of Teaching Assistant appointment (these evaluations are filed in the student's employee file). Students serving as Teaching Assistants for more than two quarters are supervised on a quarterly basis and also have an evaluation completed by their faculty.

Research Assistants are supervised on a quarterly basis by the faculty member employing them.

Additionally, all graduate students are required to submit a comprehensive formal annual report to the Graduate Program Coordinator, who reviews these reports for any concerns or problems. Before submitting the report, students must consult with their supervisory committee to review the report contents.

Training

Teaching Assistants participate in the following:

1. PHYS 501, 502, 503 (training courses)
2. Center for Instructional Development and Research (CIDR) Teaching AssistantOrientation (offered to incoming graduate students at department orientation)
3. Teaching Assistant Orientation offered by the Department's Teaching AssistantCoordinator at department orientation

9.5 Nanotechnology

Physics is one of ten participating departments in the interdisciplinary Nanotechnology PhD Program. The core philosophy of the dual degree program combines depth in a single discipline with breadth in nanoscale science and technology. To receive a dual degree in Physics and Nanotechnology, students must meet all the standard requirements for a PhD in physics, with their dissertation on an approved topic in nanoscale science and/or technology in addition to the following breadth requirements:

1. Complete the core interdisciplinary course, Frontiers in Nanotechnology (3 credits)
2. Attend the Nanotechnology Seminar for at least 4 quarters (1 credit each);
3. Complete three courses relevant to nanoscale science and technology, at least two of which are outside physics (=3 credits each, =400 level);
4. Complete the equivalent of at least one quarters research in a research group outside physics (or in a department other than the home department of their advisor, should they work for an adjunct member of the physics faculty), either at UW or elsewhere.

Four of the first 24 PhD graduates in the Dual Degree Program (2001-2006) were in Physics; currently about 5 graduate students are officially enrolled in the program, and several others are working towards the Dual Degree, but have not yet filed their nanotechnology paperwork. Three faculty members (Fain, Cobden and Olmstead) have advised Dual Degree students to date, as have several adjunct faculty members (Keller, Campbell, Ohuchi, Krishnan, Lin, and Dunham). Two physics students are currently supported by year-long fellowships through the Center for Nanotechnology (CNT), and we offer up to four one-quarter CNT Early Bird Fellowships to aid in recruiting students with interest in nanoscale physics.

9.6 Students

This section contains a variety of data about past and current graduate students in an extensive list of tables.

Doctoral Exam Titles

The first section consists of a series of tables containing the names, current position (if known), advisor, and thesis title of the students who graduated between Autumn 1997 and Summer 2007. The information in presented in Tables 9.4 - 9.19, on pages 189 - 204. The area of the thesis is given in parentheses with the advisor.

Student Name (Current Position)	Exam Title	Advisor (Group)
	Autumn Quarter 1997	
Petersen, TW	Tabletop internal source ensemble xray holography	Sorensen (CME)
	Winter Quarter 1998	
Goodson, AP	The formation of stellar jets	Winglee (Geophysics)
Harris, MG	A search for a macroscopic CP violating interaction, using a spinpolarized torsion pendulum	Heckel (Gravity)
Haskel, D	Local structural studies of oriented high temperature superconducting cuprates by polarized XAFS spectroscopy	Stern (CME)
Markoff, DM	Measurement of the parity nonconserving spin-rotation of transmitted cold neutrons through a liquid helium target	Adelberger (CENPA)
Wang, F	XAFS study of solid-solid transitions under high pressure	Ingalls (CME)
Weiss, ER	A measurement of the branching ratio Rb using a minimun missing P_t corrected mass tag	Cook (EPE)

Table 9.4: Doctoral Exams (Autumn 1997 - Winter 1998)

Student Name (Current Position)	Exam Title	Advisor (Group)
	Spring Quarter 1998	
Bompadre, SG	Bremsstrahlung x-ray holograph	Sorensen (CME)
Dennis, JR	Mechanisms of liquid crystal and biopolymer alignment on highly-oriented polymer thin films	Vogel (Biophysics)
Leskovar, MA (Boeing)	The stability of interfaces between dissmilar materials	Olmstead (CME)
Song, CL	An improved procedure for calculating effective interactions and operators	Haxton (NT)
Thompson, JM	The electronic structure and spectra of small metal clusters	Bulgac (NT)
Wilber, M	Plasma transport across the earth's magnetopause	Winglee (Geophysics)
	Summer Quarter 1998	
George, JS (Aerospace Corp.)	Experiment study of the atmospheric ν_μ/ν_e ratio in the multi-GeV energy range	Wilkes (PA)
Tsemekhman, KL	Current distribution and density of states in the quantum hall effect	Thouless (CMT)
Wright, DC	Toward viable supersymmetric models	Nelson (PT)
	Autumn Quarter 1998	
Freeman, TJ	A study of fermi acceleration of superathermal solar wind ions	Parks (Geophysics)
Karakowski, JJ	Can the neutron polarizabilities be determined from a deuteron compton scattering experiment?	Miller (NT)
Kay, DJ	Mixing processes in a highly straified tidal flow	Jay (Geophysics)
Lepeintre, FB	Supersymmetric models of flavor	Kaplan (NT)

Table 9.5: Doctoral Exam Titles (Spring 1998 - Autumn 1998)

Student Name (Current Position)	Exam Title	Advisor (Group)
Autumn Quarter 1998 (continued)		
Mason, BL	An experimental investigation of charge transfer during ice contact interactions	Dash (CME)
Tesenekhman, VL	Change relaxation, current distribution, and breakdown of the quantum hall effect	Thouless (CMT)
Winter Quarter 1999		
Ambrose, BS (Grand Valley State University)	Investigation of student understanding of the wave-like properties of light and matter	McDermott (PEG)
Kelly, MP	The giant dipole resonance in higly excited nuclei: Does the width saturate?	Snover (CENPA)
Spring Quarter 1999		
Kelly, SD	XAFS study of the pressure induced B1 to B2 phase transition	Ingalls (CME)
Poiarkova, AV (US Customs)	X-ray absorption fine structure Debye-Waller factors	Rehr (CMT)
Price, AC	Coherent soft x-ray dynamic light scattering from smectic-A liquid crystals	Sorensen (CME)
Frost, KL	From instantons to sphalerons: Thermal baryon non-conservation in the weak interactions	Yaffe (PT)
Kanim, SE (New Mexico State University)	An investigation of student difficulties in quallitative and quanitative problem solving: Examples from electric circuits and electrostatics	McDermott (PEG)

Table 9.6: Doctoral Exam Titles (Autumn 1998 - Spring 1999)

Student Name (Current Position)	Exam Title	Advisor (Group)
Spring Quarter 1999 (continued)		
Loverude, ME (California State University)	Investigation of student understanding of hydrostatics and thermal physics and of the underlying concepts from mechanics	McDermott (PEG)
Putz, JY	A measurement of the branching fraction of the Ds meson to a muon and a neutrino	Rothberg (EPE)
Summer Quarter 1999		
Chen, J	Effective field theory for nuclear physics	Savage (NT)
Davidson, DE (Black Hawk College)	Fluctuating steps on crystal surfaces	den Nijs (CMT)
Hendrickson, KRG	Toward a measurement of atomic parity nonconservation using a single, trapped barium ion	Fortson (AMO)
Kaplan, DE (Johns Hopkins University)	Flavor mediated supersymmetry breaking	Nelson (PT)
Kautz, CH (Hamburg University of Technology)	Identifying and addressing student difficulties with the ideal gas law	McDermott (PEG)
Ramos, RC (Drexel University)	Liquid-vapor coexistence in two-dimensional e-He^4 He mixtures	Vilches (CME)
Autumn Quarter 1999		
Cronin, AD	New techniques for measuring atomic parity violation	Fortson (AMO)
Schief, WR Jr	Phase transitions in two-dimensional model systems	Vogel (Biophysics)

Table 9.7: Doctoral Exam Titles (Spring 1999 - Autumn 1999)

Student Name (Current Position)	Exam Title	Advisor (Group)
	Winter Quarter 2000	
Moore, MW	Measuring the second harmonic amplitude of an oscillating torsion pendulum to detect small forces	Boynton (Gravity)
	Spring Quarter 2000	
He, L	A measurement of the branching fraction of the Ds Meson decay into a Tau and a Neutrino	Wasserbaech (EPE)
Krammer, AT	Computational studies of protein-membrane interactions and forced unfolding of proteins	Vogel (Biophysics)
Pittenger, B (Veeco Instruments)	Nanomechanical investigation of ice interfaces via atomic force microscopy	Fain (CME)
Schacht, MH	Spin state detection and manipulation and parity violation in a single trapped ion	Fortson (AMO)
	Summer Quarter 2000	
Uberuaga, BP	Diffusion in semiconductors: A theoretical study	Jonsson (CMT)
Steinke, RS		Baker (PT)
Krammer, AT		Vogel (Biophysics)
Geissbühler, MP		Savage (NT)
Rupaklantaimoong, G		Savage (NT)
Sun, GS		
	Autumn Quarter 2000	
McCollam, KJ	Investigation of magnetic relaxation in coaxial helicity injection	Jarboe (Plasma)
Meng, S (Micron Corp.)	Heteroepitaxial growth of Gallium Selenium compounds on sillicon	Olmstead (CME)

Table 9.8: Doctoral Exam Titles (Winter 2000 - Autumn 2000)

Student Name (Current Position)	Exam Title	Advisor (Group)
Autumn Quarter 2000 (continued)		
Schroeder, BR (Intel Corp.)	Surface modification enhanced semiconductor-on-insulator heteroepitaxy	Olmstead (CME)
Winter Quarter 2001		
Carr, LD	Solitons in Bose-Einstein Condensates	Reinhardt (CMT)
Scherr, RE (University of Maryland)	An investigation of student understanding of basic concepts in special relativity	McDermott (PEG)
Spring Quarter 2001		
Andalkar, AU	Laboratory studies of the growth, sublimation, and light-scattering properties of single levitated ice particles	Baker (Atmos)
Konsek, SL	Electronic transport in self-assembled quantum dots	Pearsall (MSE)
Summer Quarter 2001		
Parker, SC	Particle nucleation, growth, and sintering of metallic films on oxide substrates	Campbell (CME)
Nesvizhskii, A (Institute for Systems Biology)	Theory and interpretation of L-shell X-ray absorption spectra	Rehr (CMT)
Tang, J (University of New Hampshire)	Quantum mechanics of quantized vortices in dilute bose gases	Thouless (CMT)
Vija, AH (Phillips)	Simultaneous estimation of single photon emission computed tomography activity and attenuation distribution using differential attenuation information	Rehr (CMT)

Table 9.9: Doctoral Exam Titles (Autumn 2000 - Summer 2001)

Student Name (Current Position)	Exam Title	Advisor (Group)
	Autumn Quarter 2001	
Cooke, JR	Light front field theory calculation of deuteron properties	Miller (NT)
Hoyle, CD Jr (Humboldt)	Sub-millimeter tests of the gravitational inverse-square law	Adelberger (Gravity)
Liu, C	Nuclear anapole moments: A manifestation of nuclear parity	Haxton (NT)
Ortiz, LG (Arizona State University)	Identifying and addressing student difficulties with rotational dynamics	McDermott (PEG)
Shoresh, N	Applications of chiral perturbation theory	Kaplan & Sharpe (NT/PT)
	Winter Quarter 2002	
Boudreaux, A (Western Washington University)	An investigation of student understanding of Galilean relativity	McDermott & Vokos (PEG)
Chen, L (University of New Hampshire)	Bernstein-Greene-Kruskal electron solitary waves in collisionless plasmas	Parks & Thouless (Geophysics/CMT)
Stachyra, AL (MIT)	A search for astrophysical point sources of neutrinos with super-kamiokande	Wilkes (PA)
	Spring Quarter 2002	
Norsen, TT	Strange phases in neutron star matter	Haxton (NT)
Zager, EL	The impact of TeV nucleus-nucleus simulations on JACEE results	Wilkes (PA)

Table 9.10: Doctoral Exam Titles (Autumn 2001 - Spring 2002)

Student Name (Current Position)	Exam Title	Advisor (Group)
	Summer Quarter 2002	
Bedrosian, PA	Electromagnetic imaging of active fault zones	Unsworth
Chen, C (University of Pittsburgh)	Understanding avalance systems through underlying interface dynamics	den Nijs (CMT)
Chin, CS (UC San Francisco)	Stochastic fluctuations far from equilibrium – statistical mechanics of surfacee growth	den Nijs (CMT)
Fox, PJ (FNAL)	Extral Extral-Dimensions and symmetries	Nelson (PT)
Heeger, KM (University of Wisconsin)	Model-independent measurement of the neutral-current interaction rate of solar 8B neutrinos with deuterium in the sudburg neutrino observatory	Robertson (SNO)
Campbell, LW (PNNL)	Inelastic losses in x-ray absorption theory	Rehr (CMT)
	Winter Quarter 2003	
Reid, JG (Baylor Biophysics)	Event-by-event analysis methods and applications to relativistic heavy-ion collision data	Trainor (CENPA)
Smith, MWE (JPL/CalTech Mars Probe)	An investigation of matter enhanced neutrino oscillation with the Sudbury Neutrino Observatory	Elliott (SNO)
Morozov, AV	Free energy functions in protein structural stability and folding kinetics	Schick (CMT)
	Spring Quarter 2003	
Feng, Y (Advanced Photon Source)	Exciton spectroscopy using nonresonant x-ray raman scattering	Seidler (CME)

Table 9.11: Doctoral Exam Titles (Summer 2002 - Spring 2003)

Student Name (Current Position)	Exam Title	Advisor (Group)
Spring Quarter 2003 (continued)		
Ha, M (KAIST)	Scaling and phase transitions in one-dimensional nonequilibrium driven systems	den Nijs (CMT)
Hrŭska, MM (Exxon Mobil)	Transport in low-dimensional conductors	Spivak (CMT)
Maruyama, Reina	Optical trapping of ytterbium atoms	Fortson (AMO)
Summer Quarter 2003		
Luu, TC	Effective interactions within an oscillator basis	Haxton (NT)
Rhee, SW (Arkansas Medical University)	Corrections to the transverse force for superfluid vortices	Thouless (CMT)
Autumn Quarter 2003		
Donev, JMK (University of Calgary)	Non-contact atomic force microscopy studies of armorphous solid water deposited on Au(111)	Fain (CME)
Chapman, BD (Boeing)	The role of disorder in structural phase transitions in perovskite ferroelectrics	Stern (CME)
Koerber, T	Measurement of light shift ratios with a single trapped $^{138}Ba^{+}$ ion, and prospects for a parity violation experiment	Fortson (AMO)
Yu, Y	Renormalization of Hartree-Fock-Bogoliubov equations in case of zero range interaction	Bulgac (NT)
Winter Quarter 2004		
Orrell, JL (PNNL)	A search for an electron antineutrino signal in the Sudbury Neutrino Observatory	Wilkerson (SNO)

Table 9.12: Doctoral Exam Titles (Spring 2003 - Winter 2004)

Student Name (Current Position)	Exam Title	Advisor (Group)
Winter Quarter 2004 (continued)		
Rivas, G (U. Juarez)	Ab initio calculation of optical constant from UV to x-ray	Rehr (CMT)
Spring Quarter 2004		
Arndt, D	Chiral perturbation theory on the lattice and its applications	Savage (NT)
Haas, AC	A search for neutral Higgs Bosons at high tan beta in multi-jet events from pphar collisions at the Fermilab Tevatron	Watts (EPE)
Mckinney, SB	Dynamics of bose-Einstein condensates in optical lattices	Reinhardt (CMT)
Mumm, HP (NIST)	A test of time reversal violation in neutron beta decay	Wilkerson (SNO)
Strasburg, JD	Characterization of avalanche photodiode arrays from temporally resolved photon counting	Stubbs (Astrophysics)
Summer Quarter 2004		
Adams, JA (Advanced Portfolio Technologies)	A surface and interface study of aluminum selenide on silicon: growth and characterization of thin films	Olmstead (CME)
Diebel, M	Application of ab-initio calculations to modeling of nanoscale diffusion and activation in silicon	Dunham (MSE)
Kovtun, P (University of Victoria)	Non-perturbative equivalences in gauge theories with global symmetries in the limit of large N	Yaffe (PT)
Kryjevski, AB	Aspects of the influence of quark masses on the dynamics of hadronic systems	Kaplan (NT)
Lufkin, GW	Simulations of giant plant migration in gasous circumstellar disks	Quinn (Astronomy)

Table 9.13: Doctoral Exam Titles (Winter 2004 - Summer 2004)

Student Name (Current Position)	Exam Title	Advisor (Group)
Summer Quarter 2004 (continued)		
Mahmud, KW	Mean field and correlated descriptions of Bose-Einstein condensates	Reinhardt (CMT)
Rohinson, SM	The multichromatic wavelet transformation as a source identification tool for GLAST	Burnett (EPE)
Tiburzi, BC	Light-front dynamics and generalized patron distributions	Miller (NT)
Unsal, M	Supersymmetric gauge theories on lattice	Kaplan (NT)
Veatch, SL	Liquid immiscibility in model bilayer lipid membranes	Keller (Biophysics)
Wilson, TA	Thermodynamics of helium and hydrogen films adsorbed on single-walled carbon nanotube bundles	Vilches (CME)
Autumn Quarter 2004		
Bostwick, AA (Advanced Light Source)	Impact on calcium fluoride reactivity and electronic structure of photon and electron stimulated flourine desorption	Olmstead (CME)
Van Liew, S	An ultra-precise determination of the mass of He^3 using penning trap mass spectrometry	Van Dyck (AMO)
Winter Quarter 2005		
Griffith, WC (NIST)	Limiting CP violation through a search for a permanent electric dipole moment of mercury 199 atoms	Fortson (AMO)
Spring Quarter 2005		
Miceli, A	LON EOS RR Lyrae Stars as Probes of Galactic Structure and Formation	Stubbs (Astrophysics)

Table 9.14: Doctoral Exam Titles (Summer 2004 - Spring 2005)

Student Name (Current Position)	Exam Title	Advisor (Group)
Spring Quarter 2005 (continued)		
Tait, SL (Max Planck Institute)	Desorption Kinetics of Small n-Alkanes from MgO(100), Pt(111), and C(0001)/pt(111) and Studies of Pd Nanoparticles: Growth and Sintering on Al203(0001) and Methane Dissociation on MgO(100)	Campbell & Fain (CME)
Summer Quarter 2005		
Allred, JC	Observations and Radiative Hydrodynamic Simulations of Solar and Stellar Flares	Hawley (Astronomy)
Close, HG (Seattle Pacific University)	Improving Instruction in Mechanics through Identification and Elicitation of Pivotal Casses in Student Reasoning	Heron (PEG)
Elliott, RC	Phase Seperation in Mixed Bilayers Containing Saturated and Monounsaturated Lipids with Cholesterol as Determined from a Microscopic Model	Schick (CMT)
Kapner, DJ (Kavli)	A Short-Range Test of Newton's Gravitational Inverse-Square Law	E. Adelberger (Gravity)
Lee, JY (KIAS)	The Little Higgs and Some Phenomenology	Nelson (PT)
Miknaitis, KKS (Kavli)	A Search for Matter Enhanced Neutrino Oscillations through Measurements of Day and Night Solar Neutrino Fluxes at the Sudbury Neutrino Observatory	Wilkerson (SNO)
Schmidt, DA (Institute for Young Scholars)	Titanium Dioxide Thin Films: Understanding Nanoscale Oxide Heterophitaxy for Sillicon-Based Applications	Olmstead (CME)

Table 9.15: Doctoral Exam Titles (Spring 2005 - Summer 2005)

Student Name (Current Position)	Exam Title	Advisor (Group)
Summer Quarter 2005 (continued)		
Smith, JR	Quarks and Antiquarks in Nuclei	Miller (NT)
Stottrup, BL	Miscibility of Phospholipids and Cholesterol in Monolayer Systems: Comparison and Application	Keller (Biophysics)
Van De Water, RS (FNAL)	Applications of Chiral Perturbation Theory to Lattice QCD	Sharpe (PT)
Wu, JMS (TRIUMF)	Improvement of Wilson Fermions and Twisted Mass Lattice QCD	Sharpe (PT)
Autumn Quarter 2005		
Cochran, MJ (Kauai Community College)	Student Understanding of the Second Law of Thermodynamics and the Underlying Concepts of Heat, Temperature, and Thermal Equilibrium	Heron (PEG)
Miknaitis, GA	An Investigation of Cosmic Dark Energy using type ia Supernovae	Stubbs (Astrophysics)
Miller, EA (PNNL)	Structure and Mechanics of Solid Foam	Seidler (CME)
Schlosshauer-Selbach, MA	The Quantum-to-Classical Transition: Decoherence and Beyond	Fine (Foundations)
Stonehill, LC (LANL)	Development and Background Characterization of the Sundbury Neutrino Observatory Neutral Current Detectors	Wilkerson (SNO)
Triambak, S (Queen's University)	The Isobaric Multiplet Mass Equation and ft Value of the $0^+ \rightarrow 0^+$ Fermi Transition in ^{32}Ar: Two Tests of Isospin Symmetry Breaking	

Table 9.16: Doctoral Exam Titles (Summer 2005 - Autumn 2005)

Student Name (Current Position)	Exam Title	Advisor (Group)
Winter Quarter 2006		
Choi, K (Sogang University)	A new Equivalence Principle Test Using a Rotating Torsion Balance	Gundlach (Gravity)
Yamada, D (Hebrew University)	Phase Structure of Mazimally Supersymmetric Yanf-Mills Theory with R-symmetry Chemical Potentials	Yaffe (PT)
Spring Quarter 2006		
Bacrania, MK (LANL)	Search for the Second-forbidden Beta Decay of Boron-8	Storm (CENPA)
Bowen, MT (APS Congressional Fellow)	Top Quark Phenomenology at Hadron Colliders	Ellis (PT)
Clark, AB (Wilamette University)	Applications of Conformal Perturbation Theory to Novel Geometries in the Gauge/Gravity Correspondence	Karch (PT)
Duba, CA (DigiPen)	Electronics for the Netural Current Detection Array at the Sudbury Neutrino Observatory	Robertson (SNO)
Pierce, MS	X-ray Speckle Experiements on the Persistence and Disintegration of Magnetic Memory	Sorensen (CME)
Sabbey, BG	Global Properties of Nuclei with Self-Consistent Mean-Field Theory: Binding Energies and 2^+ Excitations	Bertsch (NT)
Steffen, JH	Detecting New Planets in Transiting Systems	Agol (Astronomy)
Walker-Loud, AP	Topics in Effective Field Theory for Lattice QCD	Savage (NT)

Table 9.17: Doctoral Exam Titles (Winter 2006 - Spring 2006)

Student Name (Current Position)	Exam Title	Advisor (Group)
Spring Quarter 2006 (continued)		
Zurek, KM	Looking Beyond Standard Neutrino and Axion Phenomenology and Cosmology	Kaplan (NT)
Summer Quarter 2006		
Lin, C	Phase Behaviors of Diblock Copolymers Under an External Electric Field	Schick (CMT)
Kazkaz, K (LLNL)	Finding Excited-State Decays of Germanium-76	Wilkerson (SNO)
Autumn Quarter 2006		
Shiraishi, KK (Microsoft)	Super-Kamiokande atmospheic neutrino anaylsis of matter-dependent neutrino oscillation models	Wilkes (PA)
Kim, KH (University of Washington)	Stochastic driven systems far from equilibrium	den Nijs (CMT)
Winter Quarter 2007		
Sherman, JA	Single Barium ion spectroscopy: light shifts, hyperfine strcutre, and progress on an optical frequency standard and atomic parity violations	Fortson (AMO)
Spring Quarter 2007		
Butler, TW	Nanopore anaylsis of nucleic acids	Gundlach (Biophysics)
Coffey, DC	Characterizing the local optoelectronic performance of organic solar cells with scanning-probe microscopy	Ginger (CME)

Table 9.18: Doctoral Exam Titles (Spring 2006 - Spring 2007)

Student Name (Current Position)	Exam Title	Advisor (Group)
Spring Quarter 2007 (continued)		
Crouse, AD (University of Washington)	Research on student understanding of quantum nechanics as a guide for improving instruction	Shaffer & McDermott (PEG)
Endres, MG	Topics in lattice field theory	Kaplan (NT)
Fister, TT (Argonne National Labs)	Momentum dependent x-ray Raman scattering	Seidler (CME)
Gadfort, T	Evidence for electroweak top quark production in proton-antiproton collision at $\sqrt{s} = 1.96$ TeV	Watts (EPE)
Swallows, MD	A search for the permanent electric diople moment of Hg^{199}	Fortson (AMO)
Summer Quarter 2007		
Ahn, C	Atomic scale modeling of stress and pairing effects on dopant behavior in silicon	Dunham (MSE)
Battle, AR	Kinetics and interactions of phase separated liquid lipid domains on giant unilamellar vasicles	Keller (Biophysics)
Cramer, C (Harvard)	A Torsion Balance Search for Spin-Coulpled Forces	Heckel (Gravity)
Gehman, VM (LANL)	Physics Reach of the Global Neutrinoless Double-Beta Decay Program and Systematic Uncertainties of the MAJORANA Project	Elliott (SNO)
Ling, T	High resolution gamma detector for small-animal positron emission	Burnett (EPE)
O'neill, RG	An experimental study of helicity injection current drive in the HIT-SI spheromak	Jarboe (Plasma)

Table 9.19: Doctoral Exam Titles (Spring 2007 - Summer 2007)

Doctoral Advisors

This sections consists of a series of tables listing the current PhD students, their advisors and academic advisors, and the daate of admission. If the student has not yet selected a research advisor, the student's acacdemic advisor is listed. The information is presented in tables 9.20 -9.24, pages 205 -209.

Last Name	First Name	Academic Advisor	Admission Date	Advisor
Ahmed	Towfiq		10/1/2004	Haxton
Akcay	Cihan		10/1/2002	Jarboe
Armour	Kyle	Sharpe	9/16/2005	
BackusMayes	John A		9/16/2005	Watts
Boddy	Kimberly	Sharpe	9/16/2007	
Bodine	Laura Irene		6/16/2006	Lubatti
Bolton	Daniel R		9/16/2006	Miller
Bonicalzi	Ricco		10/1/2002	Boynton
Bradley	Joseph A		9/16/2006	Seidler
Briceno	Raul	Yaffe	9/16/2007	
Brochmann	Michelle	Rehr	9/16/2007	
Buechler	Conor		10/1/2001	Sorensen
Bullard	Theresa		10/1/1998	Olmstead
Chen	Wei		9/16/2005	Cobden
Chen	Yeechi		10/1/2001	Ginger, Jr.
Chesler	Paul		10/1/2003	Yaffe
Connolly	Kevin T	Olmstead	9/16/2006	
Cook	Ted		7/1/2002	Adelberger
Cox-Mobrand	Gary A.		7/1/2000	Wilkerson
Crosswhite	Gregory M		9/16/2005	Bacon
Davis	Scott	Sharpe	9/16/2007	
DePies	Matthew		10/1/1999	Hogan
Derrington	Ian M		9/16/2005	Gundlach
Dexter	Jason A		9/16/2006	Agol

Table 9.20: Current Students and Advisors (A - Dep)

Last Name	First Name	Academic Advisor	Admission Date	Advisor
Deyo	Eric		10/1/2003	Spivak
Dietrich	Matthew R		10/1/2004	Blinov
Donovan	Rory M	Rehr	7/1/2004	
Drut	Joaquin		10/1/2003	Son
Dziomba	Michael R	Rehr	9/16/2006	
Emani	Prashant		9/16/2006	Gundlach
Famulare	Michael G	Sharpe	9/16/2005	
Fardon	Robert		4/1/2000	Nelson
Faust	Douglas		10/1/2003	Reinhardt
Feldman	Baruch		10/1/2003	Dunham
Gardner	Grant		10/1/2004	Krishnan
Groves	Michael		7/1/2002	Drobny
Hagedorn	Charles A		10/1/2004	Gundlach
Hansen	Anders	den Nijs	9/16/2007	
Harris	Orin M		9/16/2005	Watts
Hernandez Acosta	Tomas	Yaffe	9/16/2007	
Hotz	Michael T		9/16/2005	Rosenberg
Howell	Gary T.		6/16/2006	Blinov
Huang	Ludan (Amber)		10/1/2004	Lin
Inoue	Satoru	Miller	9/16/2006	Lunardini
Jamison	Alan	Yaffe	9/16/2007	
Jensen	Kristan D		9/16/2005	Karch
Jiang	Wenjun	Olmstead	9/16/2007	
Johnson	Robert		10/1/2003	Wilkerson
Jones	Andrew C		9/16/2005	Raschke
Kas	Joshua		10/1/2002	Rehr
Kerr	Matthew T	Sharpe	9/16/2006	
Kettler	David T.		7/1/2004	Trainor
Khramov	Alexander	den Nijs	9.16.2007	
Kleczewski	Adam M		10/1/2004	Blinov
Kozcaz	Can		10/1/2003	Iqbal
Kryjevskaia	Lioudmila		10/1/2004	Heron
Kurz	Nathan A.		9/16/2005	Blinov
Lay	Erin		7/1/2002	Holzworth

Table 9.21: Current Students and Advisors (Der - Kry)

Last Name	First Name	Academic Advisor	Admission Date	Advisor
Leber	Michelle		7/1/2003	Wilkerson
Lee	Jong-Wan	Sharpe	9/16/2005	
Leinweber	Isaac		9/16/2005	Shaffer
Li	Kaicui	Olmstead	9/16/2007	
Li	Kun		10/1/2004	Drobny
Li	Xiaoli		10/1/2003	Olmstead
Lindsey	Beth		10/1/2002	Heron
Lovejoy	Tracy Clark		10/1/2004	Olmstead
Luzum	Matthew		10/1/2003	Miller
Lytle	Andrew T.		10/1/2004	Sharpe
Marino	Michael G		10/1/2004	Wilkerson
Manrao	Elizabeth	Gundlach	9/16/2007	
Martin	Eric	Miller	9/16/2007	
Mattern	Brian	Gundlach	9/16/2007	
Meilicke	Kristen K.	Sharpe	10/1/2003	
Michnicki	Kamil	den Nijs	9/16/2007	
Miller	Kai		7/1/2000	den Nijs
Miner	Jacob	Sharpe	9/16/2007	
Mohrmann	Erik		7/1/1997	Snover
Nagle	Kenneth P		9/16/2005	Seidler
Nance	Jared	Sharpe	9/16/2007	
Newman	George		10/1/2000	Son
Nicholson	Amy N		9/16/2005	Kaplan
O'Bannon	Andrew		10/1/2002	Karch
Oblath	Noah		10/1/2002	Robertson
O'Neill	Robert (Griff)		10/1/2001	Jarboe
Paik	Steve T.		10/1/2004	Strassler
Park	Jae	Olmstead	9/16/2007	
Pesin	Dmytro		10/1/2004	Andreev
Philpott	Kregg A		10/1/2004	Wilkerson
Prager	James		10/1/2002	Winglee
Prange	Micah		10/1/2002	Rehr
Pratt	Benjamin W		10/1/2004	Sorensen

Table 9.22: Current Students and Advisors (Kur - Pra)

Last Name	First Name	Academic Advisor	Admission Date	Advisor
Putzel	Gregory G		10/1/2004	Schick
Rinehimer	Jared	Miller	9/16/2007	
Robertson	Amy D		9/16/2006	Shaffer
Sallaska	Anne		10/1/2002	Garcia
Schabinger	Robert M		9/16/2005	Strassler
Schubert	Alexis G		10/1/2004	Wilkerson
Shimogawa	Michael		10/1/2003	Holzworth
Shu	Gang (Rick)		10/1/2004	Blinov
Sjue	Sky		10/1/2001	Garcia
Smigielski	Brian		10/1/2003	Savage
Smith	Jana Kalista	Olmstead	6/16/2006	
Sorini	Adam		10/1/2002	Rehr
Spitzer	Christopher		10/1/2003	Nelson
Squires	Shane A	Rehr	9/16/2006	
Steuck	Mathew J		10/1/2004	den Nijs
Syphers	David	Sharpe	10/1/2003	
Takimoto	Yoshinari		10/1/2000	Rehr
Terrano	William A		9/16/2006	Adelberger
Thompson	Ethan G		10/1/2004	Strassler
Thrane	Eric		10/1/2003	Wilkes
Toups	Matthew H	Garcia	6/16/2005	
Turner	Matthew	Gundlach	9/16/2007	
Ventura	Daniel W		9/16/2005	Lubatti
Vermilion	Christopher K	Nelson	9/16/2006	
Vinson	John	Miller	9/16/2007	
Volle	Grant E	Cramer	9/16/2006	
Wagner	Todd		10/1/2003	Gundlach
Wall	Brandon Lee		10/1/2004	Wilkerson
Wallace	Eric E	Miller	9/16/2006	
Walsh	Jonathan R		9/16/2005	Strassler
Wang	Li X.		10/1/2004	Blinov
Wang	Zenghui		10/1/1999	Cobden
Wasem	Joseph V		9/16/2005	Savage

Table 9.23: Current Students and Advisors (Put - Was)

Last Name	First Name	Academic Advisor	Admission Date	Advisor
Wei	Jiang		10/1/2004	Cobden
Willcockson	Lee	Rehr	9/16/2007	
Yitamben	Esmeralda		9/16/2006	Olmstead
Yoon	Sukjin		10/1/2000	Bulgac
Zafonte	Steven		7/1/1993	Van Dyck

Table 9.24: Current Students and Advisors (Wei - Z)

Assistant preparation

9.7 PhD Program Information, Policies & Procedures

This document reflects current information, policies, and procedures for PhD students. The document is separated into the following sections: Policies of the Graduate School, Policies of the Physics Department, Doctoral Degree Requirements, Physics Department – PhD Timeline, Program Sequence, Satisfactory Progress, Financial information, Advising and Mentoring.

Policies of the Graduate School

The information in this section is excerpted from the Graduate School's web page, Instructions, Policies, and Procedures for Graduate Students, which contains a comprehensive listing of all Graduate School policies as well as additional information on the topics listed below.

Enrollment Requirement

The enrollment requirement for the master's degree is 36 credits, 30 of which must be taken at the University of Washington.

For the doctoral degree, the enrollment requirement is 90 credits, 60 of which must be taken at the University of Washington. With the approval of the degree-granting unit, an appropriate master's degree from an accredited institution may substitute for 30 credits of enrollment.

Only courses numbered 400, 500, 600, 700, and 800 can be applied to enrollment or course credit in the major field for advanced degrees.

Transfer Credits

Approved transfer credits are applied toward total credit count for the master's degree only. (Transfer credits are not applicable toward a doctoral degree.) The 18 quarter credits of numerically graded course work, and 18 quarter credits of 500-level-and-above course work may not be reduced by transfer credit. See also Doctoral Degree Requirements (http://www.grad.washington.edu/stsv/quickref.htm).

On-Leave Status and Continuous Enrollment

To maintain graduate status, a student must be enrolled on a full-time, part-time, or official On-Leave basis from the time of first enrollment in the Graduate School until completion of all requirements for the graduate degree. Failure to maintain continuous enrollment constitutes evidence that the student has resigned from the Graduate School.

A student's petition for On-Leave status must be approved by the departmental graduate program coordinator and submitted to the Registration Office (225 Schmitz Hall) no later than the fifth day of the quarter.

Full-time Enrollment

Full-time quarterly enrollment for graduate students is **10 credits**. Students who accept a Teaching or Research Assistant position during autumn, winter, or spring quarters must enroll full-time.

Summer Quarter Enrollment

Students are not required to enroll for summer quarter to maintain continuous enrollment; however, students who accept a Teaching or Research Assistant position for summer quarter must enroll for at least **2 credits**.

Graduate Courses

Graduate courses are intended for, and ordinarily restricted to, either students enrolled in the Graduate School or graduate non-matriculated students, and are given numbers from 500 through 800. Some courses at the 300 and 400 levels are open both to graduates and to upper-division undergraduates. Such courses, when acceptable to the supervisory committee and the Graduate School, may be part of the graduate program. Graduate School Memorandum No. 36 offers additional information on graduate courses.

Grading System for Graduate Students

In reporting grades for graduate students, units that offer graduate degrees use the system described herein. Grades are entered as numbers, the possible values being 4.0, 3.9, $\cdots$ and decreasing by one-tenth until 1.7 is reached. Grades below 1.7 are recorded as 0.0 by the Registrar and no credit is earned. **A minimum of 2.7 is required in each course that is counted toward a graduate degree.** A minimum GPA of 3.00 is required for graduation.

Withdrawal

It is the student's responsibility to withdraw if he or she is unable to attend for the quarter. Students may withdraw in person or write to the Registration Office, 225 Schmitz Hall, Box 355850, University of Washington, Seattle, Washington, 98195-5850. Withdrawals by mail are effective on the date of the post-mark. The University of Washington Time Schedule offers more information on withdrawal policies.

Repeating Courses

Graduate students may repeat any course. Both the first and second grades will be included in the cumulative GPA. Subsequent grades will not be included, but will appear on the permanent record. The number of credits earned in the course will apply toward degree requirements only once.

Language Competence Requirements and Examinations

It is assumed that students from English-speaking countries who are admitted to the Graduate School are competent in the English language; students from non-English-speaking countries must demonstrate a satisfactory command of English, both for admission and for appointment as teaching assistants. Refer to Graduate School Memorandum No. 8 entitled, *English Language Competence for Admission to the Graduate School.*

Low Scholarship/Unsatisfactory Progress

Admission to the Graduate School allows students to continue graduate study and research at the University of Washington only as long as they maintain satisfactory performance and progress toward completion of their graduate degree program.

Students whose cumulative or quarterly GPA falls below a 3.0 must be reviewed quarterly and be provided with an explanation of performance expectations and a timetable for correction of deficiencies. Doctoral program students are to be reviewed by their doctoral supervisory committee. Pre- and postmaster students are to be reviewed by supervisory committees, if such committees have been appointed, or by the graduate faculty members who have been designated to oversee such students' programs.

In evaluating the student's performance and progress, all of the following should be reviewed: (1) Grade reports: cumulative and quarterly GPA's computed on those courses taken while the student is enrolled in the University of Washington Graduate School. Computation is based only on courses numbered 400-599; courses graded I, S/NS, and CR/NC are excluded, as are the 600-800 series. (2) Performance during informal course work and seminars. (3) Research capability, progress, and performance. (4) Any other information relevant to graduate program academic requirements.

A determination of satisfactory performance and progress may be made upon review of the factors indicated above and consideration of the student's progress relative to other students (part-time/full-time) in the program or to an individually negotiated schedule.

Final Quarter Registration

A student must maintain registration as a full- or part-time student at the University for the quarter the master's degree, the candidate certificate, or doctoral degree is conferred.

Policies of the Physics Department

This section contains policies specific to the Physics Department, which fall outside of the general categories listed in the rest of this document.

Teaching

In recognition of the importance of teaching experience in the education of a physicist, the Physics Department requires such experience of all prospective candidates for the PhD degree. Most students serve as teaching assistants at some point in their graduate career to fulfill the teaching requirement; however, students may obtain a waiver of this requirement if they have had previous relevant teaching experience. Students who want to apply for a waiver should see the graduate program coordinator.

Complaint Policy

The Physics Department is committed to ensuring that students have a positive graduate school experience. To this end, the department makes every effort to prevent and respond to problems.

In July 2003, the Physics Department adopted a Policy and Procedure for Reporting and Handling Graduate Student Complaints in response to students' request for a clear policy which outlined a less formal environment where students could speak openly and easily about their concerns. The policy also lists additional resources.

Doctoral Degree Requirements

The information in this section is excerpted from the Graduate School's web page, Doctoral Degree Requirements , which contains more detailed information about requirements.

A Quick Reference List

In order to qualify for the doctoral degree, it is the responsibility of the student to meet the following Graduate School minimum requirements. **A student must satisfy the requirements that are in force at the time the degree is to be awarded.**

1. A minimum of 90 credits must be completed (a master's degree from the UW or another institution may be used as a substitute for 30 credits of enrollment).

2. A minimum of 60 credits must be completed at the University of Washington.

3. At least 18 credits of UW course work at the 500 level and above must be completed prior to the General Examination.
4. At least 18 numerically graded UW credits of approved 400 and all 500 level courses must be completed prior to the General Examination.
5. Completion of 60 credits prior to scheduling the General Examination (a master's degree from the UW or another institution may be used as a substitute for 30 of these 60 credits).
6. A minimum of 27 dissertation credits over a period of at least three quarters must be completed. With the exception of summer, students are limited to a maximum of 10 dissertation credits (800) per quarter.
7. A minimum cumulative GPA of 3.00 must be maintained.
8. The General Examination must be successfully completed.
9. The Final Examination must be successfully completed.
10. A dissertation accepted by the Graduate School.
11. Registration maintained as a full- or part-time graduate student at the University for the quarter in which the examinations are completed AND the quarter the degree is conferred.
12. Completion of all work for the doctoral degree within ten years.

Requirements That May Impact Progress

The following doctoral degree requirements may impact progress.

1. If a student enters the UW with a Master's degree or equivalent from elsewhere, he or she must satisfy the requirement of taking 18 graded credits in courses at the 500 level or approved 400 level courses at the University of Washington before a General Examination is scheduled.
2. A Candidate must register for a minimum of 27 credits of Physics 800 over a period of at least 3 quarters in which at least one quarter comes after the student passes the General Examination. If a student schedules his or her General Examination late, he or she may be deficient in Physics 800 credits.

Physics Department – PhD Timeline

The sample timelines below should help students identify the steps involved in completing their PhD and help them measure their progress in the PhD Program. Students should be able to identify with one of three groups based on their undergraduate preparation.

Typical Entering PhD Students

Students who took the following courses in their undergraduate education: Quantum Mechanics, Electricity and Magnetism, Classical Mechanics/Statistical Mechanics, and Mathematical Physics or a senior-level survey course.

Entering PhD Students Requiring Additional Preparation

Students who were unable to take the following courses in their undergraduate education: Quantum Mechanics, Electricity and Magnetism, Classical Mechanics, and Mathematical Physics or a senior-level survey course. It is recommended that these students take junior- or senior-level physics courses before taking the first year, graduate-level courses.

Entering PhD Students with Advanced Standing

Students who already have a Master's degree in Physics or who have transferred from another university after completing one or more years in a Physics PhD program.

	Typical Entering PhD Student	**Entering PhD Student Requiring Additional Preparation**	**Entering PhD Students with Additional Standing**
Take Required First Year Courses	1^{st} year	1^{st} and 2^{nd} year	Some or all first year courses may be waived by the graduate program coordinator.
Register for Physics 600, Independent Study/Research	Beginning spring quarter of 1^{st} year.		Beginning autumn quarter of 1^{st} year.
Take Qualifying Examination	September before 2^{nd} year.	March of 2^{nd} year or September before 3^{rd} year.	March of 1^{st} year.
Take Other Required Courses	2^{nd} year	2^{nd} and 3^{rd} year.	1^{st} year
Find a Research Advisor	2^{nd} year or 3^{rd} year	3^{rd} year	2^{nd} year
Establish a Doctoral Supervisory Committee	Within not more than 2 years, but preferably within 1 year of passing the Qualifying Exam.		
Take the General Examination	During 3^{rd} or 4^{th} year.		During 2^{nd} or 3^{rd} year.
Register for Physics 800, Doctoral Dissertation	The 1^{st} quarter after passing the General Exam.		
Establish a Reading Committee	The quarter before the Final Exam.		
Take the Final Examination	5^{th} or 6^{th} year		4^{th} or 5^{th} year

Program Sequence

The information in this section is an outline of the program sequence. Students are expected to follow this sequence in a timely manner to make satisfactory progress.

1. Take Required First Year Courses
2. Register for Physics 600, Independent Study/Research
3. Take the Qualifying Examination
4. Take Other Required Courses
5. Find a Research Advisor
6. Establish a Supervisory Committee
7. Take the General Examination
8. Register for Physics 800, Doctoral Dissertation
9. Establish a Reading Committee
10. Take the Final Examination

Take Required First Year Courses

The Physics Department requires that a student complete certain courses, or have attained an equivalent level of understanding here or elsewhere. Students should first talk with their faculty advisor about whether a waiver for a course is appropriate. The faculty advisor should make a recommendation to the graduate program coordinator who decides whether to grant the waiver. The graduate program coordinator may consult with the instructor of the course in question if necessary.

During the first year of employment as a teaching assistant, students must take Physics 501, 502, and 503, (Tutorials in Teaching Physics,) which are counted as part of the teaching assignment. The Tutorials in Teaching Physics courses may be deferred if a student enters with inadequate spoken English.

Required First Year Courses

Unless waived by the graduate program coordinator, students must register for the following courses during their first year of study.

Autumn Quarter		
Course	**Title**	**Credits**
Phys 505	Mechanics	3
Phys 513	Electromagnetism and Relativity	4
Phys 517	Quantum Mechanics	4
Phys 501	Tutorials in Teaching Physics (For students holding or expecting to hold a Teaching Assistantship)	1

Winter Quarter		
Course	**Title**	**Credits**
Phys 524	Thermodynamics and Stat. Mechanics	4
Phys 514	Electromagnetism and Relativity	3
Phys 518	Quantum Mechanics	4
Phys 528	Current Problems in Physics	1
Phys 502	Tutorials in Teaching Physics (For students holding or expecting to hold a Teaching Assistantship)	1

Register for Physics 600, Independent Study/Research

The department strongly recommends that all first year students begin the process of exploring research opportunities in the department or with adjunct faculty in other departments during spring quarter. Students may register for one credit of Physics 600 and attend research group meetings every week or every other week with no obligation to continue the relationship beyond spring quarter. Students see a selection of research options in Physics 528, which is a class students are required to take in winter quarter.

The department recommends that first year students continue to investigate different research groups by registering for Physics 600 during summer

Spring Quarter		
Course	**Title**	**Credits**
Phys 511	Topics in Contemporary Physics	3
Phys 515	Electromagnetism and Relativity	4
Phys 519	Quantum Mechanics	4
Phys 503	Tutorials in Teaching Physics (For students holding or expecting to hold a Teaching Assistantship)	1

quarter. During the second year of graduate study and in subsequent years, students will register for an increasing number of Physics 600 credits. Students may not register for more than 10 credits of Physics 600 per quarter. Students holding full or partial research assistantships must register for at least one credit of Physics 600 with the faculty member supervising their research.

Take the Qualifying Examination

The qualifying examination serves to ascertain that a PhD candidate demonstrates competency across a broad spectrum of core subjects. Furthermore, the preparation process for taking the exam is a learning and integration opportunity that allows the student to develop a more global understanding of physics, in an independent setting (meaning outside the normal course setting that students have experienced up to this point).

Students are expected to take the qualifying examination just before the start of their second year of graduate study, but may take it earlier or later with the approval of the graduate program coordinator. Students who have not passed the exam by the beginning of spring quarter of their third year will be placed on probation in the absence of extenuating circumstances.

The qualifying examination is given twice a year, two weeks before autumn quarter begins and during the break between winter and spring quarters. The exam is typically administered on a Wednesday and Thursday from 9:00 a.m. to 5:00 p.m. See current schedule.

The qualifying examination is composed of five sections: classical mechanics, electricity and magnetism, quantum mechanics, basic physics, and statistical and thermal physics.

Students can find complete information in Qualifying Exam Information. This document contains information such as the current schedule, registration, letters of recommendations, preparation, exam content, exam grading, qualification, and the appeals process.

After students pass the qualifying exam, they are eligible to receive their Master's degree provided that course credit and grade point average requirements have been satisfied. Students should apply for their non-thesis Master's degree on the Graduate School's Master's Degree Application web page. The request period begins on Monday of the third week of each quarter and closes on Friday at midnight in the second week of the subsequent quarter.

Take Other Required Courses

Students who took the qualifying examination for the first time in September 2004 or later must also pass at least two elective courses in physics areas outside the area of their thesis research. (In special circumstances, the graduate program coordinator can waive these required courses.) It is anticipated that most students will complete the required courses before taking their general examination. However, holding a general examination prior to completing these courses is permissible provided the student has a plan approved by the graduate program coordinator, specifying which courses will be taken, and when. This policy is aimed at assuring some breadth of knowledge of modern physics at a more advanced level.

The following courses are currently taught in a non-specialized manner ensuring accessibility to all graduate students. (This suggested course list may be reviewed and updated periodically by the graduate committee.)

Find a Research Advisor

Research advisors help students select specialized courses, in addition to the required courses, appropriate to their interests. A student should find a research advisor within one year of passing the qualifying examination and should begin independent research in that faculty member's field of study under his or her supervision. When a student finds a research advisor, he or she must inform the graduate program assistant.

Students who have begun independent research with a faculty member are expected to attend the department's colloquium and seminars in their fields of specialization on a regular basis. Some study in a field of physics

Advanced Course List	
Course	**Title**
Phys 506	Numerical Methods
Phys 550	Atomic Physics
Phys 554	Nuclear Astrophysics
Phys 555	Cosmology, Particle Astrophysics
Phys 557	High Energy Physics
Phys 560	Nuclear Physics
Phys 564	General Relativity
Phys 567	Solid State Physics
Or other upper level graduate courses approved by the graduate program coordinator.	

outside of a student's research specialty is required. Furthermore, students may wish to explore some study in fields such as mathematics, engineering, or other natural sciences.

Establish a Doctoral Supervisory Committee

A doctoral supervisory committee guides and assists a student in working toward a doctoral degree and is expected to evaluate the student's performance throughout the program. All members of the supervisory committee are responsible to the student and to their graduate faculty colleagues for the quality of the degree being sought. Please see the roles and responsibilities of voting members, chair, graduate school representative (GSR) and student in Doctoral Supervisory Committee Roles and Responsibilities.

Report on Progress

The doctoral supervisory committee is responsible for monitoring a student's progress. The Physics Department policy concerning the need to meet with committee members is as follows.

1. Students enrolled for five or more years are required to meet annually with their research advisor and a quorum (at least two voting members) of their doctoral supervisory committee. The GSR is not expected to attend the meeting. Students are then *required to submit a report* signed by committee members to the department chair and the graduate program coordinator. The Annual Activities Report can be used as

this report on progress. Students who fail to meet with their committee by the end of their fifth year and subsequent years may be placed on probation, final probation, and finally dropped from the program.

2. Students enrolled for fewer than five years are required to meet annually with their research advisor and a quorum (at least two voting members) of their doctoral supervisory committee. The GSR is not expected to attend the meeting. Students are *not required to submit a report*, but it is strongly recommended that they combine the requirement for an annual meeting with their Annual Activities Report.

3. The General Examination counts as an annual meeting of the doctoral supervisory committee.

Normal Composition of the Doctoral Supervisory Committee

1. Graduate School Memorandum No. 13, Supervisory Committee for Graduate Students contains details regarding the composition of a doctoral supervisory committee; however, the Physics Department has adopted its own policy regarding the normal composition of the committee, which can be found on the Supervisory Committee Form. The standard composition of a committee includes:

    (a) The Committee Chair, typically your research advisor

    (b) Another faculty member in the same research field

    (c) A theorist/experimentalist from the same area if you are doing experimental/theory research

    (d) A faculty member from another area of physics (can be a theorist or experimentalist)

    (e) The GSR (Graduate School Representative), who cannot have a faculty appointment in the Physics Department.

    It is your responsibility to find a GSR for your committee. The process of finding a GSR can take a few hours or a few weeks, and often depends on how many contacts your Committee Chair or other committee members have with faculty from other departments. If you and your Committee Chair are having difficulty finding a GSR, please come speak with the graduate program assistant.

(f) At least two of these committee members listed above should be regular Physics department faculty (i.e. not adjuncts or affiliates)

Steps in Establishing a Doctoral Supervisory Committee

1. Soon after you find a research advisor, you should have a discussion with him or her about which faculty should be on your doctoral supervisory committee. Then, you should ask the faculty if they would be willing to serve on your committee.

2. Once you have obtained the consent of the faculty to serve on your committee, you should complete the online Supervisory Committee Form and submit it electronically to the graduate program assistant (grad@phys.washington.edu). *Please note that you do not need signatures on the Supervisory Committee Form.*

3. The graduate program assistant (1) performs a degree check to make sure that you have taken all required courses (2) asks the graduate program coordinator to approve the committee, and (3) enters the information from your supervisory committee Form into MyGradProgram (MGP), the Graduate School's web-based administrative system. Once this has been processed, you, your committee members, and the graduate program assistant will receive an email from The Graduate School confirming that your doctoral supervisory committee has been officially established.

***Important Note:** The doctoral supervisory committee must be established with the Graduate School **at least four months** before the General Examination is scheduled.

Take the General Examination

The usual form of a General Examination in the Physics Department is a public presentation of research already done and research proposed, followed by an examination with only members of the graduate faculty. A student should schedule the General Examination at the earliest time agreeable with the supervisory committee.

Students can find complete information in General Exam Information. This document contains information such as the general exam facts, how to schedule a general exam, and other general exam details.

Register for Physics 800, Doctoral Dissertation

Students should register for Phys 800 after passing the General Examination. A minimum of 27 dissertation credits over a period of at least three quarters must be completed. With the exception of summer, students are limited to a maximum of 10 dissertation credits (Physics 800) per quarter.

Establish a Reading Committee

The reading committee consists of **three members** of the doctoral supervisory committee. The research advisor acts as chairperson. The Graduate School Representative cannot be a reading committee member, but must attend the exam.

Steps in Establishing a Reading Committee

1. Once you have obtained the consent of the faculty to serve on your reading committee, you should complete the online Reading Committee Form and submit it electronically to the graduate program assistant (grad@phys.washington.edu). *Please note that you do not need signatures on the Reading Committee Form.*

2. The graduate program assistant (1) asks the graduate program coordinator to approve the committee, and (2) enters the information from your Reading Committee Form into MyGradProgram (MGP), the Graduate School's web-based administrative system.

3. Immediately after the graduate program assistant enters the information into MGP, you, your reading committee members, and the graduate program assistant will receive an email from The Graduate School confirming that your reading committee has been officially established.

***Important Note:** The reading committee must be established with the Graduate School **before** the Final Examination is scheduled.

Take the Final Examination

The final examination is an oral presentation and defense of a student's dissertation.

Students can find complete information in Final Exam Information. This document contains information such as the final exam facts, how to schedule a final exam, and other final exam details.

Satisfactory Progress

Graduate School Rules

The Graduate School requires that students complete all work for the doctoral degree within ten years of admission to the Graduate School. This includes quarters spent On-Leave or out of status as well as applicable work from the master's degree from the University of Washington or a master's degree from another institution, if used to substitute for 30 credits of enrollment. The Graduate School also tracks low scholarship—quarterly and cumulative grade point averages that fall below 3.0—and sends low scholarship reports to departments each quarter. In turn, the department makes recommendations to the Graduate School.

Aside from these Graduate School requirements, it is the responsibility of the student, department (chair, graduate program coordinator, academic advisor, and graduate program assistant) and the supervisory committee to make sure that a student is making satisfactory academic progress.

Physics Department Guidelines

Students can refer to the Physics Department – PhD Timeline and Program Sequence sections to help them determine whether they are making satisfactory progress. Please note that students must be making satisfactory progress to continue their Teaching and/or Research Assistantships. In summary, these are the department guidelines for student progress:

1. For the last few years, the median time from entry into the graduate program until PhD has been in the range of 5.5 – 6 years. The department strongly urges students and advisors to aim for 4-6 years.

2. The Qualifying Examination will usually be taken the summer prior to the second year.

3. The Supervisory Committee will usually be formed within one year of passing the Qualifying Examination and should be formed within two years of passing the Qualifying Examination. During the period before formation of the Committee, students are encouraged to meet with several faculty members and to enroll in Physics 600 in areas of potential research interest.

4. The General Examination will usually be taken during the third or fourth year. Students should register for Physics 800 after passing the General Examination.

5. Entering students who do not have the normal background are encouraged to take an alternate first year program containing undergraduate upper division courses in order to attain the proficiency needed for graduate courses. Such a program is one cause of modification of the typical progression.

Annual Activities Report

To help students maintain satisfactory progress and to encourage advisor-student contact, students are required, every winter quarter, to complete an annual activities report. This report includes comments from their advisor or research advisor, as well as a proposed time schedule for finishing the degree. The graduate program coordinator will review the reports and meet with students and/or their advisors when progress appears slow. If progress is not made and informal approaches have been unsuccessful, formal action may be taken. In the case of a formal report of lack of satisfactory progress, the graduate program coordinator sends a report to The Graduate School with a recommendation for action at three different levels. The lowest level is "Warn," which has no long-term consequences. The second level is "Probation," which usually comes with a schedule for completion of various requirements. The third level, which can come only after "Probation," is "Final Probation," which will lead to termination of enrollment if the required deadline is not met by the end of the quarter.

Low Scholarship/Unsatisfactory Progress

Graduate students are required to maintain a 3.0 grade point average in 500-level and approved 400-level courses. When the cumulative grade point average for the quarter falls below 3.0, The Graduate School sends a report to the graduate program coordinator who recommends an action to the Graduate School. The possible recommendations are "No Action," "Warn," "Probation," and "Final Probation." If a student is placed on "Probation," a definite timetable for remedying the situation is required. Only "Final Probation" can lead directly to termination from the program.

Financial Support

Academic Student Employees (ASEs)

Most full-time graduate students in Physics are supported by teaching and/or research appointments (Teaching Assistants/Research Assistants). There are also a number of scholarships, fellowships, and awards that provide partial financial support. If you have accepted a Teaching Assistant or Research Assistant position, you are classified as an "Academic Student Employee" (ASE). These positions all provide a stipend and a tuition waver. All first-year students are supported by assistantships or fellowships (usually together with a department one-time supplement). Second-year students making satisfactory progress are essentially guaranteed an assistantship for the academic year (and those with Teaching Assistant support have in recent years received a small supplement to their Teaching Assistant salary to bring the level closer to that of the Research Assistant). Beyond the second year, it is the Department's aim to provide support for all students making satisfactory progress. While this support cannot be guaranteed, since it is partly based on research grants, such support has been successfully provided for many years. The support will typically be in the form of an Research Assistant, or a combination Research Assistant/Teaching Assistant, beyond the second year. It is important to note, however, that is the responsibility of the student to find a research advisor and research support.

Research Assistants are funded through the research grants held by members of the faculty. Students holding such positions participate in specified research projects; the total time commitment is 20 hours a week on the research grant (Research Assistants are also expected to be full-time students and to be working on their own research). Teaching Assistants are employed by the University to assist faculty in their teaching activities. Teaching Assistants teach undergraduate labs, grade homework and exams, design learning exercises, and meet with students during office hours; the total time commitment is 20 hours a week. Students who accept assistantships at the University are required to register as full-time graduate students (a minimum of 10 credits in the academic year, and a minimum of 2 credits in the summer quarter). During their first year as a Teaching Assistant, students are required to enroll in a training course for Teaching Assistants in Physics.

For those students who are supported by Teaching Assistantships, it is important to note that the number of Teaching Assistant positions is more limited during the summer quarter than during the academic year. Thus it is important for students with academic-year Teaching Assistantships to look for possible Research Assistant opportunities for the summer. This applies particularly to first-year students, for whom a summer Research Assistantalso presents a good opportunity to learn about a research group. In practice, for many years the total number of positions (Research Assistants and Teaching Assistants) has been sufficient to provide summer support for those students making satisfactory progress. Students with ongoing Research Assistant support are usually supported through the summer quarter by their advisors' grants.

ASE appointments are governed by a contact between the UW an the the International Union, United Automobile, Aerospace and Agricultural Implement Workers of America (UAW), AFL-CIO and its Local Union 4121 (UAW). If you want review the UW/UAW Contract, please see the UW Labor Relations Web site. You will be contacted by a union representative with information about membership and fees.

Salaries and Promotions

Students entering the Physics PhD program who are hired as ASE employees are paid at the "Assistant" level (Teaching Assistant or Research Assistant).

After passing the Qualifying Exam, students will receive a promotion to either a Predoctoral Teaching Associate I or Predoctoral Research Associate I (depending on whether you are currently a Teaching Assistant or Research Assistant) starting the next pay period after the date of the Qualifying Exam.

Similarly after passing the General Exam, you will receive a promotion to either a Predoctoral Teaching Associate II or Predoctoral Research Associate II (depending on whether you are currently a Teaching Assistant or Research Assistant) starting the next pay period after the date of the General Exam.

The departmental pay rates for Research Assistants are significantly higher than for Teaching Assistants.
(See http://www.grad.washington.edu/fellow/salaryschedule/htm for current ASE rates. Note that the Physics Research Assistant rate appears in the variable rate schedule, while the Teaching Assistant rate is the standard one. Note also that it is the "Schedule 1" rates which are relevant.) This is in part to provide an incentive to find a research group and make progress towards a degree. As noted above, however, for the first two years (when most students are expected to be supported on Teaching Assistantships), the de-

partment typically provides a bonus or supplement to Teaching Assistant stipends which brings them close to the corresponding Research Assistant stipend.

Advising and Mentoring

First Year Advising and Mentoring Program

The Physics Department has adopted the following first year advising and mentoring program.

1. Graduate students volunteer to be a graduate student mentor and are paired with a member of the Graduate Committee who is the faculty advisor to several first year students. The graduate student mentor, faculty advisor, and first year students form an advising group.

2. During orientation, advising groups meet for 30 minutes; faculty advisors meet individually with first year students for 15-20 minutes; and both faculty advisors and graduate student mentors attend the Physics Department's new student reception.

3. Advising groups usually meet once each quarter, sometimes in combination with other groups.

4. Mentors are in regular contact with the first year students throughout the year and faculty advisors meet with first year students on an as needed basis.

5. The graduate program assistant checks with first year instructors after midterms and informs faculty advisors if any students are struggling in a course. In turn, faculty advisors make contact with these students.

6. Students must submit proposed class schedules for approval to their faculty advisor each quarter and must meet annually with their faculty advisor to complete their annual activities reports.

7. Students are encouraged to discuss their courses with their faculty advisor throughout their career.

8. Faculty advisors encourage students to get involved in research (at a minimal level) during spring quarter.

9. Faculty advisors are responsible for advising students until they are established with a thesis advisor, a faculty member who has agreed to supervise a student's research.

Quarterly Advising Panels

In continuation of the first year advising and mentoring program, the Physics Department holds the following quarterly advising panels early each quarter. Panelists are senior students and the panels are moderated by the graduate program assistant.

1. Mapping a Graduate Career (Autumn)
2. The General Exam (Winter)
3. Finding a Research Group (Spring)
4. The Qualifying Exam (Summer)

Terminal Master's Degree

Should you decide to leave the Physics PhD program before completing your research and thesis, there are two options that make it possible to obtain a Masters Degree in Physics from the PhD program.

The first option is to take and pass the Qualifying Exam. After students pass the Qualifying Exam, they are eligible to receive their Master's degree provided that the Graduate School's course credit and grade point average requirements have been satisfied. These requirements are as follows:

1. At least 36 credits must be completed
    (a) All courses numbered 400-799 that are numerically graded 2.7 and above, or have a grade of Satisfactory or Credit ('S' or 'CR') count toward the 36 credit total. 498 "Special Topics" and 499 are not counted in the 36 credit total.
    (b) Courses graded less than 2.7 do not count towards the 36 credit total.
    (c) At least 18 credits must be in courses numbered 500 and above.

(d) 18 credits must be numerically graded in department approved 400-level courses accepted as part of the major and in all 500-level courses. This excludes 498 and 499 and transfer credits.

(e) No more than 6 graduate level quarter credits can be transferred from other academic institutions to count toward the 36 credit total.

(f) No more than 12 UW Graduate Non-matriculated credits can be applied to the 36 credit total.

(g) No more than 12 credits derived from any combination of UW Graduate Non-matriculated credits and transfer credits can be applied to the 36 credit total.

(h) If a student repeats a non-repeatable class, only one set of credits counts toward the 36 credit total.

2. A minimum cumulative GPA (grade point average) of 3.00 is required for a graduate degree at the University

3. The Master's Degree Request must be filed

   (a) To avoid a late fee the Master's Degree Request must be filed before the end of the seventh week in the quarter.

   (b) If the Master's Degree Request is filed during weeks eight and nine it is considered late and the student must pay a late fee.

   (c) If the Master's Degree Request is filed during weeks ten and eleven it is not accepted. The system is closed

   (d) In summer quarter, the Master's Degree Request should be filed during weeks one through six. Week seven is considered late and the student must pay a fee. A request filed in weeks eight and nine is not accepted. The system is closed.

4. Must complete all degree requirements within six years

   (a) The timeframe/clock begins on the first day of the quarter that the Graduate Student uses a course to satisfy degree requirements when he/she is coded as either a Graduate Non-Matriculated student (Department Code with class 6) or as a Graduate Student (Department code with class 8) in the department to which he/she is admitted.

(b) UW Graduate Non-matriculated credits used towards the 36 course credit total are counted in the six years.

(c) Quarters spent On-Leave and out of status are counted in the six years.

5. Must maintain registration through the end of the quarter in which the degree is conferred or, if eligible, pay the Graduate Degree Late Fee within the first 4 weeks of a quarter.

The second option is to complete a master's level thesis, which will be reviewed by your faculty advisor and the graduate program coordinator. If your work is found to be of sufficient quality AND you have satisfied the Graduate School's course credit and grade point average requirements (see above), the Physics Department will grant a terminal Master's Degree.

Students may apply for non-thesis Master's degree on the Graduate School's Master's Degree Application web page. The request period begins on Monday of the third week of each quarter and closes on Friday at midnight in the second week of the subsequent quarter.

Chapter 10

HEC Board Summary

Department of Physics
College of Arts and Sciences

Degrees offered

The Department of Physics offers a Doctor of Philosophy in Physics, a Master of Science in Physics, and Bachelor of Science in Physics.

The Masters degree is awarded to students who begin, but only complete satisfactorily a portion of the Doctoral program. In addition students interested in Applications of Physics are admitted to the Masters program directly. The courses for this program are offered in the Evening and are intended for students working in the community.

Year of Last Review

1996-1997 Academic Year

Description of the Field and its History

Physics is concerned with understanding and describing mathematically the basic nature of matter and its interactions. The roots go back to the Greeks with modern Physics starting in the 16^{th} and 17^{th} centuries. Today, physics is at the foundation of all modern science and technology.

Continuing Need for the Program

Physics is required for all students majoring in science and engineering and research in physics is continuing to lead to advances in our understanding of nature and in technological developments.

Assessment Information Relating to Student Learning Outcomes and Program Effectiveness

The implicit learning goals for physics majors are incorporated into the basic structure of our (often scrutinized) curriculum where, as each course is passed, each will represent a bench-mark, upon which a student can gauge his/her progress.

The following represents how information is collected for future assessment of the success of this program:

1. Student evaluations of courses and classroom assessments.
2. Various *ad hoc* meetings of undergraduates with faculty.
3. Undergraduate participation on various committees and faculty meeting.
4. Required independent research.
5. Required Spring advising in junior/senior years.
6. Required exit surveys upon graduation.

As an example in 2005, this department initiated an intense process of revising its entire curriculum, due in large measure to informal feedback from many of the assessment procedures listed above. As a result, topics in PHYS 224, 227, and 228 were modified and introduced during the last academic year, with similar changes for PHYS 225 and the 12x series coming this academic year. In the next few years, several third-year courses will possibly be revised and introduced.

Number of Students from Unit

	2003-2004	2004-2005	2005-2006
Undergraduate Majors	78	66	63
Master's Degrees Granted	36	31	29
Doctoral Degrees Granted	16	29	14

Plans to Improve the Quality and Effectiveness of the Program

The Department is engaged in the process of renewing itself as faculty retire; in the process it is making appointments in new areas and establishing its presence in those areas. Through the efforts of the Physics Education Group, it is continuously working on improving its teaching.

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Appendix A

Graduate Student Statistical Summary

This section presents the statistical summaries in a series of tables:

1. Table A.1, p. 248, presents the student enrollment and distributions by gender and ethnic minorities.
2. Table A.2, p. 249, gives statistical information about admissions.
3. Table A.3, p. 250, states minority and international admissions.
4. Table A.4, p. 250, gives a summary the average applicant's GPA.
5. Table A.5, p. 251, gives a summary the applicants' GRE scores.
6. Table A.6, p. 252, lists the annual degrees given.
7. Table A.7, p. 252, shows financial support for students.

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Autumn Quarter Enrollment History									
Total									
146	154	147	161	176	175	189	189	178	163
Full-Time									
120	119	121	129	138	136	134	134	134	119
Part-Time									
26	35	26	32	38	39	55	55	44	44
Male									
129	133	123	133	145	141	161	161	151	132
Female									
17	21	24	28	31	34	28	28	27	31
Ethnic Minority									
10	17	15	14	17	18	15	16	15	11
International									
34	35	40	45	39	27	29	27	22	18
Washington Resident									
74	72	59	60	73	76	86	81	78	69
Non-Resident									
72	82	88	101	103	99	103	108	100	94
New Student Enrollment									
24	40	36	37	37	42	45	42	38	29
Continuing									
122	114	111	124	139	131	144	147	140	134

Table A.1: Student Enrollments

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Applications (Sum-Spr qtrs)									
289	280	332	313	350	409	419	425	391	
Autumn Quarter Applications									
269	258	307	293	325	392	400	420	370	410
Autumn Quarter Denials									
175	144	45	171	195	270	273	281	262	306
Autumn Quarter Offers									
78	95	131	94	97	114	119	121	96	89
Autumn Quarter Percentages									
% Denied (of Applications)									
65.1	55.8	14.7	58.4	60.0	68.9	68.3	66.9	70.8	74.6
% Offers (of Applications)									
29.0	36.8	42.7	32.1	29.8	29.1	29.8	28.8	25.9	21.7
% New Enrollees (of Applications)									
8.9	15.5	11.7	12.6	11.4	10.7	11.3	10.0	10.3	7.1
% New Enrollees (of Offers)									
30.8	42.1	27.5	39.4	38.1	36.8	37.8	34.7	39.6	32.6

Table A.2: Student Application

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Autumn Minority Admissions									
Application									
22	25	23	17	20	24	25	22	36	24
Denials									
10	14	0	6	6	12	14	15	27	17
Offers									
8	11	11	9	11	10	11	7	8	7
Autumn International Admissions									
Application									
110	104	123	151	160	183	135	144	116	140
Denials									
99	77	45	125	124	169	114	115	95	120
Offers									
9	20	18	12	13	11	17	19	12	13

Table A.3: Admissions

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Applicant Average GPA									
Denied									
3.49	3.41	3.81	3.51	3.49	3.48	3.50	3.52	3.52	3.57
Accepted But Not Enrolled									
3.70	3.65	3.68	3.68	3.73	3.72	3.66	3.71	3.71	3.79
Accepted and Enrolled									
3.46	3.57	3.49	3.57	3.66	3.64	3.43	3.56	3.58	3.84

Table A.4: Student GPAs

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Applicant Average GRE									
Denied									
Verbal Score									
562	530	541	566	570	531	561	560	542	544
Quantitative Score									
730	734	784	744	761	752	757	760	755	757
Analytical Score									
676	644	701	679	690	682	697	662	678	
Accepted But Not Enrolled									
Verbal Score									
622	606	611	600	595	596	628	603	605	616
Quantitative Score									
761	743	765	766	767	775	782	780	779	785
Analytical Score									
712	691	716	717	710	713	747	741	748	683
Accepted and Enrolled									
Verbal Score									
598	582	578	588	610	595	615	582	607	646
Quantitative Score									
773	742	750	754	757	751	773	769	770	781
Analytical Score									
679	667	683	707	696	703	749	696	748	717

Table A.5: Student GRE Scores

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Annual Degrees (Sum-Spr qtrs)									
Masters									
31	18	22	26	34	38	23	36	29	
Doctoral									
19	19	13	15	13	13	13	16	27	
Ph.D. Candidates									
15	13	15	9	19	20	22	18	16	

Table A.6: Degrees

Year									
97-8	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**	**06-7**
Autumn Quarter Financial Support									
Teaching									
57	59	58	60	59	59	56	58	58	55
Research Assistants									
74	86	68	80	90	86	80	84	81	82
Fellowship									
5	4	1	4	3	5	9	10	6	4
Traineeships									
0	1	2	2	3	2	2	0		1

Table A.7: Student Financial Support

Appendix B

Academic Unit Profile

The various sources of funding of the Department of Physics are summarized in the following set of tables. The first table, Table B.1, page 253, gives the funds available to the Department exclusive of research grants but including the so-called RCR (Indirect Cost Return to the Department).

Source	Fiscal Year	
	2006-07	Projections 2007-08
State Funding (Permanent and temporary funding)	$ 7,016,942	$ 7,456,336[1]
Startup Funds	$ 309,160	$ 2,144,403
Self-Sustaining Programs (Technical Services)	$ 737,832	$ 642,442
Lab Fees (Freshman and Advanced Labs)	$ 235,616	$ 209,471

[1]This includes a reserve for future startup commitmments. The 2006-07 figure does not include the reserve.

Table B.1: Physics Department Funding Sources, FY 2006-07 to 2007-08

Table B.2, page 254, indicates the amounts of indirect costs paid by the grants and the amounts returned to the Department.

The following table, Table B.3, page 254, indcates the sources of funding for graduate student support including support by grants.

Faculty and staff are supported both by University and by grant funds; the amounts and number of each are indicated in Table B.4, page 255.

Fiscal Year	Indirect Cost Recovery to UW	Research Cost Recovery to Physics Department
2006-07	$ 2,226,067	$ 519,017
2007-08	$ 2,421,664	$ 567,917

Table B.2: Indirect Cost Recovery to UW and Research Cost Recovery to the Physics Department

Source	Amount	Selection Process
Young Fellowship Endowment Fund	$ 30,043	Restricted to sponsor mandated criteria
Fellowship Endowment Funds	$ 143,767	Restricted to sponsor mandated criteria
Gift Funded Fellowships	$ 22,500	Restricted to sponsor mandated criteria
Graduate School Grant (GSFEI)	$ 27,000	Annual University-wide competition
Graduate School Travel Grant (GSFEI)	$ 10,000	University-wide competition
Research Fellowships (research assistantships with tuition waiver)	$1,995,968	These research assistantships are generally held by graduate students doing research for their PhD
State funded assistantships (teaching assistants, graduate reader/graders)	$ 760,474	TA's are usually first year students.
Total Amount Available	$ 2,989,752	

Table B.3: Student Support Funding Sources, Academic Year 2006-07

Faculty/Staff	Funding Expensed	Number of Full-Time	Number of Part-Time
Faculty on State Funds	$ 4,169,847	45	1
Staff on State Funds	$ 921,788	17	2
Staff on Self-Sustaining	$ 368,764	6	1
Research Faculty Support	$ 661,303	9	0
Research Staff Support	1,211,963	21	5

Table B.4: Faculty and Staff Support on State and Research Funds, FY 2007-08

The funds available to the Department from gifts and endowments are shown in Table B.5, page 255. The gift amounts are for direct expenditure; the endowments are presented both as the value of the endowment and as the revenue distributed. Note that Professor Cramer's research attracts a significant amount of public support as expressed in direct gifts.

The final Tables, B.6 – B.7, pp 256 – 257, show the total grant income for each Principal Investigator. A number of the grants are 'umbrella grants' which support an entire group, not just one Principal Investigator.

Purpose	Endowments		Gifts
	Market Value	Distribution	
Awards & Prizes	$ 530,525	$ 21,212	$ 2,525
Department Support	$ 35,171	$ 1,469	$ 32,900
Graduate Support	$ 4,180,968	$ 173,810	$ 20,000
Professorships	$ 1,812,425	$ 79,643	
Undergraduate Support	$ 206,429	$ 8,624	
Physics Restricted (Cramer)[2]			$ 37,795
CDO[3]			$ 2,500
Total Amount Available	$ 6,765,518	$ 284,758	$ 95,720

[2]Professor Cramer's work on possible causality violations attracts direct contributions from the public which are shown here.

[3]Career Development Organization (see 9.1)

Table B.5: Physics Department Endowments & Gifts, FY 2006-07

PI	**Amount ($)**
Astrophysics & Gravitational Physics	
Adelberger	435,000.00
Boynton	423,700.00
Gundlach	635,084.00
TOTAL:	1,493,784.00
Atomic Physics	
Blinov	128,024.00
Fortson	333,000.00
Nagourney	35,000.00
Van Dyck	180,000.00
TOTAL:	676,024.00
Biophysics	
Gundlach	310,101.00
TOTAL:	310,101.00
Center for Experimental Nuclear Physics and Astrophysics	
Storm[4]	7,553,763.00
Wilkerson	90,175.00
TOTAL:	7,643,938.00
Condensed Matter Experiment	
Cobden	193,485.00
Olmstead	188,256.00
Seidler	49,839.00
Sorensen	119,467.00
Vilches	260,000.00
TOTAL:	811,047.00

[4]Umbrella grant supporting the entire group.

Table B.6: PI Grants (by group)

PI	**Amount ($)**
Condensed Matter Theory	
Andreev	46,545.00
den Nijs	121,000.00
Rehr	641,780.47
Schick	90,193.00
Spivak	100,000.00
TOTAL:	999,518.47
Elementary Particle Experiment	
Burnett	276,176.00
Lubatti[5]	979,110.00
Zhao	18,000.00
TOTAL:	1,298,811.00
Institute for Nuclear Theory	
Bertsch	57,926.00
TOTAL:	57,926.00
Nuclear Theory	
Miller[5]	743,637.00
TOTAL:	743,637.00
Particle Astrophysics	
Wilkes	58,000.00
TOTAL:	58,000.00
Particle Theory	
Rosenberg	190,000.00
Strassler	25,525.00
Wilkes	205,000.00
Yaffe[5]	962,963.00
TOTAL:	1,383,488.00
Physics Education Group	
McDermott[5]	1,788,606.12
TOTAL:	1,788,606.12
GRAND TOTAL:	16,775,336.59

[5] Umbrella grants supporting an entire group.

Table B.7: PI Grants (by group)

Appendix C

Faculty

C.1 Faculty by Rank

Last Name	**First Name**	**Group**
	Professor	
Bertsch	George	Institute for Nuclear Theory
Boulware	David	Chair
Boynton	Paul	Astronomy
		Astrophysics & Gravitational Physics
Bulgac	Aurel	Nuclear Theory
Burnett	Thompson (Toby)	Center for Experimental Nuclear and Particle Astrophysics
		Elementary Particle Experiment
		Particle Astrophysics
Chaloupka	Vladimir	Foundations of Physics
Cramer	John	Center for Experimental Nuclear and Particle Astrophysics
den Nijs	Marcel	Condensed Matter Theory
		Biophysics
Ellis	Stephen	Particle Theory

Table C.1: Faculty by Rank Professors (B-E)

Last Name	**First Name**	**Group**
		Professor
Fain	Samuel	Condensed Matter Experiment
		Ice Physics
Garcia	Alejandro	Center for Experimental Nuclear and Particle Astrophysics
Gundlach	Jens	Center for Experimental Nuclear and Particle Astrophysics
		Astrophysics & Gravitational Physics
		Biophysics
Haxton	Wick	Nuclear Theory
		Institute for Nuclear Theory
Heckel	Blayne	Astrophysics & Gravitational Physics
		Atomic Physics
		Center for Experimental Nuclear and Particle Astrophysics
Heron	Paula R. L.	Physics Education Group
Hogan	Craig	Astronomy
Kaplan	David	Institute for Nuclear Theory
Lubatti	Henry	Elementary Particle Experiment
McDermott	Lillian C.	Physics Education Group
Miller	Gerald	Nuclear Theory
		Biophysics
Nelson	Ann E.	Particle Theory
Olmstead	Marjorie	Condensed Matter Experiment
Rehr	John J.	Condensed Matter Theory
Robertson	R.G. Hamish	Center for Experimental Nuclear and Particle Astrophysics
Rosenberg	Leslie	Experimental Astrophysics
Rothberg	Joseph	Elementary Particle Experiment
Savage	Martin	Nuclear Theory
Schick	Michael	Condensed Matter Theory
		Biophysics
Sharpe	Stephen R.	Particle Theory

Table C.2: Faculty by Rank Professors (F-S)

Last Name	First Name	Group
	Professor	
Son	Dam Thanh	Institute for Nuclear Theory
Sorensen	Larry	Condensed Matter Experiment
Spivak	Boris	Condensed Matter Theory
Van Dyck	Robert	Atomic Physics
Wilkerson	John	Center for Experimental Nuclear and Particle Astrophysics
Wilkes	R. Jeffrey	Particle Astrophysics Center for Experimental Nuclear and Particle Astrophysics
Yaffe	Laurence	Particle Theory
	Associate Professor	
Andreev	Anton	Condensed Matter Theory
Cobden	David	Condensed Matter Experiment
Goussiou	Anna	Elementary Particle Experiment
Seidler	Gerald	Ice Physics Condensed Matter Experiment
Shaffer	Peter S.	Physics Education Group
Watts	Gordon	Elementary Particle Experiment
	Assistant Professor	
Blinov	Boris	Atomic Physics
Gupta	Subhadeep	Atomic Physics
Karch	Andreas	Particle Theory
Tolich	Nikolai	Experimental Astrophysics
	Senior Lecturer	
Pedigo	R. Daryl	
Pengra	David	
	Research Professor	
Doe	Peter	Center for Experimental Nuclear and Particle Astrophysics
Nagourney	Warren	Atomic Physics

Table C.3: Faculty by Rank Professors (S), Research Professors (D-N)

Last Name	**First Name**	**Group**
	Research Professor	
Storm	Derek	Center for Experimental Nuclear and Particle Astrophysics
Trainor	Thomas	Center for Experimental Nuclear and Particle Astrophysics
	Research Associate Professor	
Zhao	Tianchi	Elementary Particle Experiment
	Research Assistant Professor	
Detmold	William	Nuclear Theory
Romatschke	Paul	Institute for Nuclear Theory
Schlamminger	Stephan	Center for Experimental Nuclear and Particle Astrophysics
		Astrophysics & Gravitational Physics
Stetzer	MacKenzie	Physics Education Group
	Adjunct Professor	
Baker	David	Biochemistry
		Biophysics
Buck	Warren	Nuclear Theory
Campbell	Charles	Chemistry
		Condensed Matter Experiment
Drobny	Gary	Condensed Matter Experiment
Dunham	Scott T.	Condensed Matter Experiment
Fine	Arthur I.	Foundations of Physics
Hawley	Suzanne	Astronomy
Holzworth	Robert	Earth & Space Sciences
Jarboe	Thomas	Aeronautics & Astronautics
Krishnan	Kannan	Condensed Matter Experiment
Ohuchi	Fumio	Condensed Matter Experiment
Quinn	Thomas	Astronomy
		Astrophysics & Gravitational Physics
Reinhardt	William	Chemistry
		Condensed Matter Theory
Winglee	Robert	Earth & Space Sciences

Table C.4: Faculty by Rank Research, Adjuncts

Last Name	First Name	Group
Adjunct Associate Professor		
Dalcanton	Julianne	Astronomy
Keller	Sarah L.	Biophysics
		Condensed Matter Experiment
Lin	Lih	Condensed Matter Experiment
Rieke	Frederick	Biophysics
Adjunct Assistant Professor		
Agol	Eric	Astronomy
		Astrophysics & Gravitational Physics
Doran	Charles	Particle Theory
Ginger, Jr.	David	Condensed Matter Experiment
Iqbal	Amer	Particle Theory
Li	Xingde	Biophysics
Raschke	Markus B.	Chemistry
		Condensed Matter Theory
Adjunct Research Assistant Professor		
Ao	Ping	Condensed Matter Theory
Bacon	Dave	Computer Science & Technology
Affiliate Professor		
Alberg	Mary	Nuclear Theory
Balantekin	A. Baha	Institute for Nuclear Theory
Barrett	Bruce	Nuclear Theory
Bichsel	Hans	Energy & Environment
		Center for Experimental Nuclear and Particle Astrophysics
Bowles	Thomas	Center for Experimental Nuclear and Particle Astrophysics
Cahn	John W.	Condensed Matter Theory
Chayes	Jennifer	Condensed Matter Theory
Cleveland	Bruce	Center for Experimental Nuclear and Particle Astrophysics
Friedman	William A.	Nuclear Theory

Table C.5: Faculty by Rank Adjuncts, Affiliates

Last Name	First Name	Group
	Affiliate Professor	
Nordtvedt	Kenneth	Center for Experimental Nuclear and Particle Astrophysics
Raab	Frederick	Astrophysics & Gravitational Physics
Riedel	Eberhard	Condensed Matter Theory
Stubbs	Christopher	Astronomy
		Center for Experimental Nuclear and Particle Astrophysics
Tung	Wu-Ki	Particle Theory
Van Bibber	Karl	Nuclear Theory
Wettlaufer	John	Ice Physics
		Condensed Matter Experiment
		Condensed Matter Theory
	Affiliate Associate Professor	
Elliott	Steven	Center for Experimental Nuclear and Particle Astrophysics
van Kolck	Ubirajara (Bira)	Nuclear Theory
	Affiliate Assistant Professor	
Schwenk	Achim	Nuclear Theory
	Emeritus Professor	
Adelberger	Eric	Center for Experimental Nuclear and Particle Astrophysics
		Astrophysics & Gravitational Physics
Baker	Marshall	Particle Theory
Bardeen	James	Astronomy
		Astrophysics & Gravitational Physics
Bodansky	David	Energy & Environment
Brown	Frederick C.	Condensed Matter Experiment
Brown	Lowell S.	Particle Theory
Clark	Kenneth C.	Atomic Physics
		Earth & Space Sciences
Cook	Victor	Elementary Particle Experiment

Table C.6: Faculty by Rank Affiliates, Emeritus

Last Name	**First Name**	**Group**
	Emeritus Professor	
Dash	J. Gregory	Condensed Matter Experiment Ice Physics
Dehmelt	Hans	Atomic Physics
Fortson	E. Norval	Atomic Physics
Halpern	Isaac	Center for Experimental Nuclear and Particle Astrophysics
Henley	Ernest M.	Nuclear Theory
Ingalls	Robert L.	Condensed Matter Experiment
Puff	Robert	Nuclear Theory
Stern	Edward	Condensed Matter Experiment
Thouless	David	Condensed Matter Theory
Vilches	Oscar	Condensed Matter Experiment
Wilets	Lawrence	Nuclear Theory
Williams	Robert W.	Elementary Particle Experiment
	Emeritus Research Professor	
Mockett	Paul	Elementary Particle Experiment
Snover	Kurt	Center for Experimental Nuclear and Particle Astrophysics
Weitkamp	William G.	Center for Experimental Nuclear and Particle Astrophysics
	Emeritus Senior Lecturer	
Robertson	Charles E.	

Table C.7: Emeritus Research - Lecturer

C.2 Faculty by Group

These Tables, C.8-C.13, on pages, 266-271, list the faculty by group.

Last Name	**First Name**	**Title**
	Aeronautics & Astronautics	
Jarboe	Thomas	Adjunct Professor
	Astronomy	
Agol	Eric	Adjunct Assistant Professor
Bardeen	James	Emeritus Professor
Boynton	Paul	Professor
Dalcanton	Julianne	Adjunct Associate Professor
Hawley	Suzanne	Adjunct Professor
Hogan	Craig	Professor
Quinn	Thomas	Adjunct Professor
Stubbs	Christopher	Affiliate Professor
	Astrophysics & Gravitational Physics	
Adelberger	Eric	Emeritus Professor
Agol	Eric	Adjunct Assistant Professor
Bardeen	James	Emeritus Professor
Boynton	Paul	Professor
Gundlach	Jens	Professor
Heckel	Blayne	Professor
Quinn	Thomas	Adjunct Professor
Raab	Frederick	Affiliate Professor
Schlamminger	Stephan	Research Assistant Professor

Table C.8: Faculty by Group – Astronomy & Astrophysics

Last Name	First Name	Title
	Atomic Physics	
Blinov	Boris	Assistant Professor
Clark	Kenneth C.	Emeritus Professor
Dehmelt	Hans	Emeritus Professor
Fortson E.	Norval	Emeritus Professor
Gupta	Subhadeep	Assistant Professor
Heckel	Blayne	Professor
Nagourney	Warren	Research Professor
Van Dyck	Robert	Professor
	Biochemistry	
Baker	David	Adjunct Professor
	Biophysics	
Baker	David	Adjunct Professor
den Nijs	Marcel	Professor
Gundlach	Jens	Professor
Keller	Sarah L.	Adjunct Associate Professor
Li	Xingde	Adjunct Assistant Professor
Miller	Gerald	Professor
Rieke	Frederick	Adjunct Associate Professor
Schick	Michael	Professor
	Center for Experimental Nuclear and Particle Astrophysics	
Adelberger	Eric	Emeritus Professor
Bichsel	Hans	Affiliate Professor
Bowles	Thomas	Affiliate Professor
Burnett	Thompson (Toby)	Professor
Cleveland	Bruce	Affiliate Professor
Cramer	John	Professor
Doe	Peter	Research Professor
Elliott	Steven	Affiliate Associate Professor
García	Alejandro	Professor
Gundlach	Jens	Professor

Table C.9: Faculty by Group – AMO - CENPA

Last Name	**First Name**	**Title**
Center for Experimental Nuclear and Particle Astrophysics		
Halpern	Isaac	Emeritus Professor
Heckel	Blayne	Professor
Nordtvedt	Kenneth	Affiliate Professor
Robertson	R.G. Hamish	Professor
Schlamminger	Stephan	Research Assistant Professor
Snover	Kurt	Emeritus Research Professor
Storm	Derek	Research Professor
Stubbs	Christopher	Affiliate Professor
Trainor	Thomas	Research Professor
Weitkamp	William G.	Emeritus Research Professor
Wilkerson	John	Professor
Wilkes	R. Jeffrey	Professor
Chemistry		
Campbell	Charles	Adjunct Professor
Raschke	Markus B.	Adjunct Assistant Professor
Reinhardt	William	Adjunct Professor
Computer Science & Engineering		
Bacon	Dave	Adjunct Research Assistant Professor
Condensed Matter Experiment		
Brown	Frederick C.	Emeritus Professor
Campbell	Charles	Adjunct Professor
Cobden	David	Associate Professor
Dash	J. Gregory	Emeritus Professor
Drobny	Gary	Adjunct Professor
Fain	Samuel	Professor
Ginger, Jr.	David	Adjunct Assistant Professor
Ingalls	Robert L.	Emeritus Professor
Keller	Sarah L.	Adjunct Associate Professor
Krishnan	Kannan	Adjunct Professor
Lin	Lih	Adjunct Associate Professor
Ohuchi	Fumio	Adjunct Professor
Olmstead	Marjorie	Professor
Raschke	Markus B.	Adjunct Assistant Professor

Table C.10: Faculty by Group – CENPA - CME

Last Name	**First Name**	**Title**
	Condensed Matter Experiment	
Seidler	Gerald	Associate Professor
Sorensen	Larry	Professor
Stern	Edward	Emeritus Professor
Vilches	Oscar	Emeritus Professor
Wettlaufer	John	Affiliate Professor
	Condensed Matter Theory	
Andreev	Anton	Associate Professor
Ao	Ping	Adjunct Research Associate Professor
Cahn	John W.	Affiliate Professor
Chayes	Jennifer	Affiliate Professor
den Nijs	Marcel	Professor
Dunham	Scott T.	Adjunct Professor
Rehr	John J.	Professor
Reinhardt	William	Adjunct Professor
Riedel	Eberhard	Affiliate Professor
Schick	Michael	Professor
Spivak	Boris	Professor
Thouless	David	Emeritus Professor
Wettlaufer	John	Affiliate Professor
	Earth & Space Sciences	
Clark	Kenneth C.	Emeritus Professor
Holzworth	Robert	Adjunct Professor
Winglee	Robert	Adjunct Professor
	Elementary Particle Experiment	
Burnett	Thompson (Toby)	Professor
Cook	Victor	Emeritus Professor
Goussiou	Anna	Associate Professor
Lubatti	Henry	Professor
Mockett	Paul	Emeritus Research Professor
Rothberg	Joseph	Professor
Watts	Gordon	Associate Professor
Williams	Robert W.	Emeritus Professor
Zhao	Tianchi	Research Associate Professor

Table C.11: Faculty by Group – CME - EPE

Last Name	**First Name**	**Title**
	Energy & Environment	
Bichsel	Hans	Affiliate Professor
Bodansky	David	Emeritus Professor
	Experimental Astrophysics	
Rosenberg	Leslie	Professor
Tolich	Nikolai	Assistant Professor
	Foundations of Physics	
Chaloupka	Vladimir	Professor
Fine	Arthur I.	Adjunct Professor
	Ice Physics	
Dash	J. Gregory	Emeritus Professor
Fain	Samuel	Professor
Seidler	Gerald	Associate Professor
Wettlaufer	John	Affiliate Professor
	Institute for Nuclear Theory	
Balantekin	A. Baha	Affiliate Professor
Bertsch	George	Professor
Haxton	Wick	Professor
Kaplan	David	Professor
Romatschke	Paul	Research Assistant Professor
Son	Dam Thanh	Professor
	Nuclear Theory	
Alberg	Mary	Affiliate Professor
Barrett	Bruce	Affiliate Professor
Buck	Warren	Adjunct Professor
Bulgac	Aurel	Professor
Detmold	William	Research Assistant Professor
Friedman	William A.	Affiliate Professor
Haxton	Wick	Professor
Henley	Ernest M.	Emeritus Professor
Miller	Gerald	Professor

Table C.12: Faculty by Group – Energy - NT

Last Name	First Name	Title
	Nuclear Theory	
Puff	Robert	Emeritus Professor
Savage	Martin	Professor
Schwenk	Achim	Affiliate Assistant Professor
Van Bibber	Karl	Affiliate Professor
van Kolck	Ubirajara (Bira)	Affiliate Associate Professor
Wilets	Lawrence	Emeritus Professor
	Particle Astrophysics	
Burnett	Thompson (Toby)	Professor
Wilkes	R. Jeffrey	Professor
	Particle Theory	
Baker	Marshall	Emeritus Professor
Brown	Lowell S.	Emeritus Professor
Doran	Charles	Adjunct Assistant Professor
Ellis	Stephen	Professor
Iqbal	Amer	Adjunct Assistant Professor
Karch	Andreas	Assistant Professor
Nelson	Ann E.	Professor
Sharpe	Stephen R.	Professor
Tung	Wu-Ki	Affiliate Professor
Yaffe	Laurence	Professor
	Physics Education Group	
Heron	Paula R. L.	Professor
McDermott	Lillian C.	Professor
Shaffer	Peter S.	Associate Professor
Stetzer	MacKenzie	Research Assistant Professor

Table C.13: Faculty by Group NT – PEG

Appendix D

Mission Statement

The mission of the Department of Physics of the University of Washington is to provide education and perform research in physics at the highest level. In fulfillment of this mission, the Department educates students at all levels from general education, through preparation for teaching and scientific careers, to doctoral and post-doctoral education.

Appendix E

Staffing Report

Winter 2008 Physics Staffing Committee Report
Department of Physics
University of Washington

February 4, 2008

EXECUTIVE SUMMARY

The Physics Department at the University of Washington (UW) is recognized as one of the premier physics programs in the nation. This strength stems in part from the Department's success in recruiting faculty who emerge as leaders in their fields. It is our common goal to support and improve the strength, vitality, and intellectual diversity of our Department. A first-rate Physics Department should be recognized as being leaders in some disciplines and should also include a sufficient breadth of activities to provide educational opportunities for students and to contribute to areas where new discoveries are being made.

The following is the report of the Physics Department Staffing Committee. The Committee is charged with recommending the Department's strategic faculty-hiring goals over the next five years. Choosing those areas to which resources and hires should be applied is a balance between responding to the immediate needs of the Department, the Department's long-range strategy, and special opportunities that may arise. Alongside strategic searches are targets-of-opportunity and searches coupled to initiatives. Targets-of-opportunity are difficult to anticipate and are therefore largely outside this report. Initiatives (e.g., Experimental Gravity and Tera-Scale Physics) are usually, but not always, generated by groups of individuals within the Department and are likewise largely outside this report. Although outside this report, the Staffing Committee feels that targets-of-opportunity and initiatives are an important source of outstanding faculty and programs and are important components of hiring. The full charge to the Staffing Committee includes encouraging and evaluating targets-of-opportunities and initiatives.

Per the discussion below, we anticipate approximately ten hires over five years (two per year), and this is our target number of recommendations. This report is organized for convenience by subfields, but we recognize that this organization is somewhat arbitrary and good programs and candidates can and will overlap existing subgroups or be in new directions. Our overall strategy for recommending searches was to assemble information to aid us in making the difficult determination as to whether a search should be a priority. Factors in this determination are the direction the subfield is heading—here we were aided particularly by Department and National Research Council (NRC) studies—and whether staffing in that subfield is adequate, projected over five years. We further considered whether a subfield was a "pillar" of the Department's research, representing a significant source of intellectual activity and graduate education. We did not give great weight to arguments based on maintaining head count. We were asked to make a five-year recommendation, and found we had clarity on Department priorities for the near term, but our vision was hazy for the out years. We note that Staffing recommendations are revisited each year, and therefore these recommendations, especially for the out years, are not static. Finally, other Committees within the Department provide useful information for staffing. In particular, the Graduate Committee reports on graduate student enrollments, their research subfields, and sources of funding. Unfortunately, we do not have this report at the time of writing this document.

In the near term, we envision a major initiative in Condensed Matter Experiment, supported by perhaps three hires. Condensed Matter is the largest subfield of Physics, and lends itself to the kind of innovative experiments our Department does best. We feel the Department is underrepresented in this area and that there are opportunities we can exploit. Also, in the near term, we envision increasing our activity in Experimental Astrophysics, broadly defined. This is another subfield that is of growing importance and lends itself to innovative, UW style experiments. Also in the near term, we advocate filling out a three-person group in experimental Large Hadron Collider (LHC) science. We find the Department split on whether LHC science should be a near-term recommendation. However, the Committee feels that the LHC, which is scheduled to start operation this year, has a high likelihood of discovering important new science. We note the Department has a large investment in the LHC experiment through the ATLAS muon detector system. The Committee certainly recognizes the challenges a university group faces in such a large and remote research enterprise, but we expect the LHC theorists and experimenters will be able to fully participate while maintaining their intellectual center at the University of Washington.

Also in the near term, we recommend building up Astrophysics Theory. The likely loss of Craig Hogan is a serious setback to the Department's Astrophysics initiative and should be addressed at very high priority.

BACKGROUND

In 2004, a five-year Staffing Plan was approved by the Department. The 2005 Staffing Plan Update provided a progress report and outlined the remaining staffing priorities. In the 2006-07 academic year, the Staffing Committee met with representatives of various groups in the Department to assess continuing needs and evaluate priorities for faculty hiring. In early 2007 another Staffing Plan Update summarized the information presented to the Staffing Committee and included a first response of the Committee to the presentations. Since that early 2007 update, the Staffing Committee has solicited short updates from the various groups and individuals within the Department. We also listen to the vigorous discussion of staffing issues among the faculty.

The original 2004 Plan highlighted staffing priorities in five areas: Astrophysics, Atomic Physics/Quantum Manipulation, Experimental Neutrino Physics, Experimental High-Energy Physics and Theoretical Physics. Since then, substantial progress has been made towards fulfilling the plan. An appointment has been made in Experimental Neutrino Physics (Tolich). Two appointments have been made in Atomic Physics/Quantum Manipulation (Blinov and Gupta). An appointment has been made in Experimental High Energy Physics (Goussiou). Two appointments have been made in Experimental Astrophysics (Morales and Rosenberg).

Since the priorities in the 2004 Plan are well on the way to being satisfied, this is a good opportunity to reevaluate our staffing recommendations. If we assume that faculty searches will be authorized one-to-one as people retire (at the estimated age of 70), then we plan on filling ten positions over the next five years. We may be surprised, pleasantly or unpleasantly, by the number of authorized searches; two per year over five years is our present working number.

There are several Department commitments that affect hiring plans over the next several years. These include: A Department vote that a search in LHC Theory be included as part of a broad theory search should Nelson et al.'s "Tera-Scale" funding request be supported; a Department vote to include Particle Experiment in the next broad search in Experimental Physics (the "Goussiou commitment"); and a similar commitment for Astrophysics Experiment (the "Morales commitment").

CHARGE TO THE COMMITTEE

The present Staffing Committee was constituted by the Department Chair in July 2007. Pursuant to this report, our charge is:

Identify areas of physics in which staffing is a priority based upon consideration of anticipated developments in physics. Recommend the broadly defined areas in which the Department should seek to search during the following year, such as 'theory', 'experiment' or 'education', and what emphases in these areas should be.

The summary of the Committee's findings and recommendations are given below. Since the motivations and plans for hiring in Astrophysics and Experimental Particle Physics are already well documented in Department reports and the reports are still relevant (the 2004 and 2005 Staffing Committee reports, the Astrophysics Strategic Plan, and the Experimental Particle Physics vision document), these subfields are only briefly addressed below. Two new reports since the 2004 plan, one reviewing CENPA (Hogan et al.), the other evaluating opportunities in Biological Physics (Kaplan et al.), are summarized below. The Committee recognizes that the Department Chair, in consultation with the faculty and Dean, "packages" search priorities into search requests to the UW Administration. The sense of the Committee is that, for strategic searches, in general the Department is better served by broad searches.

FINDINGS AND RECOMMENDATIONS

Condensed Matter Experiment (CME)

The Committee feels that CME is our Department's area in most urgent need of strengthening. CME is the largest area of physics and is highly diverse, interdisciplinary, and technologically relevant. Further, much of this experimental activity is of the type that fits into our Department's tradition of innovative basement-scale experiments. These science opportunities are described in the recent NRC Condensed Matter Decadal Survey "CMPP2010". Recent searches have demonstrated that outstanding candidates interested in coming to the UW can be identified.

The Physics Chair floated several ideas for assisting this strengthening process, including an "external & internal" review or perhaps a purely "internal-to-UW" review. He also encouraged the CME group to align with UW's increased interest in interdisciplinary programs and consider a center-like proposal with connections to other units within the University. These discussions are ongoing and are outside of this report. We note, however, that the potential of three hires in CME represents an opportunity to launch a high-profile, high-impact CME initiative.

Within the context of a CME plan, at co-highest priority, we recommend a junior-level search. We also recommend the Department be aggressive in identifying targets of opportunity; for this, we note the interdisciplinary nature of condensed matter experiment makes it a natural partner in University initiatives. Further, partnership in an interdisciplinary initiative and the recommendation of three hires may allow hiring at the senior level, or a "cluster hire", and may provide access to facilities attractive to condensed matter experimenters. Such joint initiatives have been encouraged by the University administration, especially over the last two years. We therefore recommend exploring joint opportunities for multi-college initiatives with other units on campus.

Although the exact nature of the strengthening plan for Condensed Matter Experiment remains to be established, *we envision that an effective plan could include a total of three hires in this subfield over five years.* Given the diversity of CME, these hires could overlap with Atomic Physics and/or Biophysics.

Particle Experiment

The Large Hadron Collider at CERN in Geneva, Switzerland, is designed to explore particle physics at the TeV scale. It is scheduled to start operation this year, and the Committee feels that it has a high likelihood of discovering dramatic new TeV-scale science; here supersymmetry comes to mind, but other, even more dramatic discoveries are certainly possible. The Department is invested in the LHC through the ATLAS muon detector system. We therefore advocate filling out to a three-person group in experimental LHC science. We recognize that some faculty in the Department do not support such a recommendation. The main objections are that the UW shouldn't increase its participation in a distant and huge research enterprise where it's not clear we would have a significant identifiable impact, and that the future of accelerator-based particle physics is in danger. Regarding the first objection, the Committee certainly recognizes the challenges of a university group in such a large and remote research enterprise and this is a *bona fide* concern. The majority of the Committee feels, however, that the likely science payoff is sufficiently great to override this concern. We do expect, moreover, that UW theorists and experimenters will be able to fully participate in the LHC while maintaining the intellectual center at the UW. Regarding the second objection, we feel accelerator-based particle physics, in the scenario where the LHC finds dramatic new science, is likely to be interesting at least through the 10—20 years of LHC operations. Whether or not this leads to a beyond-LHC accelerator is unknown for now. There is a risk that LHC science is barren with a shorter lifetime for the LHC, but the majority of the Committee believes this is a small risk. *The Committee therefore recommends at co-highest priority, a junior-level search in Particle Experiment.* This recommendation is consistent with the "Goussiou Commitment".

Astrophysics Experiment

A Department study, Adelberger et al., (June, 2004) identified Astrophysics as a key Department area for expansion. This study mirrored the NRC "Connecting Quarks with the Cosmos" report (Turner et al., 2003) in concluding that Astrophysics is key, along with particle physics, nuclear physics and gravitational physics in understanding the universe and its contents. Likely, the quality of UW's activities in astrophysics and cosmology will be increasingly important to the stature of our Department. Astrophysics is also a popular choice for those entering graduate students who declare a field of preference. The Department recently brought Rosenberg and Morales into the Astrophysics program. Rosenberg is in the process of bringing a large axion-search experiment to CENPA. He is also interested in large optical surveys to map dark matter and energy in the universe. The axion search experiment directly addresses the question of the nature of dark matter, and it will be a significant addition to the UW on-site experimental program. Morales, who will join the faculty fall 2008, is a principal in the Mileura Widefield Array, sited in Australia, a large antenna array designed to find the signature of the epoch of reionization in the microwave background. Recently Eric Adelberger retired, and this is a substantial loss across a broad range of activities in the Department, including Astrophysics. The likely departure of Craig Hogan is also a very serious blow to Astrophysics at UW, since he is the only theorist at the UW with a thorough grasp of the astrophysical and astronomical observations and surveys. The Department voted for the "Morales commitment", that astrophysics experiment be included in the next broad experiment search. However, since Morales won't arrive at the UW until fall 2008, the UW Astrophysics group will likely defer this search for a year. *The Committee therefore recommends continuing the astrophysics initiative with a junior-level 2009-2010 search in Astrophysics Experiment.*

Theoretical Physics

Theoretical Physics is a particular strength of our Department. In addition to outstanding programs in individual subfields, the Department fosters connections between Particle, Nuclear, Astrophysics, and Condensed Matter Theory, as well as the Institute for Nuclear Theory (INT) and connections to our programs in experimental physics. However, the aging of the faculty is of growing concern, particularly in Nuclear Theory. There is some concern that there are large and very active areas of Theoretical Astrophysics, Cosmology and Condensed Matter Theory in which the Department does not significantly participate. Particle Theory has recently lost two people (Aganagic and Strassler). More positively, the Department recently voted to promote string-theorist Andreas Karch.

Astrophysics will likely lose Craig Hogan. Hogan is the only Astrophysicist within Physics and Astronomy who integrates theory with the huge number of astrophysical surveys and observations. His loss is therefore a significant blow to our growing Astrophysics initiative. The Committee feels that hiring in Astrophysics Theory therefore has a very high priority.

A major strength of the UW Particle Theory group is the unusual breadth of activities, covering the range of intellectual interests from a close connection with experimental particle physics to a close connection with string theorists in the Mathematics Department. At the same time, the members of the group overlap enough in their interests to allow significant cross-fertilization. An example of this is string theorist Matt Strassler evolving into a bona-fide LHC phenomenologist while working with Ellis. Another example is Karch and Yaffe employing string-inspired field theory for describing relativistic heavy-ion collisions. These activities are significantly compromised by the departure of Strassler.

Strength in Condensed Matter Theory will aid in building Condensed Matter experiment within the Department. Also, Biophysics experiment would be strengthened by a strong Biophysics concentration within Condensed Matter Theory. Within five years, Condensed Matter Theory will likely have a retirement (Schick). Although the majority of the Committee feels hiring in Condensed Matter Theory is not an immediate priority, the growth of Condensed Matter Experiment and Biophysics within the Department would increase the urgency for a Condensed Matter Theory hire.

Nuclear Theory is a pillar in our Department. The strength comes in part from the DOE/Nuclear Physics supported group plus research within the INT, as well as the overlap with other groups within the Department. Although we do not consider Nuclear Theory an immediate staffing priority, we do recommend including this field in broad searches in the out years.

At co-highest priority, we recommend a junior-level search in Astrophysics, broadly construed. We envision this as a broad search with emphasis in Astrophysics/Cosmology. Should the Tera-Scale initiative be funded, we recommend this search be broadened to include LHC phenomenology.

A reasonable plan to maintain the Theory program could include a total of four hires over five years. These positions could come from a broad set of subfields, including Astrophysics & Cosmology, Particle Theory, Nuclear Theory or Condensed Matter Theory. Since the Committee lacks clarity for these out-year priorities, this report has no recommendations as to the emphasis subfield for the out-year searches. However, we recommend that after the successful Astrophysics search, the next theory search be a broad search across subfields.

Physics Education Group (PEG)

Physics Education Research is a small but growing field in which the UW has attained national prominence, recently recognized by the PEG Group receiving the APS Excellence in Education Award. PEG argues that a faculty hire will be required, for instance, to maintain existing programs in K-12 teacher preparation and curriculum development.

There was significant disagreement within the Staffing Committee on whether a hire should support ongoing programs or support new programs, whether a faculty hire is the appropriate type of hire to support the proposed programs, and the priority of this hire relative to other Department needs. The Committee considered recommending that a PEG search be included within broad searches in Experimental Physics, but unfortunately did not reach broad agreement and therefore makes no recommendation in this report.

Nuclear Experiment

The Center for Experimental Nuclear Physics and Astrophysics (CENPA) is a DOE Nuclear Physics "University Center for Excellence" and is a highly visible and successful component in experimental physics at the UW. This was noted in a recent report, Craig Hogan et al., responding to a charge by the Department Chair to review CENPA. The report concludes that CENPA is the engine of much important experimental work within the Department and educates a large number of graduate students. In recent years, activity at CENPA has broadened to include gravity and dark-matter research, but the core of CENPA's infrastructure is supported by DOE Nuclear Physics (the "core program"). A recent hire in neutrino physics (Tolich) strengthened this program, but CENPA had a recent retirement (Adelberger) and further retirements are likely within the next five years (Cramer and Robertson). These retirements will reduce the number of faculty at CENPA and will diminish the core nuclear science program. The most serious consequences will be in CENPA's research in Relativistic Heavy Ion Collisions, one of the core programs; this will likely shrink substantially with Cramer's retirement. To maintain the vitality of CENPA, and by extension, the vitality of experimental physics within the Department, the Department should support initiatives in important scientific areas where UW Nuclear Experiment/CENPA can play a leading role, for example the "DUSEL" or "RIBF" projects. These new initiatives can replace the nuclear physics efforts that will be lost through retirements and ramp-down of programs (e.g., SNO and RHIC).

Although the plan for nuclear physics initiatives remains to be established, we envision that supporting opportunities in the Experimental Nuclear Physics core program will at minimum include a junior-level search within the next five years.

Biological Physics

In 2006, the Department Chair charged a Biological Physics study committee, chaired by David Kaplan, with making recommendations on Biophysics opportunities in our Department. Paraphrasing, the main report conclusions are: (1) Biophysics is a highly interdisciplinary and growing field that many in the Department believe should be part of our program; (2) Efforts to hire in this area may require collaboration and joint initiatives with other units within the UW in order to create new positions within the Department; (3) Physics hires should closely overlap with our Department's other research to maximize the positive impact within our Department of the Biophysics activity.

The Staffing Committee accepts the main recommendations of the Kaplan report: we therefore recommend that the Department identify promising candidates through broad searches in experimental condensed matter physics. We also note that the current Nanotechnology Director search has considered candidates with interest in nanomedicine. If such a center were to be established at UW, there will likely be opportunities to pursue positions related to this new area of research. We recommend that if this occurs, the Department should explore potential positions in this area that might have ties to a broader interdisciplinary initiative.

Atomic Physics

The Atomic Physics group recently added Boris Blinov and Subhadeep Gupta and has hired Tom Loftus as a Research Scientist. However Norval Fortson retired. In addition, Bob Van Dyck is ending his research. The new hires (Blinov and Gupta) have provided renewed vitality to the group as evidenced by their NSF/MRI proposal with Markus Raschke and Munira Khalil from Chemistry to acquire a "frequency comb", enabling extremely high precision frequency measurements and tracking of high speed chemical reactions. It is likely that this activity will lead to new opportunities within the next few years.

The Staffing Committee recommends that, should the renewed activity lead to new opportunities, there should be a junior-level hire supporting this area.

The Atomic Physics group asked the Staffing Committee to consider hiring in Atomic Theory. The Staffing Committee considers this by itself a lower priority than the experimental search, but *the Committee recommends overlaps with Atomic Theory should be considered in future Theory searches.*

SUMMARY OF SEARCH RECOMMENDATIONS

It is important that this summary should not be read in isolation, but should be considered in the context of the above discussion.

Near Term Priorities

For 2008-2009, the majority of the Staffing Committee has a common set of clear priorities. The most urgent experimental priorities are strengthening Condensed Matter Experiment, continuing to pursue the Astrophysics initiative, and addressing the Department's commitment to Particle Experiment. Since the experimental Astrophysics search will be deferred for a year, in the near term, therefore, these priorities translate into a recommendation for a broad search in experimental physics with emphasis in Condensed Matter Experiment and Experimental Particle Physics. By "emphasis", we envision, e.g., the job posting reading "UW seeks applications in all areas of experimental physics, particularly in the subfields of Condensed Matter and Particle Physics ...". We also expect the Search Committee and faculty to solicit and be attentive to applications from good candidates in all subfields. We encourage faculty to participate in searches by scanning on-line applications for promising candidates: this is especially important for broad searches. The most urgent theory priority is rebuilding Astrophysics Theory, and so we recommend a search in this area.

Five-Year Priorities

Our projections of priorities over the out years are less clear. Assuming that the faculty size stays approximately constant, there will be a need for ten successful searches over the next five years, or about two hires per year. Consistent with the above discussion, a majority of the Committee sees a potential sensible scenario of hires for the ten positions could be as follows: seven in experimental physics (three in condensed matter, one in astrophysics, one in particle, one in nuclear and one in atomic), and four in theoretical physics (one in astrophysics, and three across all theory subfields). This scenario includes the 2008-2009 searches. It is likely that in practice these searches will include broad searches emphasizing particular areas, as well as targets of opportunity tied to new initiatives.

These recommendations call for eleven hires over the next five years, to be compared to our estimate of ten for the number of searches at our assumed replacement rate.

CLOSING THOUGHTS

Overall, the Physics Department has made good progress towards meeting its staffing goals. However, it could well happen that the number of pressing staffing searches will outnumber the number of allowed searches over the next five years. Through strategic hires, targets-of-opportunity and initiatives, we therefore need to remain imaginative, aggressive, and willing to make hard decisions in our staffing to ensure the continued strength of our Department.

Leslie Rosenberg (Chair) David Boulware David Cobden Steve Ellis Blayne Heckel Dam Son John Wilkerson