Department of Physics

University of Washington

Ten Year Self-Study Report

1985-86 to 1995-96

February 28, 1997

INTRODUCTION/OVERVIEW/SUMMARY

Introduction

The following document is intended as an introduction to and evaluation of both the Department of Physics and its instructional programs, covering both the last ten years and the next ten years. Since the Department's instructional programs are inextricably connected to its research activities, both will be thoroughly described in what follows. In preparing this Self-Study Report the faculty of the Department has taken this opportunity to act as a "Futures Committee of the Whole" so that we have all been involved in the data gathering and in the analysis of our current and future situation. We apologize to the readers of this document if the result of our labors seems overlong. We wanted a study that was essentially self-contained. In many instances important points are made in more than one place. Even a motivated reader may not find it necessary to read the entire document (and certainly not all of the appendices) to obtain an accurate picture of the Department.

Overview

The specific structure of the document is an attempt to follow the outline (if not the page limit) supplied by the Graduate School. The pages are number separately within each of the eleven sections and the appendices. An overview of the contents follows.

Section I. ORGANIZATION Outlines the organizational and administrative structure of the Department. (4 pages)

Section II. DESCRIPTION Reviews the history of the Department and its programs. The three basic degree programs and their various parameters are introduced. (8 pages)

Section III. FACULTY Introduces the members of the various components of the faculty of the Department. Various characteristics of the faculty, *e.g.*, distributions by age and research interest, are presented. The concepts of mortgaged faculty positions and the retirement queue is introduced. (7 pages)

Section IV. STUDENTS Introduces the general characteristics of the various student cohorts that we instruct. Structural details of the three degree programs are explained, including enrollment and graduation patterns and career placement. (8 pages)

Section V. CURRICULUM Provides a description of the general structure of our various curricula, including recent changes. This discussion includes both the degree programs and more service oriented instruction. The role of research in instruction is also highlighted. (11 pages)

Section VI. RESEARCH AND CREATIVITY ACTIVITY Provides descriptions and various measures of the current research activity within the Department. It includes (not so) brief summaries of the progress in each of the research areas within the Department and is, by far, the longest section. (As the status of the research groups is briefly summarized again in Section X, some readers may wish to skim this section.) (26 pages)

Section VII. SERVICE Outlines the various forms of professional, University and community service activities in which the faculty participate. (2 pages)

Section VIII. EVALUATION Describes the various ways in which the Department evaluates the progress of its faculty, its students, its instructional programs and its research. The results of these evaluations are also presented. (5 pages)

Section IX. RESOURCES Provides a discussion of the various sources of funding that support our instructional programs (and our research activities) and the trends in that funding. The issue of salaries here versus our peers is introduced in this section. The question of possible increases in efficiency is also briefly touched. (5 pages)

Section X. SUMMARY Summarizes the current status of the Department, including those future changes that can be reasonably reliably predicted (*e.g.*, retirements). Topics covered include space, staff, faculty and the instructional programs. This is probably the single most important section. (11 pages)

Section XI. FUTURE GOALS AND PLANS Supplies the Department's known plans and expectations for future changes in the instructional programs. It also outlines various scenarios for how the Department might evolve over the next ten years. The responses of the Review Committee are solicited. (6 pages)

Appendix A Basic Program data supplied by the University.

Appendix B Departmental Committees, their responsibilities and current memberships; instructional and administrative organizational charts.

Appendix C Courses in Physics and their assigned Student Credit Hours.

Appendix D Physics faculty with a separate listing indicating research area and recent students.

Appendix E Recent speakers at the "Careers for Physicists" seminar series.

Appendix F Students materials given to 1) undergraduate majors, 2) MS students, 3) Ph.D. students.

Appendix G 1996 participants in the UW REU program.

Appendix H 1995 Graduate School Teaching Assistant Review Committee Report.

Appendix I Minor in Physics Proposal.

Appendix J Undergraduate exit survey and summary of the most recent results.

Appendix K Faculty honors and awards.

Appendix L March 1996 memo to the Dean of Arts and Sciences outlining the Department's funding needs.

Summary

If this Self-Study report does its job, the reader will recognize a Department that has just completed a remarkably successful decade, for both its instructional programs and its research activities. This success has been marked by outside recognition in the form of grant support and awards to the faculty, including a Nobel Prize. The Department is enjoying and trying to make optimum use of the new building provided by the State and the University. The instructional programs in Physics are robust, if imperfect, and are receiving constant attention from the faculty. The Department's recent additions to the faculty, while few in number, have added greatly to its vitality. The faculty maintains a culture of collaboration and optimism.

The Department's concerns are focused primarily on what seem to be likely, or at least possible, trends during the next ten years. As described in Section X, keeping to our existing hiring agreement with the Dean (the retirement queue) will lead to a serious negative impact on both our instructional and research programs. If the Federal research support agencies are forced to play a large role in balancing the budget, all of our activities will likely feel the squeeze, especially the support of our research faculty and graduate students. Small increases in State funding for support and administrative staff and equipment upgrades would lead to a major enhancement of the Department's activities. As was true ten years ago, the faculty remains concerned by the low salary levels of senior faculty and the low rate of increases seen at the University.

Overall the Department is excited about the new challenges and possibilities for the next ten years. We ask the Review Committee and the University to assist us in planning for that future.

I. ORGANIZATION

1.1 Unit awarding degrees: Department of Physics

1.2 College: College of Arts and Sciences

1.3 Degree titles: Bachelor of Science, Master of Science, Doctor of Philosophy

1.4 Administration:

The Department is under the general administrative direction of the Chair with the assistance of two Associate Chairs. Currently these three positions are occupied by Professors Ellis, Boulware and Vilches. One of the Associate Chairs oversees the Graduate Program while the other oversees the Undergraduate Program. Individually they serve as Chairs of the appropriate Departmental Committees as explained in more detail below. The oversight of most areas of Departmental activity lies with Faculty Committees. As a general rule the Department of Physics functions by consensus as opposed to executive order. The members of the Departmental committees are chosen by the Chair with the guidance of the Executive Committee. The Executive Committee itself is appointed by the Chair from among a small group of candidates nominated by the faculty. An attempt is made to have a balanced representation of the major research areas on the Executive Committee. The Chair seeks the advice of the Executive Committee on most issues that directly affect the faculty. Committee members serve for a year at a time. If possible, faculty are assigned to committees of their choosing. Ad hoc committees are appointed to address special problems outside the purview of the standing committees or to relieve a standing committee when the demands of a special task exceed some reasonable bound.

The names of the various standing committees are listed here. A brief summary of the responsibilities of the various committees is provided in Appendix B (Appendix A is the Basic Unit Data supplied by the University). The current (1996-97) members of the various committees are also indicated in Table B-1 in Appendix B.

- *Aesthetics*
- *Awards*
- *Blair/Picnic/FFF*
- *Building/Space*
- *Colloquium*
- *Computing*
- *Course Assignments*
- *Development*
- *Executive*
- *Graduate Committee* - The standing subcommittees of the Graduate Committee include:
  - *Graduate Program Coordinator*
  - *Graduate Admissions Coordinator*
  - *MS Program Coordinator*
  - *Admissions*
  - *Examination*
  - *MS Program Committee*

Teaching Assistant Affairs

- *Instructional Quality*
- *Library*
- *Ombudsman*
- *Safety and Security*
- *Secretary*
- *Technical Services*
- *Undergraduate Committee* - The standing subcommittees of the Undergraduate Committee include:
  - *Teacher Education and External Credit Coordinator*
  - *Advising*
  - *Instructional Facilities*
- *Summer Session*

The time demands of the various committees vary greatly, with the Graduate Committee generally being the most demanding. This committee has overall responsibility for graduate student recruiting and admissions as well as the Ph.D. qualifying Exam and the Masters of Science (Applications in Physics) Program. To guarantee a viable workload the various primary responsibilities are divided between the Associate Chair for the Graduate Program, who chairs the Graduate Committee, the Graduate Coordinator, who is the Departmental contact with the Graduate School, the Admissions Coordinator who directs the recruitment program, and the Masters Program Coordinator. The Graduate Coordinator handles the day-to-day functioning of the Ph.D. program including oversight of student advising and mentoring, monitoring student progress and collecting the yearly Student Progress Reports. The Admissions Coordinator is responsible for communicating with potential Ph.D. students, working with the Admissions Committee to select the final candidates and setting priorities for the various funded fellowships. The Masters Program Coordinator handles both admissions and daily administration of the smaller Masters Program. All of these activities are supported by the Graduate Program Assistant, who maintains records for both the Ph.D. and Masters Programs and answers the daily questions from the students.

The other major committee responsibility is the Undergraduate Committee (UC), chaired by the Associate Chair for the Undergraduate Program. Like the Associate Chair for the Graduate Program, the Associate Chair for the Undergraduate Program is a member of the Departmental Executive Committee. The UC reviews the curricula for both the major and non-major courses, evaluates new course proposals and modifications to existing courses, and oversees all undergraduate issues. The UC usually delegating specific topics to formal and informal smaller committees. The Associate Chair is responsible for budgets for the undergraduate instructional program, and supervises the Advanced Labs manager and the Research Engineer (microcomputer support) for instruction. The Associate Chair also works with the Senior Lecturer, who supervises the introductory lab technical support staff, to oversee the needs of the lower division (but high enrollment) freshman labs. Within the UC, the Advising subcommittee meets with all majors once a year for annual advising. Individual advising is available at all times. Curriculum, student progress, teacher certification, and extension and transfer credits issues are addressed by the faculty member serving as the Teacher Education and External Credit Coordinator, while administrative issues (credits, course offerings, students problems, etc.) are covered by the Undergraduate Advisor, a member of the staff. Informal counseling is available through a voluntary faculty mentor program.

Also within the UC, the Instructional Facilities subcommittee oversees the extensive equipment patrimony of the Department, organizes the best resource utilization for equipment, rooms, and personnel, prepares funding requests to the University, and periodically reviews the content of the many laboratory offerings and the available lecture demonstrations. A member of this subcommittee also supervises the lecture demonstration staff. The wide variety of equipment available to our lecturers and laboratory courses constitutes one of the underlying strengths of our undergraduate instructional program. These activities have benefited considerably from the new purchases which have been part of the move into the new building, a point we will return to below.

The organizational structure outlined in the last few paragraphs is illustrated in Figure B-1 in Appendix B.

The administrative functions of the Department associated with fiscal issues, physical plant issues, record keeping and instructional support are handled through the efforts of the Department of Physics staff. The organizational structure of the administrative and support staff of the Department and its connection to the faculty positions mentioned above are outlined in the organizational chart in Figure B-2 of Appendix B. As indicated by the budget numbers in Appendix A, State funding for staff has remained essentially flat in the last ten years (it is actually decreasing when corrected for inflation) and the staff themselves have remained essentially fixed in number. This has situation has created over-load difficulties for the staff as the audit and accountability rules have become more demanding. The new position of Fiscal Manager, which was filled during January, 1997, constitutes a major improvement in this situation but the Department remains understaffed compared to similarly large departments at this University and elsewhere. We will return to this issue in Section X.

The Department maintains strong ties with other Departments on campus through the appointment of joint and adjunct faculty. The association with the Astronomy faculty, with whom we share the building, is particularly strong: we have three jointly appointed faculty members (Boynton, Hogan, Stubbs) and two adjunct faculty members (Margon, Lakes), while Adelberger, Bardeen and Haxton are adjunct faculty members in Astronomy. Olmstead is an adjunct faculty member in Chemistry while Chaloupka is an adjunct faculty member in Music. Other Departments with adjunct faculty ties to Physics are: Chemistry (Campbell, Drobny, Engel, Jonsson, Vandenbosch), Materials Science and Engineering and EE (Pearsall), Bioengineering (Vogel), Atmospheric Sciences (Marcia Baker), Geophysics (Holzworth, Parks, Winglee) and Aeronautics and Astronautics (Jarboe), The Department has also reopened its historic connection to the Applied Physics Laboratory through the recent appointments of two affiliate faculty members from that Laboratory (Henyey and Wettlaufer).

1.5 Visiting Committee:

The Visiting Committee of the Department of Physics is comprised of seven individuals who have demonstrated a long term interest in the Department. In some cases that includes having received a degree from here. The most recent addition, Nathan Myhrvold, holds a Ph.D. in theoretical physics from Princeton and had a successful career in research before being seduced by the software industry and eventually Microsoft Corporation. All members are either retired or active participants in local industrial firms. Many of the members of the committee show up regularly for Departmental Colloquia and social functions, *e.g.*, the annual awards banquet held in May. They are also regular contributors to the various discretionary budgets that support Department activities and provide student support.

The primary "business" meeting for the Committee occurs on the day of the annual University fete for all such Committees. On that day the Committee visits the Department, hears about the recent results of some scholarly activity (last year it was the new Solar Neutrino detector at Sudbury, Canada) and is asked to provide its collective wisdom concerning some challenges faced by the Department. In the last two years the concern has focused on the career challenges faced by our students and how the students can be best prepared for them. We have discussed in detail the idea of industrial internships. While we have not solved that problem, the input of the Committee has been most useful. At the most recent meeting, at the end of January, we discussed the evening Masters Program, Applications in Physics. This program was originally designed to meet the career needs of in service physicists, largely at Boeing. That situation seems to have changed with the passing of time and, as we attempt to refocus the Masters Program, we sought the view from industry as represented by the Visiting Committee. It was an enlightening discussion.

If there is a concern about the effectiveness of the Committee, it arises primarily from the fact that, as busy people, most of them have little time to spend with us. The best communication occurs when we are all in the same room and that happens only rarely. The Department should give a higher priority to extra meetings during the year.

The current members of the Visiting Committee are Dr. David L. Dye, Mr. Theodore K. Freeman, Dr. Theodor F. Hueter, Dr. Keith B. Jefferts, Dr. Glenn L. Keister, Dr. Nathan P. Myhrvold and Dr. Wayne M. Sandstrom. Of these individuals, both Jefferts and Myhrvold are still active professionally at NW Marine Technology Inc. and Microsoft Corp., respectively.

II. DESCRIPTION

2.1 History and Objectives:

The Department and its undergraduate program have existed since the beginning of the 20th century. However, like departments at most other state funded universities, the Department was limited in size until the growth days after the Second World War. As both the university student population with a heightened interest in science and federal support for research grew after the war, so did the Department of Physics. It reached essentially its current size of approximately 43 teaching faculty members by 1970. (The question of "counting" faculty is actually rather subtle and the careful reader will see numbers varying between 42 and 60 depending on just what sort of faculty member is being counted: State-funded, Research faculty, emeritus faculty, *etc.* We will attempt to make this issue clear in each case and apologize in advance for any confusion.)

In broad terms, the role and objectives of the physics 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 then provides the underlying structure for many more practical arenas of intellectual activity helping to provide an understanding of a very diverse range of phenomena, from semiconductors to earthquakes. The boundary between physics and, say, electrical engineering or geophysics is not crisply defined and a solid education in physics is essential for working on both sides of the boundary.

The basic role of science instruction is captured nicely in the words of Richard P. Feynman[1],

> "Science is a way to teach how something gets to be known, what is not known, to what extent things *are* known (for nothing is known absolutely), how to handle doubt and uncertainty, what rules of evidence are, how to think about things so that judgments can be made, how to distinguish truth from fraud, and from show."

In motivating their "Project 2061"[2] the AAAS suggested criteria for the effective use of scientific knowledge that are very similar to those of Feynman.

- To put scientific training effectively to work, a student must have the knowledge, the quantitative, communicative, manual and critical-thinking skills, and the attitudes and inclinations necessary for effective problem-solving.

[1] From *Genius: The Life and Science of Richard Feynman*, by J. Gleick, p. 285 (Pantheon Books, New York, 1992).
[2] *Project 2061: Benchmarks of Scientific Literacy* (Oxford University Press, New York, 1993).

- 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 view ourselves as training young minds to ask questions, finds ways to define answers, recognize when they have obtained adequate answers and use those answers. At the simplest level, the goal is to train *problem-solvers.* In an ever increasingly technological world such individuals are essential both directly in technical enterprises and as informed citizens.

In more detail there are three basic goals in our teaching program: (1) to train physics and other physical science students to do work at a sophisticated level in investigating and applying physical principles; (2) to give an introductory understanding of physical principles, their mathematical analysis, and the scientific method to a very large number of students, for example, in engineering and in the biological sciences; (3) to give as many students as possible some of the intellectual and aesthetic content of the contributions made by physics to our understanding of the world. The first role is fulfilled primarily in our upper division and graduate courses, the second role in our large introductory courses, and the last role most explicitly in special "general education" courses, but also, we hope, to some extent in all courses. A listing of the course offerings in Physics is included as Appendix C. The listing includes a (hopefully informative) title and the number of Student Credit Hours (we are on a 4 quarter system) for each course. (The latter is useful for interpreting some of the enrollment data in Appendix A.) Of the courses in this list a selection of approximately 45 is offered each quarter, with multiple lectures offered in the introductory sequences.

The courses correspond to the following general categories:

a) General science courses for completion of distribution requirements;
b) Algebra based introductory physics for students in a variety of fields (like pre-medical, pre-dental, future physical therapists, *etc.*);
c) Calculus based introductory physics for engineering and science students,
d) Physics by Inquiry for future teachers of physics and physical science, students aspiring to science-related careers who have a weak preparation in science and mathematics, and for liberal arts students;
e) Lower and upper division courses for the BS in Physics;
f) Graduate courses for the MS and Ph.D. degrees.

Each of these course types is addressed later in this report under specific topics. The Department derives most of its undergraduate enrollment from its service courses in categories b) and c). This enrollment has grown with the growth of the University student population.

A strong University program also demands a dedication to the advancement of human knowledge through research. A high quality instructional program requires an accompanying active research program. The benefits of a successful research program integrated into the instructional program accrue to the nation through the growth in scientific knowledge, the development of scientific and technological manpower, and the scientific literacy of its people. The members of the Physics faculty at the University of Washington are deeply involved in research. Historically, the first major group in our Department was the nuclear physics group. While this group remains one of the national leaders in its field, the Department now also has eminent groups in atomic physics, astrophysics, condensed matter physics, elementary particle physics, and physics education. In each of these fields, our faculty has achieved international distinction for its accomplishments, gaining strong research support from the federal government, attracting distinguished visitors from around the world, and enabling us to educate our graduate and undergraduate students at the forefront of their specialties.

2.2 Program Missions and Goals.

2.2.A *Bachelor of Science in Physics*:

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 rewarding technical employment. While there are no "degree options", a multitude of paths are possible to meet the requirements for the BS (see Sec. V). 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, and 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 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 part-time 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.

2.2.B *Master of Science in Physics*:

Internally known as the "Masters Degree Program in Applications of Physics" or the "Evening Masters Program," this track to the MS degree in Physics was introduced in 1978. It was primarily intended to broaden and extend the physics training of scientists and engineers with BS degrees who work locally during the daytime. Since 1978, approximately eighteen new courses have been developed for that purpose. Although neither the college nor university has formally recognized this program as a separate entity, we were given one additional faculty position when this option was first made available. Roughly half of the department's faculty has participated in this program, either by teaching one of the courses or supervising an independent study project. An independent study project is required of each student for the degree, along with the successful completion of the core courses (described in Sec V).

2.2.C *Doctor of Philosophy in Physics*:

The Ph.D. program in Physics provides students with the training and experience to pursue independent careers in physics research and in teaching physics at the college level and above. In order to do this, we offer courses that provide our students with a broad background in Physics. This background is intended to enable the students to pursue a variety of different career paths. Students are required to complete an independent research program while apprenticed to a faculty member; this provides them with the experience required to subsequently undertake their independent program of research.

2.3 Basic Program and Unit Data.

2.3.A *Undergraduate Program:*

Data on undergraduate enrollments compiled by the University are shown in Appendix A. Enrollment in the major has been approximately steady for the last 10 years (there were 181 majors in 1985-1986, 170 in 9394, 174 in 94-95, and 177 in 1995-1996). This is not the national trend: the AIP Enrollment Report quotes a 10% decline in seniors enrollment in the 1985-1995 period. While we have not carefully studied our own enrollment patterns, the quality of the undergraduate program, the facts that the UW is the largest university in the Northwest and that the Seattle area has a large network of community colleges, which feed talented undergraduates as sophomores and juniors into our program, must play important roles in maintaining the observed stable enrollment.

As suggested by the Basic Program Data of Appendix A, the undergraduate BS in Physics degree program currently graduates between 30 and 45 students a year. This range, with yearly fluctuations of order ± 5, has remained essentially unchanged for the last twenty years. As noted above, this constancy is in marked contrast to the general experience in the nation as a whole where the total number of BS degrees has fallen to a 37 year low.[3] The magnitude of the number of yearly degrees also indicates a rather large program by national standards. The average degree output for all institutions granting the BS in Physics degree is well below 10 BS degrees/institution/year.

Since the largest numbers of students that we teach are in the major service courses (the algebra based (Phys. 114-6) and the calculus based (Phys. 121-3) introductory physics courses), it is informative to specifically discuss those numbers. Figure II-1 shows the average total enrollment *per quarter* (to correspond to the data presented in Appendix A) in these two sequences as a function of time over the last eleven years. After a slight decrease in enrollment during 1985-89, the total enrollment has steadily increased so that now it is about 50 students per quarter larger than ten years ago. (To compare to the student credit hours numbers quoted in Appendix A multiply the enrollment numbers here by 4 credit hours. If we include also the 1 credit laboratory that is required for Phys. 121-3 and taken by approximately 2/3 of the 114-6 students, we see that nearly all 100 level student credit hours arise from these two sequences.) While the calculus sequence has shown a small but steady decline over the last ten years, the non-calculus sequence has more than made up for it with a healthy increase. Currently the two sequences have nearly identical enrollments.

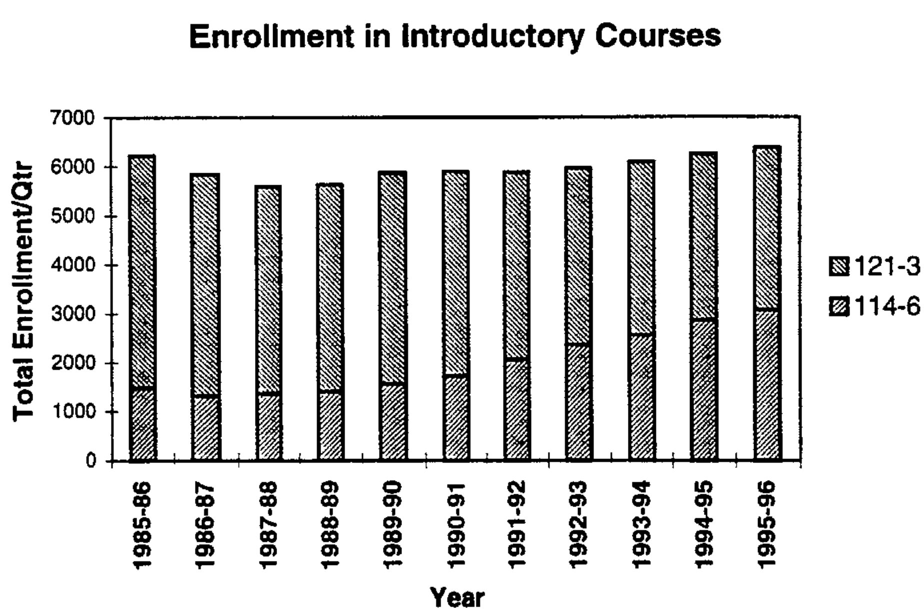

Figure II - 1

Looking to the future, we expect that, if the total University enrollment increases, as predicted, by 20% in the next 10 years, our combined enrollment in these two series will increase by about the same percentage.

[3] Patrick J. Mulvey and Elizabeth Dodge, "1995 Bachelor's Degree Recipients Report", AIP publication No. R211.27 (American Institute of Physics, Woodbury, NY, 1996).

2.3.B *Evening Masters Program*:

Although the Physics Department officially has only one Graduate degree program, we have two quite separate tracks, the Evening Masters Program and the regular degree program leading to the Ph.D. While the University Program data do not separate the two programs, the Department maintains separate records for the two programs and we will discuss them separately here.

During the ten year report period ninety-four students in the evening program have received the MS degree. Currently thirty-eight students have active status, including eight graduate non-matriculated students who plan to eventually move over to regular graduate status. The numbers since 1989 breakdown as outlined in the following table. Note that the total enrollment number is meant to represent the number of student *active* at a given time and, for that reason, is approximate.

<u>Some Evening MS Program Statistics</u>

Year	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97
Number Enrolled	37	34	49	59	46	39	41	38
Degrees Granted	7	9	5	8	16	5	8	
Number Entered	18	15	31	32	22	19	17	13
Breakdown of Entering Class								
Now Active	0	0	2	2	4	6	9	13
Graduated	7	8	12	3	8	3	0	
Transferred	3	1	2	3	1	2	0	
Inactive or Withdrawn	8	6	15	24	9	8	8	

Table II-1

In comparing the numbers in Table II - 1 to the data in Appendix A it is important to recognize that, in many cases the data in Appendix are for autumn quarter only. For example, the numbers for new student enrollment in the last table in Appendix A describe those entering both the MS and Ph.D. programs but for autumn only. This includes essentially all of the students in the Ph.D. but typically only 1/2 to 2/3 of the new MS students in a given year.

2.3.C *Ph.D. Program:*

The data in Appendix A include the number of students admitted to the overall graduate program each year since 1987 along with their grade point averages and GRE scores. The data also indicate the numbers of students who have passed various milestones: the Qualifying Examination (when they can request that a MS Degree be granted), the formation of a Supervisory Committee and passing the General Examination (when the student is admitted as a Candidate), and completing their Ph.D.s. We see that the total graduate enrollment has remained at approximately 170 $\pm$ 5 during the reported period. That number breaks down approximately into 40 in the evening master's program and 130 in the Ph.D. program at any given time. There was a small increase in the enrollment in the Ph.D. program during the early 1990's (with a peak of 140 in 1992-93) arising from slightly higher admission rates in the late 1980's coupled to lower graduation rates. The graduation rate is now back up as indicated in Appendix A. The Department has also made a conscious effort to recruit smaller, but high quality, classes for the last three years. Entering classes in the Ph.D. program are now targeted at 20 students rather than the 23 to 25 common in the late 1980's and early 1990's.

During the past decade, the quality of our entering students, as measured by their grade point averages and GRE scores, has remained quite stable with a slight hint of an increase in these measures in recent years. Average GRE scores on the Advanced Physics exam for recent Ph.D. program recruitment classes are indicated in the following table.

	1991	1992	1993	1994	1995	1996
Score	743	776	813	806	754	795
Class Size	27	23	23	20	18	20

Table II-2

Our foreign students typically have higher GRE scores and somewhat higher grade point averages than our domestic students; they generally constitute about a third of each entering class although half of the entering class of 1996 is foreign

2.4 Demand

2 4.A *Undergraduate Program:*

We expect the demand for BS in Physics graduates in the Seattle area to continue to be strong. The region's economy is based on the high technology of the aerospace, computer software and hardware, and biotechnology industries, for which a physics degree appears to be suitable. We are not aware of students having difficulties finding jobs with our BS, although we hear only from those who continue to communicate with us. No formal tracking of graduates is done.

All of the good students who wish to enter graduate school in physics seem to be able to do so. The upper quarter of our graduates of recent times have gone to Illinois, Harvard, Caltech, Pennsylvania, Cornell, *etc.*, with a very small number entering our own graduate program. Although the number of BS students interested in graduate study in physics has declined locally and nationwide, graduates seem to be able to enter other fields, particularly Computer Science, Astronomy, and Medicine.

As mentioned earlier, the Seattle campus of the University expects to experience an increase in enrollment of order 20% over the next ten years due to the coming increase in the college age population in the State. We anticipate at least that level of growth in the number of physics majors. However, this number may be conservative for Physics. It is based on the assumption that the UW satellite campuses in Tacoma and Bothell will absorb a proportionately larger fraction of the increase, but they have no facilities to train physics majors. The increased demand on our undergraduate program may grow by more than 20%.

2.4.B *Masters Program:*

The statistics given above show that there has been a recent decline in the number of students entering the program. We believe that this decline does not really indicate a reduced demand, but that it is due to the fact that for approximately the last 3 years the Boeing News (an internal Boeing newsletter) failed to print a write-up about our program. In the past the majority of students in the program were Boeing employees. A subcommittee of the Evening MS Faculty Committee is looking into the whole publicity problem. We are exploring the possibility of associating the program with the University's Continuing Education Program. If the MS program becomes part of the Continuing Education Program, one of the benefits will be enhanced marketing for the MS program.

A number of students in the Evening Masters program are, in fact, students who desire admission to the regular Ph.D. program. Since we regard the Evening Masters as a terminal degree, the admission standards are not the same as for the regular Ph.D. program. Although we occasionally find outstanding students this way, most of the students who enter the Ph.D. program this way do not succeed in completing that program. We are concerned about the number of unqualified students, but, at the same time, wish to continue to provide an opportunity for apparently marginal students to demonstrate their abilities.

2 4.C *Ph.D. Program:*

The Physics Department is experiencing strong continuing demand for its Ph.D. program. Graduate schools in the United States serve an international clientele, drawing students from all around the world. Students typically receive 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. We receive about 1500 inquiries per year which result in about 400 applications per year, from which we make about 60 offers in order to fill 20 positions in each entering class. About 50% of the applications are domestic, with the remainder being from international students. About ten applications per year come from within Washington State

III. FACULTY

3.1 Faculty List and *Curriculum Vitae*:

The faculty of Department of Physics is a complex community whose membership can be characterized in many different ways. Appendix D includes a current listing of all those faculty members with a continuing relationship with the Department. The list is broken up according to formal University titles, including regular faculty (41 professors, 4 associate professors, 3 assistant professors, 1 senior lecturer and 1 lecturer), research faculty (5 professors, 4 associate professors, 12 assistant professors), faculty emeritus, affiliate faculty, adjunct faculty and research associates (also referred to as post docs or post doctoral fellows). Faculty members who participate in federally funded research are labeled by the title of the general research area. It should be noted that these titles are often a result of history and don't fully describe the overlap of interest inherent in many types of research activities. For example, Adelberger and Heckel are listed as nuclear experiment and atomic, respectively, but their work in gravitation is more accurately characterized as astrophysics. Bardeen is listed in astrophysics but is closely associated with particle theory while Boulware is listed in particle theory but has often performed research in general relativity.

It is important to emphasize the essential role that the research faculty play in this Department. They form the backbone of our research activity. Their focused efforts ensure the success of many of our research projects and make possible some of the largest endeavors from large particle and nuclear detectors to the laser facility in the basement. The research faculty are also directly involved in the mentoring of students and occasionally in classroom instruction.

The source of support is another area of complexity. The research faculty, including the research associates, are grant supported and the full and associate research professors hold something locally called "contract tenure", whose true meaning has not yet been really tested. The majority of the regular faculty are State-funded but there are several special cases. The Department has a long and successful history of pre-hiring for or "mortgaging" future retirements. New faculty in this situation are supported by grant and State leave-recapture funds until a State-funded position becomes available. They have a well defined priority for such positions as defined by a "mortgage queue" that is up-dated, in negotiation with the Dean, for each new such hire. There are currently three faculty members in the queue (Savage, Stubbs and Wilkerson) and all are expected to be "converted" to State positions through retirements by the year 2002. Three of the faculty members on the list are joint appointments with Astronomy (Boynton, Hogan and Stubbs). Three more (Bertsch, Haxton and Kaplan) are on permanent leave as Senior Fellows of the Institute of Nuclear Theory (INT). The position of Institute Director, currently filled by Haxton, is State funded as a University contribution to the Institute. Professor Fred Brown is a special case. He retired early from the University of Illinois and holds an academic appointment here but without funding (or teaching responsibilities). He is active in research but is not included in any of the counts discussed below. There are also three faculty members who are not currently participating in grant funded research. The senior lecturer position is State-funded but untenured while the lecturer is both untenured and not State-funded (supported only from leave recapture funds and the UW Extension program).

We expect to recruit one new faculty in physics education during this academic year and that slot is included in the counts described below. According to the current queue agreement, this will be our last new hire until seven current faculty members have retired. Of those retirements, four will be recaptured by the College and three will be used to "convert" the three faculty currently in the queue. Assuming an average retirement age of 70, those presently in the queue will have been converted to State-funded positions by the end of the year 2002.

When we count faculty, we arrive at different answers depending on what is being counted. Our count for the number of State-funded FTEs is 42, slightly smaller than the University number of 42.5 in Appendix A.[1] Our count includes the two (non-queue) joint astronomy appointments (Boynton and Hogan) as 0.5 FTE each and the one senior lecturer position but does not count the three faculty in the queue nor the three at the INT (nor Fred Brown). (As noted above, we do count the State-funded faculty position already allocated to physics education that we expect will be filled by next autumn and that is currently used to support visitors in that group.) When we count the sizes of research groups we count faculty in the queue as 1 but joint appointments as 0.5. When we count teaching faculty both the joint astronomy people and the faculty in the queue count as 0.5, since they teach in physics 50% of the time. Faculty at the INT are not counted (although they occasionally teach).

A second list of faculty members, including a listing of recent Masters and Ph.D. students with each faculty name, is also included in Appendix D. Brief *Curriculum Vitae* are provided for each active faculty member and appended at the very end of this report.

3.2 <u>Visiting, Part-Time and Other Faculty</u>:

The Department has a long history of an active visitor program, with many illustrious individuals (*e.g.*, Sir Rudolf Peierls and Hans Bethe) as regular visitors to the Department (Peierls was appointed a Professor of Physics in 1975). Generally these visits were prompted by research collaborations but special lectures or courses were often offered so that students would also benefit. For example, S. Dietrich and Y. Geffen taught special topics courses in 1994-95 and Y. Yacoby in 1995-96. By far the largest visitor program is through the INT. Our students benefit from hearing seminars by speakers from all over the globe.

The closest approximation to part-time faculty is the lecturer position. Muirhead generally teaches two courses per quarter, one being in the evening extension program.

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[1] Our best efforts to understand this difference suggest that the University count includes the INT Director (Haxton) but not Hogan in Astronomy for a difference of +1.0-0.5 = 0.5.

An important feature of our teaching program is the opportunity for the research faculty to teach. In any given year approximately 6 quarters of teaching is performed by members of the research faculty filling in for faculty on leave. This exposes our students to new perspectives, especially in the advanced courses. It also gives the research faculty, especially the assistant professors, an opportunity to hone their teaching skills, which can be very helpful in finding a regular faculty position elsewhere. This experience is enhanced in the calculus based introductory sequence by the focus on instructional excellence provided by the Physics Education Group. The instructors and TAs meet weekly with the physics education faculty to discuss pedagogical issues of instruction.

3.3 Faculty Distribution:

We will consider distributions in several variables. Two interesting (linked) variables are age and rank. As is clear from the faculty list in Appendix D, the regular faculty is predominately full professors with only 3 assistant professors. This skewing towards advanced ranks is similar to but somewhat more dramatic than that in of many large physics departments in the US, where growth was rapid in the 1950's and 1960's. Using the data assembled each year by Prof. Neil Fletcher of the Department of Physics at Florida State University we can compare our current situation to that at a sampling of our peer institutions. The following table indicates the numbers of faculty of various ranks for us, and for the physics departments at the Universities of California at Santa Barbara, Illinois, Maryland and Michigan. Our numbers include the faculty in the queue but not the INT Fellows.

University	Total	Asst. Prof.	Assoc. Prof.	Prof.
Washington	43	3	3	37
UCSB	35	3	8	24
Illinois	62	6	10	46
Maryland	76	7	12	57
Michigan	61	8	12	41

Not surprisingly the age distribution of the Department exhibits a similar skewing towards the senior end. This distribution is indicated in Figure III-1. This graph includes the faculty in the queue and the joint Astronomy faculty but does not include the INT Fellows. The total count included is 44 faculty. We see that eighteen, or more than 40%, of the current faculty are 60 or more years of age. One can reasonably anticipate that these eighteen faculty members will retire in the next ten years.

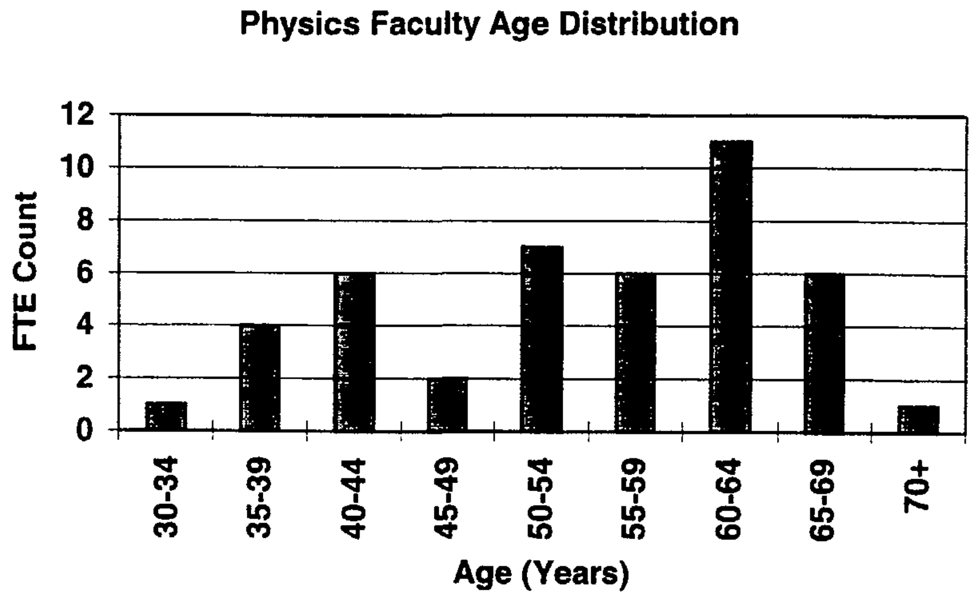

Figure III-1

The average age in the Department is nearly 54.5 years old and, with only a small new hire rate, this average increases by nearly one year per year. The average hiring-in rate for the last ten years has been only one new faculty hire per year and approximately half of these have been at a more senior level. As things currently stand, this situation is unlikely to change dramatically until after the year 2002. At that point the commitments inherent in the current mortgage queue will be satisfied and the Department will likely be trying to hire two new faculty members per year. A hiring program that exchanges "70 year olds" for "35 year olds" at the rate of two per year will lower the average age dramatically. While such a skewed age/rank distribution is not a disaster, it is a serious cause for concern. A more even distribution would help to ensure the continued vitality of the Department.

Of perhaps more direct interest is the distribution of faculty within the various research areas. Counting faculty as described above (faculty in the queue are counted, joint appointments count 0.5 and the INT faculty are included as a distinct group), the relative sizes of the ten basic research groups, as measured by percentage of faculty, is indicated in Figure III-2. Data are indicated for 1985, at the time of the last review, the current situation in 1996 and the expected situation in six years, the year 2002. The last year is relevant since it is when the current mortgage queue ends. To make this plot we assume that no further hires are made except the current one in physics education and that the average age at retirement is 70.

Faculty Distribution by Research Area

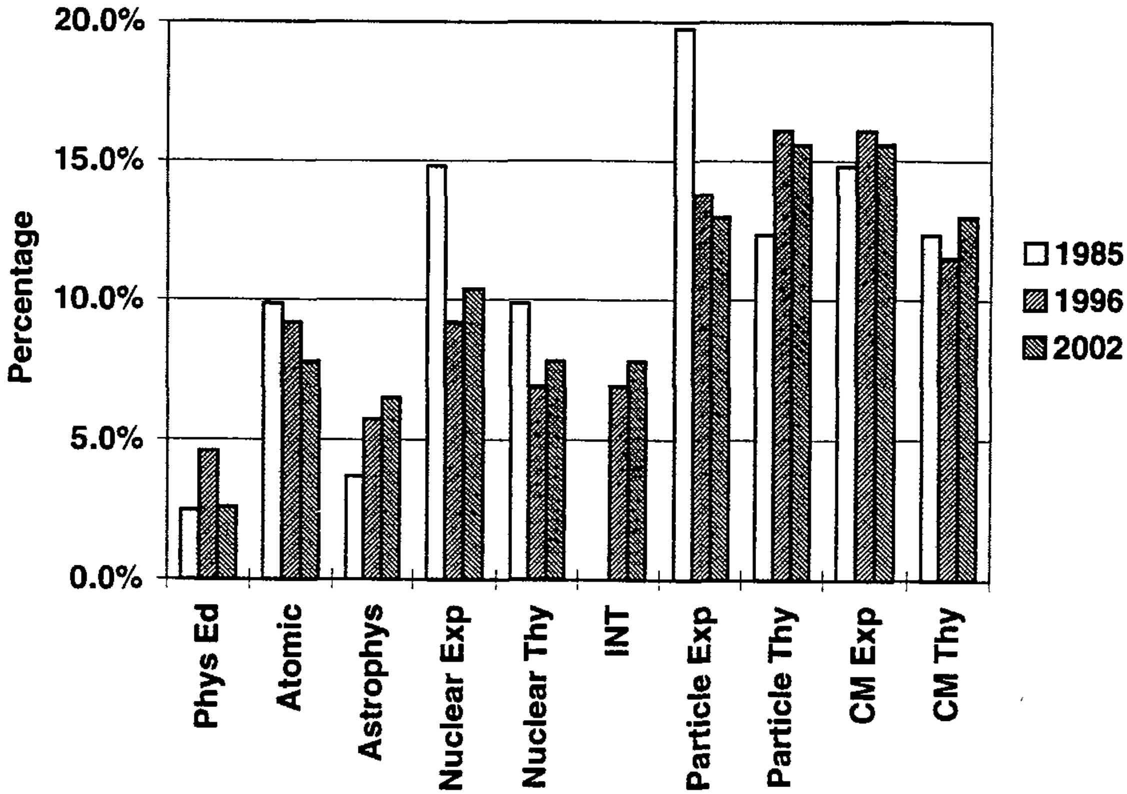

Figure III-2

The same data but in terms of numbers of FTEs are indicated in Figure III-3. The total FTE count included in 1985 is 40.5, 43.5 in 1996 and 38.5 in 2002 (seven retirements but two not currently involved in funded research). The largest relative changes have occurred in astrophysics (growth) and in experimental nuclear and particle physics (shrinkage). Currently the faculty is approximately 60% experimentalists and 40% theorists. The anticipated retirements will push this ratio towards 50/50.

Faculty Distribution by Research Area

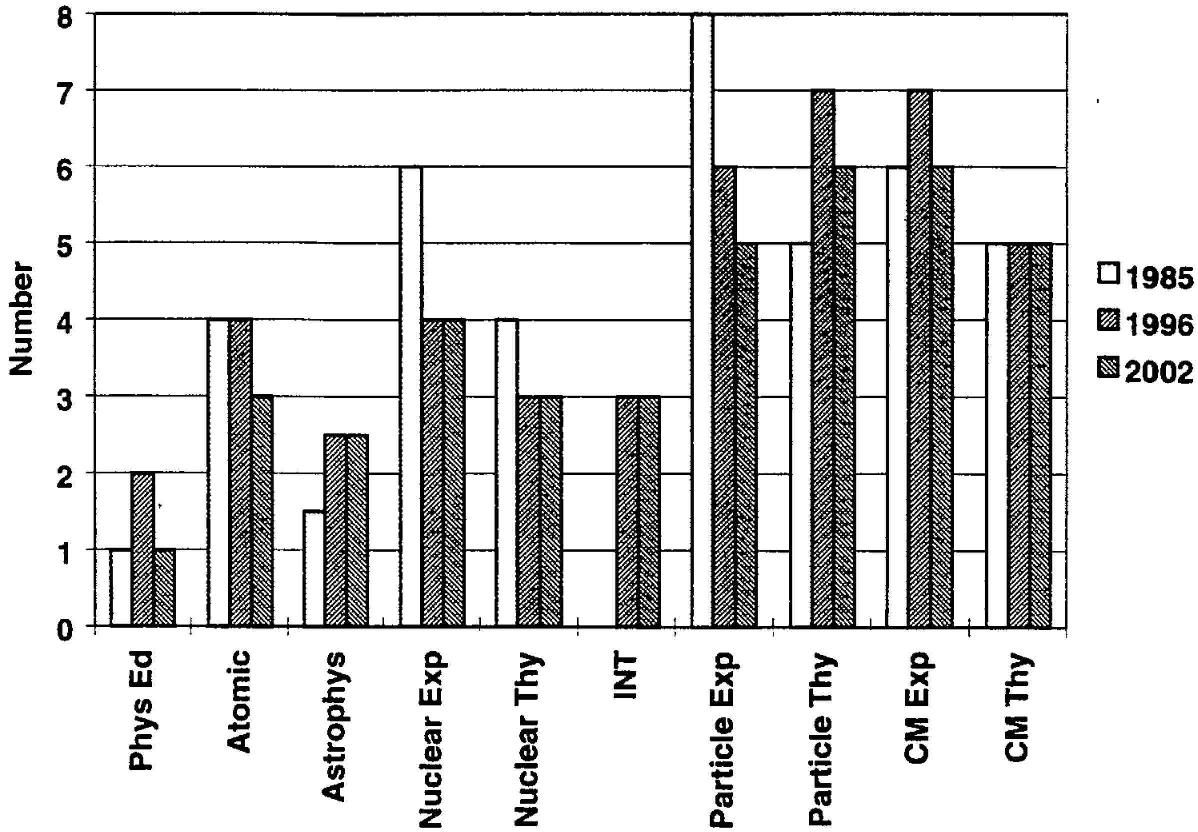

Figure III-3

The question of the adequacy of this distribution is a difficult one. Our sense that the Department is currently functioning quite well suggests that for 1996 the distribution works (and is reasonably well reconciled to the funding levels and student demands to be described below). However, the projected retirements in both atomic physics and physics education are likely to cause severe difficulties. We will return to these points when we discuss the future in Sec. X. In that section we will also discuss the related and important issue of teaching manpower.

3.4 Underrepresented Groups:

The present faculty of the Department of Physics includes three women, one Asian and one Hispanic. These are to be compared with the target levels supplied by the University[2], which are based on the fractional representation of each group in the relevant labor area. Our goal for women is three and for Hispanics is one. Thus our goal is met. For Asians our goal is a total of three, two above the current situation.

[2] University of Washington *Affirmative Action Update*, 1995-96

We consistently search for qualified minority applicants but we insist on hiring the most qualified candidates. We were very pleased to have had the opportunity to hire two women, Nelson and Olmstead, with outstanding abilities in the last ten years. In the two national searches performed by the Department last year, approximately 11% of the applicants were Asian. However, the strongest (and successful) candidates (Savage and Seidler) did not come from this subgroup. We will continue to look.

IV. STUDENTS

4.1 Baseline information:

4.1.A *Bachelor of Science in Physics program:*

There are no admission requirements other than University requirements for declaring a major. The Department advises students entering the major that they should have the equivalent of four years of college preparatory mathematics, and one year of high school physics and of chemistry, or equivalent. Since admission to the University requires the highest combined SAT and high school grades of all the Universities in the State of Washington, the quality of students entering in the major is high. A number of students transfer into the major from other state and out of state colleges and universities, including the extended community college network in the metropolitan Seattle-Tacoma-Everett-Bellevue area. The Department Undergraduate Advising office evaluates the transfer students records, and keeps track of all students who have declared a major to see that they either pass 15 physics credits/year with grades above 2.0 after their sophomore year, or have been authorized for a part-time program of study.

4.1.B *Evening masters Program:*

Applicants are primarily drawn from students working in the Seattle area. They usually have a Physics background as well as experience working in a technical area. Admission is primarily based upon interest in the program and a judgment that the student will be able to successfully complete the program. This judgment is performed by the Chair of the MS Program Committee with the concurrence of the Graduate Program Coordinator.

4.1.C *Ph.D. Program:*

Applicants for the Ph.D. program are required to provide GRE scores for the Advanced Physics, the Quantitative, the Verbal, and the Analytical Examinations, undergraduate transcripts, and letters of recommendation. Data on recent average score levels are provided in Appendix A. We admit about 60 of the most highly qualified applicants to fill an entering class of about 20 students. From one-third to a half of the entering class are foreign, the rest have graduated from domestic Colleges and Universities.

4.2 Enrollment patterns:

4.2.A *BS in Physics*:

As suggested by the data in Appendix A, enrollment in the undergraduate physics major has remained fairly constant at about 175 majors/year over the last ten years. As already noted in Sec. II, this stability of the enrollment is contrary to the slow but steady decline observed at most US universities.

The Department historically has had strong participation in the Summer Quarter program. The courses offered for the major are at the freshman and sophomore level, plus either the Electrical Circuits or the Computer Interfacing laboratories. In this quarter, the freshman introductory physics courses are essentially populated by non-majors, of which many are out-of-state students since tuition is charged at the resident rate. Most majors cite the need to work full time for not attending the University during Summer. Nevertheless, in Summer 1997 we will offer one more course, the first quarter of the Modern Physics lab. The Department also has a long tradition of offering in-service courses for elementary, middle and high school teachers, which are designed and run by the Physics Education Group with support from the National Science Foundation. One recent addition to the Summer program (1995) at the undergraduate level has been the Research Experience for Undergraduates (REU) program (Prof. W. Haxton, PI) sponsored by the NSF (See Sec. 5.4.B)

For the future the University expects that the "baby boom echo" now apparent in the State of Washington will result in increased enrollments at the Seattle campus of the UW of approximately 20% over the next ten years. While other campuses in the area and around the State will also be absorbing increases, they generally do not have capability for instruction in upper division science courses. Thus we may expect that the increase in the enrollment of majors may be somewhat above the average value of 20%. Our planning for the future must include a response to this scenario. We will return to this issue in Sections X and XI.

4.2.B *Evening Masters Program:*

The enrollment patterns of the Evening Masters program were discussed already in Section 2.3.B. Typical numbers of entering students in the program, integrated over the year, have fluctuated in the range 20 to 30 over the last ten years (see Table II-1). Most recently we have experienced a drop in the number of applicants. We understand this situation is related to a decreased effort to market the program and we intend to remedy it. The number of students in the program has ranged from 34 to 59 with an average of 43 during the past eight years.

4.2.C *Ph.D. Program:*

Enrollment patterns in the Ph.D. program were already mentioned in Section 2.3.C. We typically have from 18 to 26 entering students each year, with the smaller numbers exhibited in recent years. This is a matter of deliberate policy which we discuss below. The continuing enrollment in the Ph.D. program is approximately 130 out of the 170 total in the Graduate Program noted in Appendix A. The table in Appendix A also indicates the number of students admitted each year since 1987 along with their grade point averages and Physics GRE scores and the numbers of students who have passed various milestones: passing the Qualifying Examination, forming a supervisory Committee, passing the General Examination, and completing their Ph.D.s.

Of the students entering the program, about one-third leave without completing the Ph.D. The remainder eventually receive their degree, usually taking six to seven years to do so. A small number take significantly longer, a problem which we are trying to address. In an attempt to address the increasing difficulty which Physics Ph.D.s are encountering in obtaining academic and basic research employment, we have recently decreased the number of students we admit each year. This change has not yet worked its way through the system and we anticipate increasing difficulty in meeting our teaching responsibilities with the reduced enrollment.

4.3 <u>Graduation Patterns:</u>

4.3.A *BS in Physics:*

As suggested by the data in Appendix A the average rate of graduation by majors has remained fairly constant over the last 10 years in the range 30 to 45 but with large year-to-year fluctuations. Most of the students (approximately half) graduate in Spring Quarter, the normal end of the academic year. As mentioned earlier, most graduates seem to be able to find employment in the local area, or attend graduate school (some at the best nationwide universities). The Undergraduate committee and the Undergraduate Advising subcommittees have informal conversations, usually after advising, of the trends and quality of the students. The GPA of the graduating classes has followed University trends in the past.

One troubling trend, which seems to be University-wide, is that undergraduate students appear to be taking longer to graduate. While it is difficult to assess the true dynamics of the situation, due to the large number of students and the variety of situations, we have tried to make a simple model. Using data describing the University careers of recipients of Physics BS degrees over the last four years, we have attempted to determine why students spend more than four calendar years at the University. There are three primary sources of the extra time.

1. Our physics undergraduates tend to take approximately 30 more credit hours than is absolutely required (180 is the minimum), leading to at least two extra quarters. Some of these extra credits are in elective courses in the Department. Generally we feel that these extra experiences are a positive contribution to the student's education. Also, students with double or triple majors often cannot complete requirements in a timely fashion due to course conflicts or lack of time.
2. Our students are often enrolled only part-time, corresponding to less than 15 credit hours/quarter. For non-transfer (< 30 transferred credits) students this is true 50% of the time and for transfer students it is true 73% of the time. This typically adds between two and three quarters to the time to degree. The most apparent reason for this situation seems to be the increasing need to work while attending the University. In our Departmental exit survey (see below) of the 1995-96 graduating class, three of those responding (23 out of

34) reported not working, six worked eight to ten hours/week, nine worked 11-20 hrs/wk, three worked 21-30 hrs/wk, and two worked 40 hrs/wk.
3. Our non-transfer students also seem to typically take a fraction of a year off from classes sometime during their tenure at the University.

None of these sources seems to us to suggest any deep problem. Rather the educational system seems to be displaying praiseworthy flexibility.

An interesting measure of the "instructional productivity" of the Department is the ratio of BS degrees in Physics awarded per year to the number of faculty. To perform a comparison we have used the numbers in the AIP Report[1] and looked at the corresponding numbers for our peer institutions (as defined by the recent National Research Council ranking[2]). For the academic year 1995-96 this ratio was 0.71 (BS degrees per regular faculty member) in this Department while our peers exhibit the following ratios: UC Santa Barbara - 0.36, U of Texas (Austin) - 0.38, UCLA - 0.61, UCSD - 0.77. Clearly our productivity measured this way is near the top of our class and is something to be proud of.

4.3.B *Evening Masters Program;*

Over the last eight years (see Table II-1) we have awarded from 5 to 16 Masters each year with an average of 8 per year.

4.3.C *Ph.D. in Physics:*

Of the entering classes from 1990 through 1995, for which we have complete statistics, 135 students entered, 110 have passed the Qualifying examination, 56 have formed Supervisory Committees, 48 have passed the General Examination which admits students to Candidacy for the Ph.D., and 10 have received their Ph.D.s. Of the 125 entering students who have not yet received their degrees, 21 have dropped out or gone on leave, 8 have transferred to other Departments or Universities, 4 have left with their Masters degrees, and 92 are still in the program.

We award approximately 15 Ph.D.s each year, with about two-thirds of our students successfully completing the Program. For the group of Ph.D.s who have completed the program since March 1993, the *median* time to degree is 6 years while the *average* time is somewhat longer at 6.9 years.

The problem of ensuring that students complete their degree program in a timely fashion remains with us. Recently, we have worked to encourage students (and their advisors) to focus on making progress towards their degrees. This has resulted in the graduation of many of our more senior students and the increased graduation rate

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[1] "Graduate Programs in Physics, Astronomy and Related Fields - 1995-96", AIP Publication No. R-205-20 (American Institute of Physics, Woodbury, NY, 1995).
[2] Marvin Goldberg, Brendan Maher and Pamela Flattau, "Resarch-Doctorate Programs in the United States", (National Academy Press, Washington, D.C. 1995).

noted earlier. However, we still have seven students enrolled who entered the program more than seven years ago. Of these, all but one indicated last spring that they would finish in the first half of this year. We are watching the situation.

4.4 Placement of Graduates:

4.4.A *BS in Physics:*

For those graduates who seek employment after receiving their BS degree (typically between 1/2 and 2/3 of the graduates), the University has a placement center that students regularly use to find potential interviews. While the Department is unable to keep detailed records of the subsequent careers of our undergraduates, the University's Office of Educational Assessment does perform biannual surveys of recent graduates. The results of these surveys (with about a 50% return rate) suggest that our graduates 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.

For those students planning to continue on with graduate studies, the Undergraduate Committee organizes two annual meetings with students in the major (one in Autumn, one in Spring quarters) to discuss applications to graduate school, when to take the general GRE tests, the need for the Advanced Physics GRE if interested in graduate school in physics, the importance of independent study and letters of recommendation, and other issues. The Committee recruits younger faculty and many of the research postdocs, who have finished their graduate studies recently, to be at the meeting to offer their opinions and experience. As expected, the faculty write a considerable number of letters of recommendation on behalf of the graduates.

4.4.B *Evening Masters Program:*

Virtually all the students in the Evening Masters program are already employed. We do not have comprehensive information on how the graduates of the program have made use of their degrees. However, we do in fact know that some have used their degree to further advance their positions in education or industry, including moving into new startup high-tech companies, while others have used it as a stepping stone to a more advanced degree.

The results of the survey from the University's Office of Educational Assessment clearly indicate a high rate of employment in technically oriented positions. Again the reported salaries are generally larger than those for MS degree holders in other areas of Arts and Sciences.

4.4.C *Ph.D. Program:*

Thesis advisors carry the primary responsibility for placing students in research and teaching positions. There are electronic bulletin boards on which post-doctoral positions are announced, advertisements are placed in *Physics Today*, and faculty receive announcements of available positions. Those students who do not seek positions in academic research or teaching use the Campus Placement Center and advertisements in a number of media to locate possible job opportunities.

The job market facing our graduates is a matter of some concern. The number of available academic and industrial basic research jobs is limited (although the overall unemployment rate of Physics Ph.D.s is only about 2%, well below the population-wide number). On the other hand, we believe that a Ph.D. in Physics can provide an excellent training for a wide variety of occupations (recall Sec. II). In order to realize this promise, we must provide our students with both a broad background and a willingness to seek employment outside the usual opportunities.

As a step in this direction we have instituted a series of talks, Careers in Physics, in which former physics students and others make presentations to our students about the variety of careers that they are pursuing. Attendance has been good and it appears to have had some beneficial effects. It has been organized by the graduate students, with support from the Department Chair; this works very well when an energetic student is willing to take the initiative. A listing of recent presentations in this series is included as Appendix E.

The new course Topics in Contemporary Physics (Phys. 511) covers a range of experimental topics and represents another aspect of our effort to broaden the students' backgrounds. Other approaches are under discussion. We have made some attempts to encourage students to take summer jobs in industry during the summer prior to their first year, or between their first and second years. These efforts have not been particularly successful because of pressures on the students to pass the qualifying examination at the beginning of their second year, and to begin being active in research as soon as possible. The students also do not find that they have much time to explore other fields.

Despite these difficulties, our students have been successful in finding employment and their jobs have not been restricted to the standard academic and basic research areas. Of the 71 Ph.D. recipients from this Department in the last five years (including two from the current year) 6 (8%) currently hold tenure-track faculty positions, 18 (25%) are in university post-doctoral research positions, 8 (11%) are performing research at government laboratories, 11 (15%) are working in a technical capacity in industry (4 at Microsoft Corporation), 1 (1%) holds a non-technical but science related position in a government agency, 2 (3%) are working in non-technical positions in businesses, 3 (4%) are pursuing advanced training in other fields, and the career status of 22 (31%) is not known. This suggests that nearly half of our graduates are successfully pursuing careers in academia and/or research and that approximately 2/3 of our students find careers that directly utilize their training in science. The survey results from the Office of Educational Assessment confirm this picture of solid employment of our Ph.D.s, with most being able to directly use their graduate school training. We feel that this is a record that we can be proud of.

4.5 Underrepresented Groups:

4.5.A *BS in Physics:*

In physics the underrepresented groups are ethnic based and women. Women form the largest underrepresented group. The national average of women recipients of the BS is 16% in large research universities, and 18% in colleges according to AIP numbers[3]. In our Department, in 1996 the percentage of graduating women was 15%. The ethnic minorities were, from Basic Program Data (and the AIP Report), African-American 0% (AIP, 4%), Asian 15% (AIP, 4%), Hispanic 0% (AIP, 2%). Note that we are dealing with small numbers, but the Asian descendent population in the Seattle area is large, while the African-American population is small compared to many urban areas nationwide. Two Hispanics and one African-American have graduated with a BS in the previous two years.

4.5.B *Evening Masters Program:*

According to our records approximately ten percent of our evening MS students come from underrepresented populations. Of the 94 graduates in the last ten years, eleven are women. Four of the present 38 active students are women.

4.5.C *Ph.D. Program:*

Traditionally underrepresented minorities in physics include women, Hispanic-Americans and African-Americans but does not include Asian-Americans. These categories are defined by normalization with the current population pool and usually not by the normalization with the number candidates for admission to the Ph.D. physics programs. This is a weakness in the usual definition. We have tried to understand why traditionally underrepresented minorities are underrepresented in our applicant pool. The goal is to develop methods of evaluation of potential students that will help us to select more wisely those candidates who will be successful in Ph.D. studies in physics. The Department has a highly competitive pool of applicants with the average successful applicant having an Advanced Physics GRE score of around 800.

Based on our experience with past students we have found that an index composed of the undergraduate GPA, the quality of the undergraduate college, the General GRE and the Advance Physics GRE scores is positively correlated with the performance in graduate school. At the same time, we have found that traditionally underrepresented minorities candidates who perform well in graduate school often have a 100 point deficit

[3] Patrick J. Mulvey and Elizabeth Dodge, "1995 Bachelor's Degree Recipients Report", AIP publication No. R211.27 (American Institute of Physics, Woodbury, NY, 1996).

in the Advanced Physics GRE score compared with the average majority student. We have effectively included this consideration into our screening criteria for several years. The data in Appendix A suggest that our rate of offers to minority students is at least as high as the overall average offer rate.

4.6 Nontraditional Students:

4.6.A *Undergraduate Program:*

The percentage of non-traditional students in the major is small, usually students changing careers or returning to the University to complete studies. The percentage in the service courses, particularly the algebra based series, is somewhat higher. The Department offers the algebra based series through University Extension in the evening, open to all students but particularly appealing to those who have other responsibilities during the day.

4.6.B *Evenings Masters Program:*

The Evening Masters program is explicitly directed toward the non-traditional student. Almost all of the students are locally employed in a technical job and attend on a part-time basis, primarily in the evening in order to obtain additional training.

4.6.C *Ph.D. Program:*

The Ph.D. program has few non-traditional students. Occasionally, after starting out on a full-time basis, a student seeks outside employment and is able to continue to complete his/her degree on a part-time basis. However, this situation is rare as the demands of completing the degree program are difficult to meet on a part-time basis.

V. CURRICULUM

A. *Undergraduate*

5.A.1 Degree Programs/Options:

BS in Physics. There is only one undergraduate degree offered. In addition to the university and college requirements, the Department requires that all majors complete: 1) 48 credits in basic physics courses from a list that includes 36 credits in required courses, and several options for completing the requirements ,depending on the goals of student; 2) Five additional credits in physics and cognate subjects; 3) Nine additional credits in a related science or individually approved engineering courses. There is an additional minimum requirement of 18 credits in calculus and linear algebra. A listing of Physics courses and credits is given in Appendix C and the handout given to undergraduates when they declare the major, including a listing of recommended courses, is provided as Appendix F.1.

5.A.2 General and Service Education:

As mentioned previously, our service courses occupy a very large portion of the faculty time dedicated to undergraduate education and provide the majority of the undergraduate enrollment.

There are four levels of introductory/general/service courses:

a) Physics by Inquiry for Pre-college Teacher Preparation (Phys. 101-102, 103; Phys. 210,211,212; Phys. 405, 406, 407, 408, 409). These courses are described in more detail in the Physics Education Group (PEG) contribution to the Department. The first two volumes of the laboratory-based curriculum developed by PEG have been published by John Wiley & Sons. The third volume is in preparation. The materials are being widely used in the US and Canada. The curriculum is intended also for liberal arts students, special preparatory courses in the minority engineering program, and for under prepared students who aspire to science related careers and will encounter difficulties directly entering the standard required courses.

b) Courses with no prerequisites, intended for the fulfillment of general university requirements or student personal interests: i) Liberal Arts Physics (Phys. 110, 111), basic concepts of physics, primarily for students in the arts, humanities, and social sciences; ii) Physics of Music (Phys. 207), a course on the phenomenology of sound, waves, the ear, and musical sounds; iii) Physics of Sports (Phys. 208), concepts in motion, forces, momentum, energy, power applied to the performance of top athletes in tennis, baseball, sprinting, high jumping, *etc.*; iv) Light and Color (Phys. 214), Order and Disorder (Phys. 215), and Time and Change (Phys. 216), a set of three independent courses, which emphasize quantitative comparison between commonly accepted explanations of natural phenomena with actual physical explanations of the same phenomena.

c) General Physics (Phys. 114, 115, 116) and the corresponding General Physics Laboratories (Phys. 117, 118, 119). This is the standard, algebra-based introductory physics course which covers mechanics, heat and thermodynamics, electricity and magnetism, optics, and some modern physics in a one year course. It is taken by students in many different majors, with the majority intending to enter medicine, dentistry, physical therapy, or other biological sciences.

d) Introductory University Physics (Phys. 121, 122, 123) with required Introductory Laboratories (Phys. 131, 132, and 133). This is the calculus-based introductory physics course which is required for engineering students and several other majors, including our own. Recent changes in this series are described in detail in Section 5.C.1.

The Department is in general satisfied with the distribution of courses it offers between majors and service/general education. The recent changes in the Phys. 121, 122, 123 series, which were instituted in response to the University's Entry Level Initiative, led to the creation of the Senior Lecturer position, the addition of 16 TAs and the allocation of some additional resources for increasing the number of laboratory sections and staffing the tutorials. Nevertheless, later cuts in the total TA allotment (5 positions) have been felt by all other courses. Current faculty interest is in improving the algebra-based course by trading a lecture for a tutorial/problem solving session. An experiment with faculty volunteers will be run during Spring Quarter, 1997, organized by Heckel when he teaches Phys. 117, the Optics/Modern Physics quarter. If this trial proves successful, further resources will be requested from the University.

Additional faculty interest has been expressed in introducing courses for non-majors which have a strong biology component, or are taught jointly with faculty in one of the medical sciences or bioengineering departments. These efforts are not being actively pursued for lack of faculty. A single course along these lines, but for majors, was tried during autumn quarter, 1996 (see 5.A.3 and 5.C.1).

5.A.3 Interdisciplinary Programs:

For the first time an interdisciplinary course in biophysics was taught this last autumn quarter (Phys. 428). This course seems to have been a success as measured by an enrollment of 15 students, comparable to our other senior level specialty courses. We have also historically taught in shared courses with the College of Engineering on environmental and nuclear power issues (Phys. 341-3). However, neither of these examples could be considered part of a "Program".

5.A.4 Participation in Research:

While undergraduate participation in research does not seem to be included in the standard report outline, it does play an important role in the Department of Physics and we felt that it should be mentioned. As you will note in Section 6.1, in the descriptions of the various research groups, many employ undergraduate students in their laboratories (see, *e.g.,* the atomic physics group). Physics majors are encouraged to get involved in the Department through their senior projects and senior laboratories and, in fact, have their own room in the building to work in around-the-clock (room B135 is dedicated to the Society of Physics Students and majors in general).

Another program, primarily aimed at undergraduate students from other universities is the REU (Research Experiences for Undergraduates) funded by the NSF and active in this Department for the last two summers. A brief report of last summer's program is appended here.

RESEARCH EXPERIENCES for UNDERGRADUATES: In 1995 the Institute for Nuclear Theory and the Department of Physics, University of Washington, began a Physics Research Experiences for Undergraduates Program. The 1996 program is discussed here. As in 1995, the 1996 program was directed by Wick Haxton.

The program was advertised via a poster and a Web site, which contained all relevant information on the program. The poster was mailed to most active physics departments in the US and to over 700 Society of Physics Students chapters from the American Physical Society. The director also wrote a number of personal letters to his colleagues teaching in historically black colleges, asking them to help in recruiting minority candidates.

Applicants completed an information form and an optional form on ethnicity, military status, *etc.* They also provided transcripts and two letters of recommendation. The applications came from throughout the US, with the Northwest, California, and the Midwest most strongly represented. The quality of the applicants was remarkably high: perhaps 20% of the applicants had GPAs in the range of 3.9-4.0. We received a total of 123 applications, and accepted 13 students, one of whom was supported by INT funds. The ratio of their acceptances to our offers was about 70%.

Approximately half of the faculty in the INT and Department had expressed interest in advising an REU student. The process of matching accepted students to faculty advisors was done by the director, who initially asked the students to pick favored projects from a list he had compiled from faculty suggestions. He then negotiated an acceptable match. A list of accepted students, their faculty advisors, and their research areas is included as Appendix G.

As the University of Washington is on the quarter system, our starting date was relatively late in June. To accommodate the many students from schools on semesters, we were flexible in the starting and ending dates, allowing students to begin their ten-week programs one or two weeks early. All students remained in the program for a minimum of 10 weeks. Students were housed together in a campus dormitory, in single rooms.

In addition to the work with their faculty advisors, the students met with the program director twice each week. The Monday morning meeting was informal, a time set aside for casual physics discussions, for questions, *etc.* The Friday morning meeting was a faculty seminar, usually a broad overview lecture on some area of physics. This gave students a broader perspective on the kinds of physics done at a major research university. All of the experimental students also took the department's machine shop course, which provides about 14 hours of instruction. During the last three weeks of the program, these meetings were used for a different purpose: each student gave a 20-minute talk to the other students (and usually several interested faculty) on his/her research. The students also prepared a short report on their summer research. In several cases, the reports were incorporated into publications. The faculty response to the REU program has been extremely strong. This is an excellent program for encouraging students to continue in physics. The exit surveys completed by the students show that they hold very similar views.

B. Graduate:

5.B.1 Master's Degree:

The Master of Science degree is reached by three different paths in this Department. The majority of the Ph.D. students are awarded a MS degree (if they ask for it) after they complete the core graduate courses and successfully pass the Qualifying Exam. Students leaving the Ph.D. program, who have satisfied the course requirements and have embarked on research but who either do not take or do not pass the Qualifying Exam, can obtain a MS degree after passing an oral exam, typically on their research topic. The final path to the MS degree is internally known as the "Masters Degree Program in Applications of Physics" or the "Evening Masters Program."

The Evening Masters Program regularly offers three core courses: electromagnetic waves, introduction to quantum mechanics and applications of quantum mechanics. During the last ten years approximately twelve other courses have been periodically offered on topics ranging from optics and lasers, plasma physics, fluid mechanics, mathematical methods, and condensed matter physics. Physics by Inquiry, the Department's courses for precollege teachers, are also available to students in the MS program. New courses offered recently were: physics of neutron stars, applications of synchrotron radiation, nonlinear dynamics and chaos and a laboratory course in atomic and condensed matter physics. Individual students have augmented their studies with many other courses both inside and outside the department. Roughly half of the department's faculty has participated in this program, either by teaching one of the courses or by supervising an independent study project, something that each student must complete for the degree. The handout supplied to new students and describing the program is included in this report as Appendix F.2.

Some representative titles of projects that led to recent degrees include:

"Fabrication and characterization of superconducting tunnel junctions"
"The optically pumped rubidium magnetometer"
"Design study of RF separators"

"CN abundance in luminosity class iv subgiant stars"
"Development of a pre-optics curriculum for physical science students"
"Proton emission from 3He induced reactions"
"Design of a crystal microbalance and vacuum system for studies of isotherms"
"Critical velocities in superfluids"

It is clear that this is a robust, though rather diverse, program, fulfilling a great range of needs.

5.B.2 Doctoral Degree:

The basic curriculum expected of entering graduate students consists of one quarter of Classical Mechanics (Phys. 505), including some non-linear dynamics, three quarters of Quantum Mechanics (Phys. 517-9), three quarters of Electrodynamics and Mathematical Physics (Phys. 513-5), one quarter of Statistical Mechanics (Phys. 524), and one quarter of Topics in Contemporary Physics (Phys. 511), an experimentally oriented course. They are also expected to participate in the two quarter sequence Current Problems in Physics (Phys. 527-8), which provides an introduction to the research activities in the Department. In the second year, students have a somewhat lighter course load in that they are expected to continue for two quarters in the Advanced Quantum Mechanics and Introduction to Quantum Field Theory course (Phys. 520-1), take one quarter of Numerical Methods (Phys. 506), and appropriate courses for their field of specialization. (Possible courses are: Condensed Matter Theory, Nuclear Theory, High Energy Physics, Statistical Mechanics, and Introduction to Modern Quantum Field Theory.) In addition, students are expected to begin independent study by their second year at the latest. The general format of the required courses is illustrated in the following table.

First Year			Second Year		
Autumn	Winter	Spring	Autumn	Winter	Spring
501*	502*	503*	520	521	
505	524	511		506	
513	514	515			
517	518	519			
527†	528†				

* = Required of TAs only (see below).

† = Expected only.

A portion of the handout given to entering Ph.D. students that provides details about their first year activities is included with this report as Appendix F.3.

This curriculum is modestly different from that of three years ago. We have combined much of the content of the prior Mathematical Physics course with the Electromagnetism course. In this way, what was previously two quarters of Mathematical Physics, Classical Mechanics, and Numerical Methods in the first year has been reduced to just one quarter of Classical Mechanics in the first year with Numerical Methods being offered in the second year. The Statistical Mechanics course offered in the first year has been increased to four credits and is now the only statistical mechanics course expected of all students. The time released has been used to offer the more experimentally oriented course, Topics in Contemporary Physics (Phys. 511), which is taught on two different topics by two experimentalists.

There are other small changes in the second year curriculum: The second year Statistical Mechanics course (Phys. 525) is now an advanced topics course intended for students interested in Condensed Matter physics. The Advanced Quantum Mechanics course has been extended to two quarters and includes more topics in Quantum Field Theory than was previously the case. Theoretically inclined students are expected to take the Introduction to Modern Quantum Field Theory course (Phys. 522) and all students are expected to take courses in their area of specialization.

The changes were introduced to reduce the course load in the first years and allow students to move more rapidly into research. They were also intended to give the students a somewhat broader background. We are continuously seeking the correct balance between providing a thorough background while moving the students quickly into research and completion of their degrees.

Since the time of the last review, we have instituted seminars in all the major fields of research. The graduate students are expected to take an active part in these seminars, including giving talks regularly. In this way they achieve mastery of the material and hone their communication skills. The new physics building has had the effect of greatly enhancing the environment of the students. They generally have offices near those of their advisors, which they share with students with similar interests. We are very pleased with the resulting level of interaction and collaboration, which we view as an important part of the students' training.

5.B.3 Instructional Relationship to Other Programs:

The other graduate programs whose students most often take graduate courses in physics are Geophysics and Electrical Engineering. These students constitute approximately 8% of the enrollment in our graduate courses. We also encounter smaller numbers of students from Applied Mathematics, Astronomy, Biophysics, Chemical Engineering, Chemistry and Material Sciences and Mathematics. A specific example is the current enrollment in Graduate Electricity & Magnetism (Phys. 513-5). In the autumn the 25 students included five from outside Physics.

5 B.4 Teaching Participation:

Teaching opportunities: Graduate teaching assistants in the Department are provided with a variety of teaching experiences. All first-year TA's spend part of the year teaching in the tutorials for the introductory calculus-based course and part of the year in the associated laboratories. They also grade for these courses as part of their assignment. In addition, during the entire year, they are assigned to the Physics Study Center in which they work with individual students from the first and second year courses. Graduate students who are TA's during subsequent years have an opportunity to teach in the upper-division laboratories. Each year, several advanced graduate students also volunteer to teach in the tutorials to obtain additional teaching experience. During the course of a student's career, he/she typically spends two years (six quarters) as a TA. A copy of the report from the spring, 1995 Graduate School Teaching Assistant Review Committee is included with this report as Appendix H.

Graduate Teaching Seminar: The Graduate Teaching Seminar (Phys. 501-3) is a graduate course required of all first year teaching assistants and all instructors in the tutorials for the introductory calculus-based course. This is a unique opportunity available to our students as a result of the research interests of the Physics Education Group. During the weekly seminar, the TA's work through the same materials that they are expected to teach later in the week. Experienced instructors provide guidance in helping the TA's to learn to listen to students and to teach by questioning rather than by telling. In each of the tutorials, the TA's are accompanied by an experienced TA who can serve as a mentor. During the course of the year, the Head TA for the department and members of the Physics Education Group observe the TA's during their tutorials and meet with them to discuss issues about teaching that may arise.

Post-doctoral experience: For each of the last few years, between 5 and 10 of the post-docs and young research faculty in the Department have volunteered a few hours of their time each week to teach in the tutorials for the introductory calculus-based course. They attend the Graduate Teaching Seminar and participate in two tutorials each week. In so doing, they obtain a monitored teaching experience that goes beyond that of teaching a standard problem-solving session and that can help to make them more competitive when they seek employment as tenure track faculty.

5.B.5 Preparation and Participation in Research:

Entering graduate students are expected to take Physics 527-8, Introduction to Research, in which various faculty members describe the research activities of their groups. Later, during their first and/or second years, students are expected to engage in Physics 600 with a faculty member to explore research possibilities. This experience is expected to lead into a thesis research project. Typically students find their research home in one of the groups sometime during the second or third year of study. Snapshots of how students where distributed amongst the research groups, both ten years ago and today are exhibited in Figure V-1. Students working with the Fellows of the INT are included in the Nuclear Theory Category.

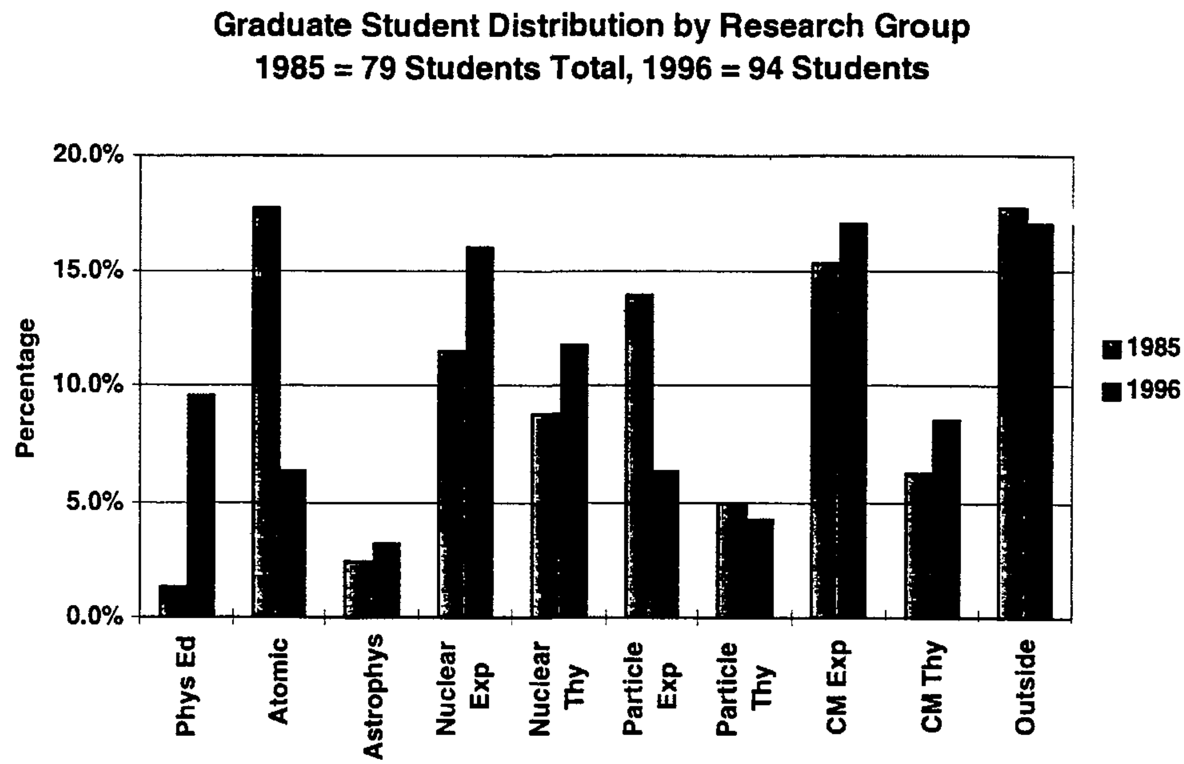

Figure V-1

Clearly the students are active participants in the research of all the research groups in the Department: Atomic Physics, Astrophysics and General Relativity, Experimental and Theoretical Condensed Matter Physics, Experimental and Theoretical Nuclear Physics, Experimental and Theoretical Particle Physics, and Physics Education. While there is some correlation between the number of faculty in a group (see Figures III-1 and III-2) and the number of students; generally experimental groups have relatively many more students than theory groups. The role of the physics education group in the Ph.D. program has clearly grown, matching its rise in visibility both inside and outside of the Department. The drop in the number students in atomic physics is likely a temporary fluctuation, resulting from a large number of new Ph.D. theses in the last two years. Many of the students labeled as nuclear or particle experiment are really doing research in astrophysics.

The last category in Figure V-1, "Outside", deserves special comment. For the last ten years approximately 15% of our students have performed their research with Adjunct Faculty outside of the Department, who hold positions in other departments but supervise students taking a Ph.D. in physics. The research opportunities available to our students are broadened by this role for the Adjunct Faculty. We regard it as important to monitor such students to ensure that they are really receiving training in physics, and are not just students in their advisors' departments who happen to receive a physics degree. In such cases it is important that the regular (Physics) faculty members on the thesis committee play an active role in the education of the student. In some cases there is close collaboration between the Adjunct Faculty and research groups in physics. For example, there are seminars in Ice Physics and in Surface Science in which both adjunct and regular faculty members participate. In some other cases the links are weaker, but we are trying to cultivate them; the University Initiative in Nanostructures involves regular Physics faculty together with Adjuncts in Bioengineering, in Electrical Engineering and Materials Science and Engineering, and in Chemistry. In other cases, such as Geophysics and Plasma Physics, the involvement of our regular faculty with these research areas is more limited.

5.B.6 Funding:

Almost all students are fully funded throughout their studies. Most students receive Teaching Assistantships during their first one or two years (a few are supported as Research Assistants). As students become involved with research they are usually supported by the research grant of the faculty member with whom they are working. Sometimes students will return to the Teaching Assistant rolls, either for additional teaching experience, or because the research grant does not have sufficient funds to support all the students working on research supported by the grant. A very few students who are taking a long time to complete their degrees are not funded. These students must obtain outside employment.

C. Undergraduate and Graduate

5.C.1. Curricula change:

Undergraduate

The most dramatic change to the undergraduate curriculum in the last five years has been in the introductory calculus-based physics course (Phys. 121-3). Important changes have also occurred in the content of several other courses, in particular, the Advanced Physics Laboratories.

Undergraduate Lower Division Instruction (Physics 121, 122, 123 and Physics 131,132, and 133, the Introductory calculus-based course and associated laboratories)

Since 1991, as part of the Entry-Level Initiative, the Department has made several modifications to the introductory calculus-based sequence in an attempt to improve instruction. Instead of having four lectures each week, the course now consists of three lectures and one small-group *tutorial* session. The laboratory, which had been optional, is now required and has been more tightly linked to the courses. Every examination includes at least one question from the tutorial and one from the laboratory. The lecture and laboratory are considered as a single integrated course; students receive the same grade for both. Since the Department moved to the new Physics-Astronomy Building, efforts have been made to make the Physics Study Center in room AM018 more useful to students. The changes to the course are described in more detail below.

Tutorials: The tutorials are an attempt to improve student learning by increasing the level of intellectual engagement of the students. During the tutorials, students work in small groups of three or four on worksheets that are specially designed to take into account research on the learning and teaching of physics. The tutorials are staffed by teaching assistants and volunteers from the Department. Typically there are two or three instructors for about 24 students: one experienced instructor and one or two new instructors. Tutorial homework is assigned on a weekly basis. The tutorial instructors receive comprehensive preparation in the weekly Graduate Teaching Seminar.

The tutorials are integrated with the lectures and are explicitly tested for on each examination. The lead tutorial instructors contribute one question to each of the three midterm examinations and two question to the final examination. Student comments on the evaluations for the course typically rank the tutorials as being one of the most useful components of the course in helping them to learn the material.

Laboratory: Prior to the Entry-Level Initiative, only about 40% of the students in the calculus-based course took the laboratory concurrently with the lecture. The laboratory is now required of all students in the sequence. The experiments and equipment have been modified to be more tightly synchronized with the lectures. In addition to being graded on their laboratory write-ups, students are tested on the experiments explicitly on each examination. The laboratory instructor contributes one question to each of the three midterms and to the final examination.

Physics Study Center: All of the teaching assistants assigned to the tutorials and many of those assigned to the laboratory hold office hours in the Physics Study Center. It is staffed nearly continuously from 9:00 A.M. to 5:00 P.M., Monday through Friday by teaching assistants. The lecturers for the calculus-based course also hold their office hours in the Study Center. The teaching assistants receive guidance on how to manage students in the Study Center at the start of the year and in the Graduate Teaching Seminar.

Computer Labs:
A set of Macintosh computers are available for use by students in the calculus-based course. The computers are located near the Physics Study Center. There are several computer programs assigned as tutorial homework during the year. Occasionally tutorial sessions that use the computers meet in the computer lab. Other classes also use the computers on an irregular basis. A second, PC based, computer lab is also available to students in room B101.

The Advanced Physics Laboratories (Phys 431, 432, and 433): The advanced laboratories were thoroughly modernized due to the initiative of the Laboratory Manager, John Stoltenberg, and Vilches, who obtained a NSF DUE University Laboratory Improvement grant ($25,000 from NSF and $25,000 from UW). Additional funding for the improvements came in the form of a state-of-the-art laboratory space (included in the new building), residual building funds, and the freeing of some UW resources with the use of the NSF funds. Several new instruments and experiments were added: the X-ray diffractometer, the scanning tunneling microscope, the pulse nuclear magnetic resonance experiment, the Zeeman effect experiment, the positron annihilation experiment, the superconducting tunneling experiment, several new computers, several digital oscilloscopes, video data acquisition, complete renovation of the multi-channel scalers and analyzers, *etc.* The laboratory is now a real "modern physics lab". The availability of the new instrumentation has prompted Sorensen to use it for the evening MS program, and to propose both new graduate and undergraduate labs.

In Autumn quarter, 1996, we offered for the first time an Introduction to Biophysics course for physics majors (Phys. 428). The course was proposed by Schick and Adjunct Assist. Prof. Vogel of Bioengineering, was funded in part by the Department, and was taught by a physicist post-doctoral associate in Vogel's group. The course was well received.

New offerings which have been proposed last year and are going through the University review are the introduction of a Physics Minor, and a sophomore level introductory physics laboratory.

The University of Washington started a Minors program in an effort to officially acknowledge considerable work done by students in departments in which they are not majors, and have the opportunity to Minor in a College other than the College of the student Major. After considerable debate, our Department approved a proposal from the UG Committee to introduce the Minor in Physics as soon as it receives University approval. The actual proposal is included as Appendix I. The impact of the Minor on our own Major student registration is difficult to predict, but we expect some students who take the complete introductory physics with calculus sequence (in addition to Phys. 121,2,3,131,2,3, the Thermodynamics course, Phys. 224, and the Modern Physics course, Phys. 225) to "venture" into taking a few other courses (which may be just laboratory courses) and complete the Minor.

We have proposed to start an Introductory Experimental Physics course (Phys 231) in Autumn 1997. This course will be based on experiments which measure or are related to fundamental constants (speed of light, Planck's constant, charge of the electron, Boltzmann's constant, universal gravitational constant, *etc.*) and which introduce students to rigorous acquisition and analysis of data. Equipment for this laboratory has been purchased. Seidler (with assistance from Vilches) will be the first instructor.

Graduate

The recent changes in the Ph.D. curriculum are discussed in Section 5.B.2.

VI. RESEARCH AND CREATIVE ACTIVITY

6.1 Current Research and Creative Activity:

The research activity within the Department can be loosely characterized in terms of nine major areas. While these areas do correspond to canonical sub-areas of physics and the structure of the funding agencies, the actual intellectual activity freely crosses these boundaries. The faculty are constantly looking for shared areas of interest. This has long been the case between nuclear physics, particle physics and astrophysics, between atomic and particle theory, and between experimental condensed matter and atomic physics. More recently there has been cross fertilization between condensed matter (theory and experiment) and nuclear and particle theory.

The basic structure of the federal support for all of the research groups as a function of time is indicated by the yearly numbers in Appendix A. The numbers indicate stable to slightly growing support, not accounting for inflation. In an era of shrinking Federal support the stable funding situation for the last several years is a strong endorsement of the Department. However, the outlook for future support from the usual sources (NSF and the DOE) is less certain. The changes in the way this support is distributed amongst the groups in indicated in terms of percentages Figure VI-1. (These figures correspond to internal Department records and do not correspond precisely to the total numbers supplied by the University in Appendix A.)

Grant and Contract Expenditures by Research Areas
Total Dollars: $7.3 M in 1984-85, $ 9.1 M in 1995-96

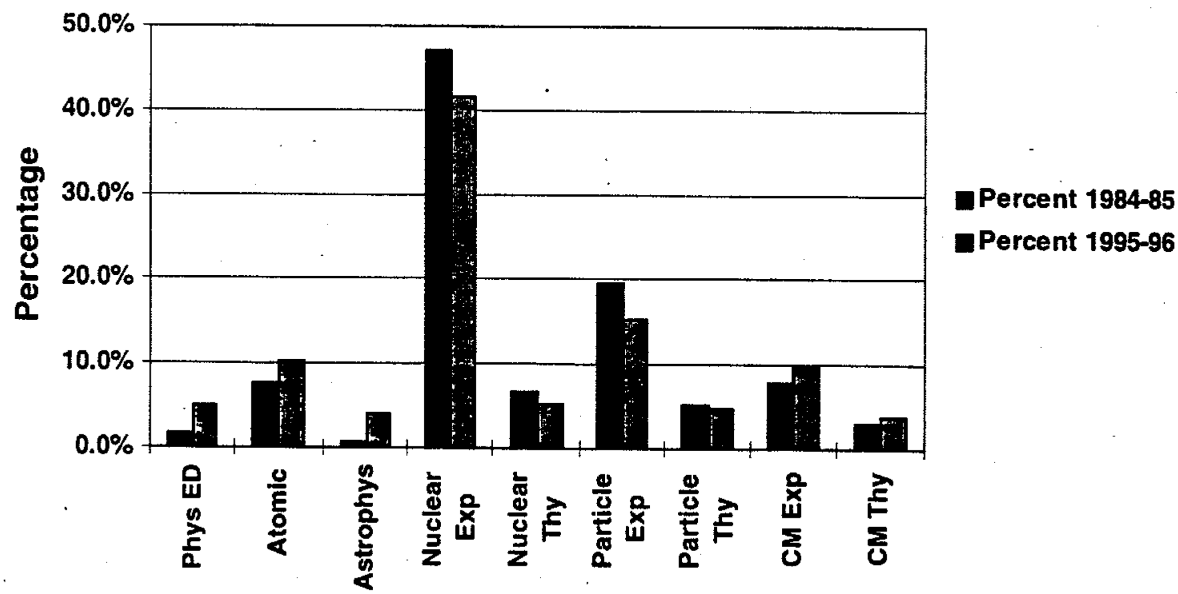

Figure VI- 1

The same data presented in terms of then-year dollars is indicated in Figure VI-2.

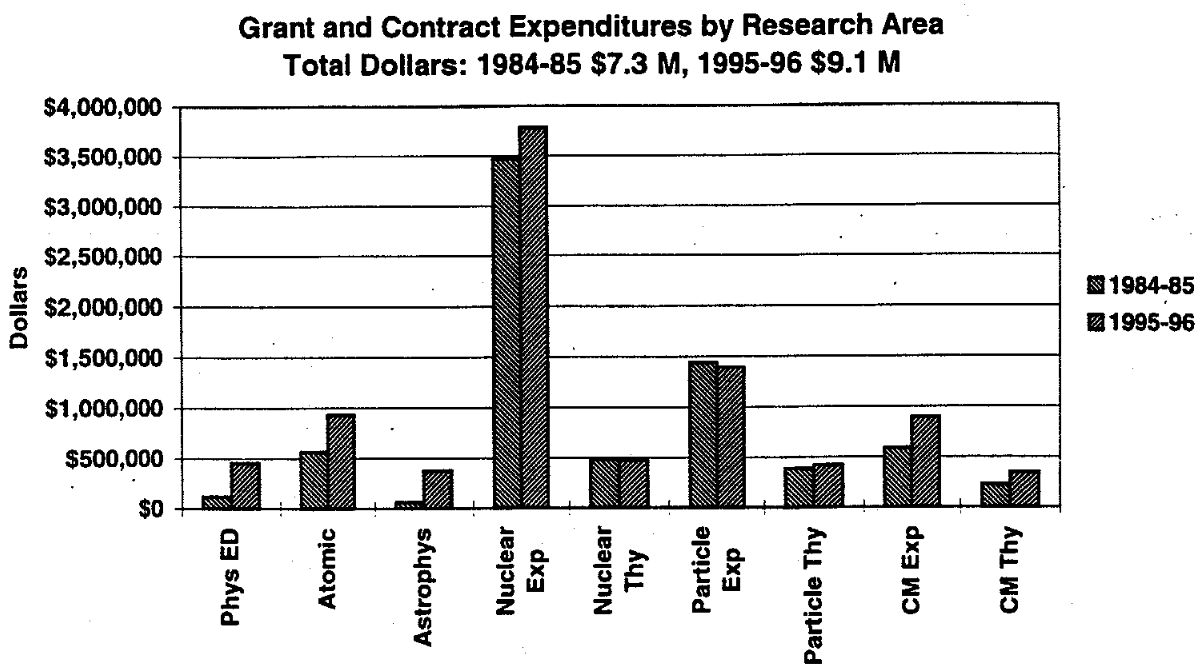

Figure VI- 2

In general this data indicates that the previously small activities in physics education and astrophysics have experienced dramatic growth in support in the last ten years. The growth in support for atomic physics, condensed matter experiment and to a lesser extent condensed matter theory have also been larger than the overall average (hence the increase in the percentage) while particle theory, nuclear theory and nuclear experiment have grown more slowly than the average. Particle experiment has seen a small decrease in funding.

The following are "brief" summaries of recent research activities in each of the areas. It is important to note the many overlapping activities, which will be characterized by being mentioned under more than one heading. The Department of Physics is an interdisciplinary program all by itself.

6.1.A *PHYSICS EDUCATION GROUP:*

Since 1986, the Physics Education Group (PEG) has grown substantially in size and in the scope of its activities and influence. Within the emerging field of physics education, the group has a national and international reputation for its coordinated program of research, curriculum development, and instruction. Under the direction of Prof. Lillian C. McDermott, the group is currently engaged in three major projects: improvement of instruction in introductory physics; preparation of graduate students as future faculty; and preparation of precollege teachers to teach physics and physical science as a process of inquiry. A particularly novel feature of this program is that it is *in* the Department of Physics. Its research involves the regular undergraduate instructional program and its graduate students earn Ph.D.'s in physics (not education). In addition to McDermott, PEG faculty are Research Assistant Professors Shaffer and Vokos and Postdoctoral Research Associate Heron.

Since 1984, McDermott has been awarded NSF grants totaling more than $4.7 million, with current per year support at approximately $800,000. The group has provided the model for physics education groups at other institutions, such as The Ohio State University and the University of Maryland, and for programs and systemic initiatives for the preparation of precollege teachers in states such as Ohio, Michigan, and Texas. Since mid-1995 group members have put on a dozen faculty development workshops in Physics by Inquiry or Tutorials in Introductory Physics at national, international, and regional conferences of physicists and science faculty, and have conducted five TA workshops on preparing future faculty in other science departments at this University. The PEG is responsible for more than half of the articles on physics education research which have appeared in the American Journal of Physics.

Since the last departmental review, four graduate students have received their doctorates for research in physics education, and two others will receive their Ph.D.s by the end of the academic year. Five have received master's degrees in physics for projects related to physics education. Six post docs have been trained and are working in academic positions. Nine doctoral students are currently working with the group. In the past the group has relied on the assistance of visiting professors to make possible this dramatic growth. In 1997, as noted earlier, the visiting position will be converted to a tenure-track position and a new faculty member will join the group. The future of this increasingly active research group is an important question for the Department and we will return to it in Sec. X.

Graduate students in the Physics Education Group select physics education as their field of research for the Ph.D. degree in physics. The group conducts in-depth research on student understanding of traditional topics in physics (current examples are dynamics, electricity and magnetism, waves, physical optics), and is beginning similar research in thermal physics, relativity (Galilean and special) and quantum mechanics. Through these investigations, the group seeks to identify and analyze common difficulties that students encounter in studying physics. Results of this research are used to guide the development of instructional materials and strategies designed to address specific conceptual and reasoning difficulties and enhance the effectiveness of instruction.

The following provides a brief description of the Physics Education Group's current activities:

- The group assumed a leadership role in 1991 in the departmental initiative to improve the quality of student learning in introductory calculus-based physics. The result has been the development of a curriculum, *Tutorials in Introductory Physics,* which is an integral part of the introductory course (Phys. 121,122,123). The objective of the tutorials is to promote a deeper intellectual engagement by students than is likely to occur through lectures alone. *Tutorials in introductory Physics is* being pilot-tested at 10 other US colleges and universities, and a preliminary version is being prepared for commercial publication in 1997. In addition to developing the instructional materials and methodology, the group coordinates the effort to integrate the tutorials with the lecture and laboratory components of the course. PEG graduate students serve as lead TAs in the tutorials.

- An essential component of the tutorial effort is a weekly Graduate Teaching Seminar (Phys. 501,502,503) for graduate students (and faculty). The purpose of the seminar is to prepare the TA's and volunteer instructors to lead the tutorials. Preparation is both in the subject matter and in the instructional methods. The seminar is required for all first-year graduate students with teaching assistantships. More than 80 graduate students have participated in the seminar and the tutorials since the course was begun in 1991. In addition, several post-docs and junior faculty (more than 25 since 1994) have volunteered for the training and teaching experience. The group is currently working on identifying various factors that need to be considered in preparing most effectively graduate students and faculty for their role as instructors. One goal of the research associated with this project is to develop an appropriate model for preparing future faculty that can be used at other colleges and universities.

- The group's established model for precollege teacher preparation, *Physics by Inquiry,* is the result of a major effort of more than twenty years: a year-round program for prospective and practicing teachers at elementary, middle, and high school levels. During the academic year, the group teaches special courses in physics for preservice teachers (Phys. 101-102,103; Phys. 210,211,212; Phys. 407,408,409). During the summer, with NSF support, the group conducts an all-day, six-week intensive Summer Institute for Inservice Teachers. The courses offered include Phys. 405, 406, 407, 408. All these courses have provided a realistic setting for the development of *Physics by Inquiry,* a laboratory-based curriculum to prepare precollege teachers in physics and physical science. Volumes I and II have been published by John Wiley & Sons, Inc. in 1996. Volume III is in preparation. These instructional materials are also suitable for liberal arts students and have been used in special preparatory courses for students in the minority engineering program and for underprepared students who aspire to science-related careers but whose background in science and mathematics is weak.

6.1.B *ATOMIC PHYSICS:*

1986 - 1996 was a banner decade for atomic physics at the UW. Hans Dehmelt, who originated the trapping of single ions here, received the Nobel Prize in Physics in 1989, the Rumford Medal of the American Academy of Arts and Sciences in 1993, and the Presidential National Medal of Science Award in 1995 while Norval Fortson was elected to the American Academy of Arts and Sciences. All our atomic physics research programs were active and successful, and maintained stable federal funding. In addition, a laser facility was founded in the new building with an NSF grant and UW matching funds.

The atomic physics group consists of 4 State-funded faculty, Professors Dehmelt, Fortson, Heckel and Van Dyck, 4 research faculty, Associate Professors Nagourney and Schwinberg and Assistant Professors Mittleman and Yu, and typically 3 postdocs and 8 graduate students, plus other faculty in joint projects. Since 1985-86, 13 students have received their Ph.D.'s after working in the atomic physics group and 5 young Ph.D.'s have advanced their careers by performing research here. During this same period over 25 undergraduates participated in research projects, including several quite substantial ones such as quantum jumps, the linear Stark effect, and the Casimir force. Atomic physics is clearly one of the most visible groups in the Department.

Although there are many atomic physics experimentalists in our department with diverse research interests, most of the activity has one unifying theme: carrying out local small-scale experiments to probe basic forces. Trapped ion research, clearly one of our major atomic programs, scored new triumphs in the past 10 years: measurement of the magnetism of the electron and positron to 3 parts in a trillion; measurement of atomic ion masses to such a precision that the energy of molecular bonding can actually be weighed; observation of quantum jumps between electronic states of a single atomic ion; and resolution of optical transitions to a part in 100 billion.

Experiments that probe atoms for tiny asymmetries - such as right vs. left, or forward vs. backward in time - also scored notable successes: a measurement of right-left asymmetry in thallium atoms to 1% became the most precise of its kind and an exacting test of fundamental electro-weak theory; a search for a permanent electric dipole of mercury atoms set the best world limit on the size of such a dipole and imposed strict constraints on time-reversal symmetry violation in elementary particle theories; and UW leadership on the famous neutron electric dipole experiment at Grenoble, France helped improve on previous neutron results by a factor of 10 and set constraints on time-reversal asymmetry comparable to those of the mercury experiment.

Outside recognition brought a big boost to atomic physics at the UW in 1992 with the award of a Tunable Laser Facility grant under the NSF Academic Research Infrastructure Program, $400K from the NSF matched by $400K from the Physics Building Fund, and then again in 1996 with the award of a similar ARI grant for the laser facility (partly shared with Chemistry) totaling $238K from the NSF matched by $235K from the University. Continuing grant support for the atomic physics group comes mainly from the NSF, and totals (excluding the Laser Facility) approximately $1 million annually.

The following is a brief listing of activities in the atomic physics group.

- *Atomic Ion trapping experiments* - involving Dehmelt, Nagourney and Yu to develop the most precise atomic clock possible and Dehmelt, Mittleman, Schwinberg and

Van Dyck to improve on the 1987 value of the electron g-factor. One recent advance in the clock work is the observation by Nagourney and Burt of viable optical forbidden lines in In^+ after the Tl^+ homologues had been identified as the ideal clock atoms earlier by Dehmelt. In the g-2 work one of the recent advances is the measurement of the long hypothesized trap-cavity shift of the g-factor performed by Mittleman, Dehmelt and Kim in 1995.

- *Penning trap mass-spectrometry-* involving Van Dyck and Schwinberg to develop a mass spectrometer accurate to parts in 10 billion. One recent challenge was caused by the move to the new Physics-Astronomy Building with its very large external magnetic field noise sources, which have been overcome by the use of a sensitive flux-gate magnetometer driving 2-meter Helmholtz coils surrounding the superconducting solenoids and collaboration with the Metro Bus people.

- *Measurements of atomic PNC* - involving Fortson to study atomic parity nonconservation as a probe of the fundamental electro-weak force. Using a completely rebuilt optical rotation apparatus, this group has carried out the two most precise measurements of PNC to date, with lead and thallium vapors (however, these results are about to be superseded by the cesium experiment at Boulder). The thallium result provides an exacting test of the fundamental electro-weak theory. Fortson and Nagourney have begun extending these techniques to a single atomic ion.

- *Time asymmetry and the search for a permanent atomic EDM* - involving Fortson and Heckel to develop a sensitive experiment to search for a permanent electric dipole moment of the mercury atom, as a way to test time reversal symmetry. They have set the smallest world EDM limit in what has become an ideal probe for evidence of new physics violating time reversal symmetry, including supersymmetric models.

- *Other optical pumping and related experiments-* involving Fortson and Heckel to perform a variety of challenging measurements including the observation of spontaneous spin polarization in cesium vapor, the setting of bounds on the size of nonlinear terms in quantum mechanics and on any coupling of gravity to nuclear spin and the measurement of new linear Stark effect via a change in optical polarization of the rubidium D1 line in the presence of an external electric field. While a member of the group, Lamoreaux (a former research associate professor now at Los Alamos National Lab) made the first measurement[1] that confirms the long standing prediction of the force between two conducting plates (the Casimir Force) due to the zero point EM oscillations in the space between the plates.

- *Neutron experiments* - involving Heckel to use studies of reactor produced neutrons to complement the investigations of parity and time reversal symmetries in atoms. Although neutron physics straddles the boundary between atomic and nuclear

[1] See the *Science* page of the New York Times, January 21, 1997.

physics, the neutron EDM experiment usually fits in atomic physics; other neutron work is described here for convenience, and includes the participation of nuclear physics faculty. Measurements include: the Neutron Electric Dipole Moment Experiment at Grenoble; the Parity Violating Neutron Spin Rotation Experiment with Adelberger and Heckel to measure the parity non-conserving rotation of the spin polarization of a cold neutron beam as it traverses a target of liquid helium; the measurement of the D coefficient in Neutron Beta Decay with Wilkerson and Robertson to measure the time reversal symmetry violating D coefficient in free neutron beta decay.

6.1.C *ASTROPHYICS AND GRAVITATION:*

Ten years ago, it was recognized within the Department that astrophysics was a field of growing importance, intellectual interest, and opportunity. At that time, Wick Haxton was a newly appointed professor whose presence help catalyze the Department's interest in this field. Previously the Department had several, largely disjoint programs in astrophysics including work by Bardeen to perform calculations concerning density fluctuations in the early universe; by Boynton, who holds joint appointment with the Astronomy Department, to study satellite observations of X-ray pulsars, by Adelberger to measure nuclear cross sections of interest to the understanding of solar burning, and by the JACEE group with Lord and Wilkes pursuing balloon measurements of cosmic rays. Since that time, the Department has benefited from strong growth in the field of astrophysics and the development of an experimental gravitation program. This growth has come from the addition of new faculty members and from new research directions undertaken by faculty members already in the Department. The combined efforts in astrophysics and gravitation by both the Physics and Astronomy Departments have made the UW one of the leading institutions in these fields.

In 1990, Hogan, a rising star in the field of astrophysical cosmology, was appointed as a Joint Associate Professor of Physics and Astronomy. He currently is chair of the Astronomy Department. In 1994, three appointments were made that have a strong presence in astrophysics. Stubbs, an experimental cosmologist, was appointed as Joint Associate Professor of Physics and Astronomy. Stubbs subsequently received the 1996 National Academy of Science Award for Initiatives in Research. Hamish Robertson and Wilkerson, who are leading the US effort in the Sudbury Neutrino Observatory, were appointed as Professors of Physics. Currently, the Physics Department is involved in a number of programs that fall under the labels of astrophysics and gravitation. These programs are outlined briefly below.

- *Theory* - involving Bardeen, Haxton and Hogan to pursue calculations on the evolution of large scale structure and clustering in the universe, to study the role of neutrinos in the sun and other stars, and to study the inhomogeneous big bang evolution of the universe (work now referred to as the Applegate/Hogan scenario), respectively. This group provides much of the impetus for the experimental work below.

- *Astrophysics at the INT*- involving Haxton and collaborators to make the Institute for Nuclear Theory a center for the study nuclear astrophysics. Three large workshops devoted to astrophysical issues have been held already, as have four smaller workshops.

- *MACHO* - involving Stubbs as a leader in the MACHO collaboration, whose goal is to detect non-luminous compact matter in the galactic halo through the micro-lensing of star light.

- *SNO* - involving H. Robertson and Wilkerson as leaders of the effort to construct the Sudbury Neutrino Observatory (SNO) where the detector will observe both charged and neutral current neutrino interactions to determine if the "missing" solar electron neutrinos are oscillating into other neutrino flavors.

- *Super Kamiokande* - involving Wilkes and Young working with the Super Kamiokande detector in Japan to study high energy solar neutrinos and atmospheric neutrinos created by cosmic rays, both of which may provide evidence for neutrino flavor oscillations.

- *Primordial Abundance* - involving Hogan and collaborators using the spectra of high redshift quasars to measure the primordial abundance of deuterium in the universe. (This work is described in the Dec. 1996 issue of Scientific American Magazine.)

- *Apache Point*- involving Hogan, Stubbs, and collaborators using the 3.5m telescope at Apache Point to measure the light curves of distant supernovae, yielding the relationship between redshift and brightness at large distances. This relationship will provide a measure of the global deceleration and curvature of the universe.

- *Sloan Digital Sky Survey* - involving the UW group in a consortium (Sloan Digital Sky Survey) to construct a telescope at Apache Point that will use the world's largest CCD array to image a quarter of the sky, providing the first high precision digital multicolor image of over 100 million galaxies.

- *X-ray Pulsars* - involving Boynton to use data from the NASA satellite X-ray Timing Explorer to test accretion flow models for matter falling onto neutron stars by studying the correlations between fluctuations in X-ray luminosity and the angular acceleration of the pulsar SMC X-1.

- *Experimental Nuclear Astrophysics* - involving Adelberger and collaborators at the Nuclear Physics Laboratory in the first measurement of the $^{13}N(p, \gamma)$ cross section that is a key process in the C-N-O cycle of solar burning. The NPL is also measuring the $^{7}Be(p, \gamma)$ cross section, which is the reaction providing the highest energy neutrinos in solar burning.

- *Experimental Gravitation* - involving the two groups of Adelberger and Heckel (EotWash) and Boynton searching for a possible "fifth force". The Boynton group uses a torsion balance with novel pendulum designs to search for a deviation of the $1/r^2$ law at the remote sites of Mt. Index and the Hanford reservation. The Eotwash group has built laboratory based torsion balances with interchangeable test bodies, operated near the hillside of the Nuclear Physics Laboratory demonstrating, for example, that the universality of free fall is valid in the gravitational field of the earth to one part in 10^{12}.

The future of research in astrophysics looks bright in our department. This field provides an area of common interest to many research groups and has already forged additional ties between many of the groups. The projects summarized above will carry us into the foreseeable future. In addition, new projects, such as the formation of a UW user group for the Laser Interferometer Gravitational-wave Observatory (LIGO) (already under discussion), undoubtedly will be undertaken.

6.1.D *EXPERIMENTAL NUCLEAR PHYSICS:*

The primary experimental nuclear physics activities in the Department occur in the Nuclear Physics Laboratory (NPL). The NPL has changed in many ways since the last external review. The most significant of these is the addition of Professors H. Robertson and Wilkerson and Research Professor Doe. Their arrival has given the lab major new roles in solar neutrino physics and weak interactions. The NPL currently supports the research of five Physics Professors, Adelberger, Cramer, Heckel, H. Robertson and Wilkerson, one Chemistry Professor, Vandenbosch, three Research Professors, Doe, Snover and Storm, one Research Associate Professor , Trainor, three Research Assistant Professors, Elliott, Gundlach and Lestone, nine research associates and 14 graduate students. During the last ten years 17 students received their Ph.D. while working at the NPL while 13 students, who did not go on to the Ph.D., received their Masters Degree.

The lab operates a 9 MeV tandem accelerator and a superconducting LINAC booster, and supports faculty research at a number outside facilities, such as CERN, Michigan State, NIST, and SNO. The lab maintains a strong technical staff with excellence in electronics, mechanical instrument construction and software development. The NPL is funded by the DOE with an annual budget of $3.46M. The DOE has told us to expect 2% cost of living increases through 1999. An increasing fraction of the NPL research no longer relies on the local accelerator and it is likely that sometime in the next decade operation of the NPL accelerators will no longer be funded by the DOE. To maintain the rest of its sophisticated experimental program, it will be crucial for the NPL to maintain its technical infrastructure.

The NPL houses the torsion-balance experiments of the EotWash group involving Adelberger and Heckel, Research Assistant Professor Gundlach, a postdoc and 2 graduate students all supported by the NSF.

In this overview, we briefly discuss the major elements of the research program at the NPL.

- *Neutrino Physics* - involving H. Robertson, Wilkerson and Doe in the Sudbury Neutrino Observatory (SNO) project, a 1000-tonne heavy water Cerenkov detector under construction deep underground in northern Ontario, Canada. When construction is completed in 1997, SNO will be the first solar neutrino detector with the capability of detecting neutrinos of all active flavors and distinguishing them from the electron neutrinos produced by thermonuclear reactions in the Sun.

- *Nuclear Astrophysics* - involving many at the NPL to measure the rates of key hydrogen-burning reactions, and on improving the uncertainties in efficiencies of solar-nuclear detectors. This group made the first determination of the $^{13}N(p,\gamma)$ cross section that controls the conditions that trigger the "hot CNO cycle", and the rate of the $^{17}F(p, \gamma)$ reaction involved in the "breakout" of that cycle. The group is now focusing on neutrino physics.

- *Fundamental Symmetries* - focusing on precision studies of weak interactions, in particular on beta decay and parity-violation in the N-N interaction. The ongoing beta decay and associated gamma-ray studies focus on the symmetries of the induced currents (tests of Vector Current Conservation and searches for second class currents in the ^{8}Li, ^{8}Be, and ^{8}B multiplet), on the Lorentz structure of the interaction (study of the β-ν correlation in $0^+ \rightarrow 0^+$ transitions to search for scalar weak processes), and on time reversal invariance (measurement of the D coefficient in neutron decay).

- *Giant Resonances* - focusing on the shapes of highly excited "hot" nuclei over a wide range of excitation energy up to $\approx$100 MeV, angular momentum up to the maximum sustainable by a nucleus, and nuclear species ranging across the periodic table. The experiments used a technique developed at the NPL to look at high energy photons evaporated from hot nuclei. Future studies will concentrate on nuclear properties at excitation energies up to 200 MeV.

- *Heavy Ions* - focusing on the early stages of nuclear dissipation when the projectile velocity is comparable to the Fermi velocity, using both pre-equilibrium n and p emission and high energy photons. Future work will be directed towards establishing time scales associated with nuclear dissipation and projectile-target amalgamation during the fusion, and of shape changes during the nuclear fission process.

- *Cluster Physics* - focusing on the D + D nuclear reaction rate when the projectile is imbedded in a cluster, showing that there is no rate enhancement. Future work will be directed towards understanding fragmentation of collisionally excited buckyballs.

- *Ultra-Relativistic Heavy Ion Physics* - involving Cramer and Trainor and focusing on ultra-relativistic heavy ion physics studying nucleus-nucleus collisions where the kinetic energy greatly exceeds the rest mass-energy. The group participates in experiment NA49 at the CERN SPS and in the STAR detector project that will use the RHIC machine at Brookhaven which should be operational in 1999. The challenge of NA49 and STAR is to demonstrate definitively that a quark-gluon plasma phase was created.

- *Gravitational Physics* - focusing on the use of torsion balances in order to improve tests of the equivalence principle (more precisely of the universality of free fall). These instruments, which have set world records for sensitivity, test the standard theory of gravity and probe for new ultra-feeble interactions that are generically expected to violate the universality of free fall, have shown that a proposed "fifth force" did not exist, ruled out theories that predicted that antiprotons should fall with perceptibly different acceleration than ordinary protons, and provided laboratory evidence that gravitation is the dominant interaction between ordinary matter and galactic dark matter. The next step is an instrument that is expected to give a factor of 10 or more higher sensitivity.

6.1.E *THEORETICAL NUCLEAR PHYSICS:*

Nuclear Theory has long been one of the main strengths of the Physics Department. The group had its origin with Blair, Jacobsohn and Henley beginning in 1955 and later spawned the Particle and Condensed Matter Theory Groups. The most recent offspring is the widely-praised national Institute for Nuclear Theory (INT), which is discussed in more detail below. The funded group members in 1986 were Haxton, Henley, Miller, Puff and Wilets. In 1996 there are Bulgac (1993), Miller and Savage (1996). Although "retired", both Henley and Wilets remain active. While no longer supported by the grant, Puff is still on the faculty. One Research Assistant Professor and two Research Associates are currently supported by the Nuclear Theory Group. The Nuclear Theory Group and the INT are both funded by the DOE but function as distinct financial and administrative units. The three fellows of the INT, Bertsch, Haxton and Kaplan, have faculty appointments and occasionally teach. Bertsch and Kaplan are fully-funded by the INT grant, while Haxton receives special State support as the INT Director.

The Nuclear Theory Group (NTG) has long been known for work that leads to experiments, broadens the horizons of the field and creates new subfields. During the last ten years these efforts included topics in: symmetries, quark and QCD aspects of hadronic, nucleon and nuclear physics, nuclear structure theory and cluster physics. The UW nuclear physics effort has been ranked as second in the country behind only MIT[2]. In the last ten years the NTG has produced 19 Ph.D.s and supported the research of 23 research associates and 4 research assistant professors. Fourteen of these are now hold faculty or laboratory staff positions at other institutions. The NTG plays a strong role in the Department, with highly productive interactions with the other theoretical and experimental groups.

The funding of this group has increased from $516,000 in FY86 to a level between $620,000 and $640,000 for FY97 (details still in discussion)

[2] US News & World Report, March 18, 1996, see (http://www.usnews.com/usnews/ fair/gbphyspe.htm).

The NTG members have consistently been at the intellectual forefront of the field and have held leadership roles in the national and international community including President of the APS and President of the Division of Nuclear Physics. All tenured members of the group have been elected as fellows of the APS and AAAS.

The research of Bulgac focuses on two primary areas. The first area is nuclear many-body theory. Issues studied include the determination of a systematic surface contribution to the ground state binding energies, the discovery of an unexpected character of the momentum distribution (a nonsphericity of the Fermi surface) and the proposal of experiments to measure the effect, the development of a coherent theoretical model to describe dissipation on a microscopic level and its application to a series of generic problems, the observation of the emergence of chaotic behavior and other features in the dynamics of many-body systems beyond the adiabatic approximation. The second area is Atomic cluster physics. Bulgac has performed exhaustive studies of the properties and excitation mechanisms of electronic collective states in buckyballs, the character of phase transitions in small metallic clusters, and the temperature dependence of the electronic properties and the character of collective states. He has also suggested various experiments to study phase transitions and temperature effects, and has developed a nontrivial generalization of the local density approximation and a generalization of molecular dynamics formalism.

The theme of the work by Henley can be characterized as the study of symmetries and (non)conservation relations. He has proposed experiments to obtain the parameters of the underlying theory of parity non-conservation and the electro-weak theory. He has estimated the magnitude of the expected "anapole moment" and suggested ways to determine it experimentally. He has studied the issue of time reversal invariance (CP) through suggested experiments, a calculation of the neutron electric dipole moment with QCD sum rules and the decays of the neutral B mesons. He has also applied the QCD sum rules to the calculation of the weak axial coupling constant and changes of hadronic properties in a nuclear medium. Henley has explored flavor asymmetries in the nucleon and strange baryons, especially strangeness in the nucleon, and developed possible experiments to determine them. On the question of charge asymmetries, he has employed QCD sum rules to determine meson mixing and meson-nucleon couplings, studied mass differences of baryons and suggested tests of charge symmetry in the structures of nucleon. He has also studied the annihilation of antinucleons into mesons and baryons, calculating the ratios of various modes, angular and energy dependence, and various polarization and depolarization levels.

The research work of Miller involves several topics including color transparency, quark nuclear physics and fundamental symmetries. 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 compute the nuclear consequences of this effect. He also suggested diverse experiments to test this idea and originated the related concept of chiral transparency which refers to pionic interactions. In the field of quark nuclear physics Miller has used quark ideas to stimulate experiments on pion nucleus interactions. He developed a theory of nuclear deep inelastic scattering, including binding effects and correlations; and invented a new relativistic treatment of nuclei applicable to these and other high momentum transfer experiments. He also used the strong coupling limit of QCD to reproduce the central features of nuclear physics. In his studies of fundamental symmetries Miller predicted parity violation effects in nucleon-nucleon scattering. He has also predicted, suggested and explained experiments which discovered charge symmetry violation in neutron-proton scattering. He studied the role of light quark mass differences in nuclear physics and estimated effects of CP violation in Lambda decay. He has also examined the consequences of chiral symmetry in proton-proton interactions.

The research interests of Savage lie in the phenomenology of the standard model of strong and electro-weak interactions. Dealing with non-perturbative hadronic structure in the regime of nuclear physics and in heavy quark systems has been a central focus. He has ongoing interests in the role that the strange quark plays in the structure of nucleon. Two particular areas of activity are the contributions of the strange quark to nuclear parity violation and the spin content of the nucleon. With collaborators Savage has made recent progress in efforts to describe the interactions between nucleons with the goal of developing a better understanding of nuclear matter and nuclei using effective field theories, as pioneered by Weinberg. In addition, the large N limit of QCD has been utilized to understand the symmetries of the nucleon interaction. The structure and decay of systems containing heavy quarks has been the other focus of his activities. Inclusive decays of heavy hadrons allow extraction of the weak mixing angle between b and c quarks with accuracy comparable to that obtainable with exclusive decays. Savage has been involved in the determination of higher order perturbative QCD contributions, in understanding the limitations of the inclusive formalism, and also the role of renormalons in effective field theories. The spectroscopy of hadrons with b and c quarks has flourished recently producing large amounts of experimental data and Savage has been active in using the symmetries of QCD to understand the observations. Savage has recently co-covened (with M. Procario from CMU) the working group on heavy baryons for the C0 detector planned at Fermilab for the next decade.

The research interests of Wilets also span a variety of topics. He has developed a wave equation for a composite particle (nucleon) and studied the role of ghost poles in the nucleon propagator. He has formulated a chirally invariant chromo-dielectric soliton model applied it to the problems of spatial and color confinement, hadrons, the six-quark N-N interaction, and the charge structure of He. Wilets has studied the question of the collapse of color flux tubes. He has compared the structure of proton-antiproton to Lambda-antiLambda collisions. He has studied quarks sea excitations, including strangeness, for the nucleon. He has applied the formalism of quantum molecular dynamics to the problems of the proton stopping power and atomic capture of antiprotons on He. He has looked at the question of the shielding of nuclei in a finite temperature electron plasma, with application to fusion. Finally he has worked on the general problem of parity non-conservation effects in nuclei.

The future work of the group will continue to be driven, in large measure, by the investments in nuclear physics accelerators and instrumentation now being made in the U.S. The vital tasks of interpreting and using the new data, exploiting their implications, and suggesting new experiments are the purview of the nuclear theorist. Two major new accelerators are The Thomas Jefferson National Accelerator Facility (TJNAF), already in operation, and the Relativistic Heavy Ion Collider (RHIC) at Brookhaven Laboratory that will soon be in operation. TJNAF provides an electron "microscope" for studying the nucleus with unprecedented resolving power at very short distance scales. The aim is to study the transition region in which the conventional model, where a nucleus is made up of interacting neutrons and protons, gives way to a more fundamental model, where those objects are made up of quarks and gluons. RHIC is aimed at studying a new nuclear regime of high nuclear temperature and pressure in which quarks and gluons will be free to move independently over relatively large distances, forming a "quark-gluon plasma". The quark-gluon plasma may exist in the core of neutron stars, and it may have existed during the first millionth of a second after the Big Bang.

6.1.F *INSTITUTE OF NUCLEAR THEORY:*

While not formally part of the Department, the Institute plays such an important role in the intellectual life of the Department that it seems more than appropriate to include a section describing the INT in this Review.

The national Institute for Nuclear Theory was established at the University of Washington on March 1, 1990, following a recommendation of the Nuclear Science Advisory Committee (NSAC) and a competition judged by a DOE appointed selection committee. The initial funding was for $0.6M, with ramps of about $0.3M/y to full funding of about 1.77 M. This goal has almost been reached ($1.70M), despite DOE funding problems. In addition, the University provides space and other major continuing support, including the salary of the Director. The space in the new building consists of 22 offices, a seminar and conference room.

The "mission" of the INT is to create a research environment which encourages innovative work; to encourage interdisciplinary work at the intersection of nuclear physics with related disciplines; to nurture young people so as to optimize their creativity and ability to contribute to the field; to contribute to scientific education; and to strengthen international cooperation in nuclear theory.

The INT is run by a director who is advised by a National (actually international) Advisory Committee (NAC) composed of members who represent the various segments of the nuclear physics community, including intersections with related fields (*e.g.*, astrophysics, particle physics). The NAC helps determine future programs and workshops of the INT. There are close relationships with the Department of Physics and particularly with the nuclear theory group (NTG). The INT has been an important asset to individual researchers in both the Physics and Astronomy Departments, as well as to the Departments themselves. Several faculty members have co-organized programs, spent time at the INT, and many Department members have participated in INT programs.

At present, the INT has reached its full complement. In addition to the Director (Haxton) there are two senior members (Bertsch and Kaplan) who have tenure in the Department. The INT also has two 5-year Fellows (research assistant professors in the Department, currently Frank and Musolf) and 3 to 4 postdoctoral research associates. There are often visiting research fellows from Europe or elsewhere. From its inception, the emphasis of the INT has been on young physicists. The senior members of the INT participate in all departmental activities, teach courses from time-to-time, and supervise graduate students. Two of these have received Ph.D.s.

The INT runs three programs/year of 2-3 months duration; typically, they bring together 15-20 visitors (at any given time) to work on forefront topics in nuclear theory. For instance during the past year there were programs on "Quark and Gluon Structure of Nucleons and Nuclei", "Nucleosynthesis in the Big Bang, Stars and Supernovae", and "Ultrarelativistic Nuclei: From Structure Functions to the Quark-Gluon Plasma". Topics are proposed by the nuclear physics community and selected by the Director on the advice of the NAC. The INT also organizes about two short (4-10 days) workshops/ year. On a fairly regular basis one of these is with TJNT (CEBAF) and one with RHIC, in alternate years. The INT has an administrator and two program coordinators who work with the organizers.

The INT has succeeded in its goal of attracting and recruiting to the University the best senior and junior researchers in nuclear theory, a feat that would not have been possible without it. It also attracts some of the best postdoctoral research associates in nuclear theory in the U.S. This success has enhanced the University's status in physics and physics education and has made it a desirable place for visitors to spend their leaves or sabbaticals. The INT has also provided students, postdoctoral research associates and faculty with opportunities for study, research, and contacts with outstanding world-wide physicists.

6.1.G *EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS:*

The research of the high energy elementary particle research group has been directed mainly toward studies of fundamental interactions and particle astrophysics. The group includes six teaching faculty, Burnett, Chaloupka, Cook, Lubatti, Rothberg and Young, three Research Professors, Mockett, Wilkes and Zhao, one Research Assistant Professor, Wasserbaech, five staff members and 7 graduate students, in addition to several part time student employees and undergraduate assistants. The two major lines of research pursued by the group are characterized by the of sources of high energy particles used in the research: high energy accelerators and astrophysical sources.

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 which can lead to publications needed by young researchers, and thesis topics for graduate students; and second, preparation for the "next" major experiment involving detector development and experimental design. This provides opportunities for students to participate in all phases of a modern high energy experiment without requiring that they spend 10 years or more to complete their research.

The projects listed below illustrate this experimental plan.

Accelerator Research:

In the past ten years, the major efforts have been :

- *SLD at SLAC* - using the colliding beams of electrons and positrons produced by the SLC (Single pass Linear Collider) at SLAC to study physics at the Z° mass. It addresses the same physics as the experiments at LEP (CERN), but with polarized electrons and with a much smaller interaction region than is available at LEP. Three students have earned Ph.D.'s based on this data and a fourth is currently writing his thesis.

- *E-777* (Search for $K^+ \rightarrow \mu^+\pi^+e^-$) at Brookhaven National Laboratory where the UW designed and built a system of 4 large multicell Cerenkov counters. The experiment resulted in an improved upper limit for the K^+ decay, and the first measurement of the rare decay $\pi^0 \rightarrow e^+ e^-$. Five papers were published in refereed journals, and there was one UW Ph.D. thesis.

- *E-665* (Deep Inelastic Muon Scattering) at Fermilab and designed to study deep inelastic muon scattering with the world's highest energy muon beam (500 GeV) until the experiment ended in 1992. The University of Washington group provided a significant fraction of the E665 spectrometer: There have been over 20 publications in refereed journals resulting from the 87-88 and 91-92 runs. At the University of Washington, five Ph.D. thesis will have been completed by the end of the current academic year.

- *BES* at Beijing where the group has been a charter member since 1990. We were initially involved only with data analysis and then joined in planning an upgrade to the detector. These tasks have been accomplished and the BES experiment has been taking data at close to full intensity since May. In addition to the world's best measurement of the tau-lepton mass, recent results on J/Psi radiative decays strongly suggest that observed peaks in the $\pi^\circ \pi^\circ$ spectrum are the long sought for vector glueballs.

- *EMU01* has studied multiparticle production in relativistic heavy-ion collisions using nuclear emulsion techniques since the first CERN nucleus beams became available in 1986, and has an impressive record of publication in this field. Two students received Ph.D.s based on work on this project. Following a recent exposure (11/96), no further data-taking runs are planned, but analysis based on previously acquired data will continue.

- *ALEPH at CERN* using the 45 GeV electron-positron collider (LEP) at CERN to produce and study the intermediate vector bosons Z°. The Z° 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 electro-weak interactions. This last year (1996) the collider (now called LEP2) is running in a new energy regime never before accessible to electron-positron physics. Charged intermediate vector bosons (W) are being produced and the searches for supersymmetry are being pushed to higher limits. One student was awarded the Ph.D. in 1994 and one MS degree student finished his project at about the same time. Two students are currently working on Ph.D. dissertations.

- *ATLAS* at CERN (LHC) (and preparation for SSC in the US which led to involvement in ATLAS) which provides a unique opportunity to explore the mass-energy region of 1 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. The US ATLAS group, of which our group is a member, presently consists of scientists and engineers from 27 US universities and 3 national laboratories. The group's work on the ATLAS muon spectrometer work builds on past efforts on muon detector development for the Fermilab deep-inelastic muon scattering experiment (E665) and for the SDC detector at the SSC. The design chosen for the SDC muon detector was the one proposed by the group. During the design and development of the SDC muon system, the group developed a very close working relationship with Profs. C. Daly and P. Reinhall of the University of Washington Mechanical Engineering Department. Lubatti is the co-coordinator of the Precision Chamber Group of the ATLAS Muon Spectrometer subsystem and co-coordinator of the U.S.ATLAS Muon Group while Mockett is the ATLAS coordinator for Muon Detector Control Systems. Chaloupka has sole responsibility for the ATLAS Muon System data base.

Particle Astrophysics:

This work has focused on three major efforts:

- *SUPER-KAMIOKANDE:* "SUPER-K" is a 50 kT water Cerenkov detector located 1000m underground near Toyama, Japan. In addition to observing the flux and spectral shape of solar neutrinos with unprecedented statistical weight, SuperK will observe atmospheric and astrophysical neutrinos, underground muon fluxes, maintain a supernova watch, and search for nucleon decays. The experiment was formally commissioned April 1, 1996 and has been taking data continuously ever since. Our group is active in solar neutrino flux measurement, atmospheric neutrino flux measurement and upward-going (astrophysical neutrino-induced) muon analysis. Two graduate students are doing thesis research on this project.

- *DUMAND (Deep Underwater Muon and Neutrino Detector)* - took the first steps in the new field of high energy (>GeV) neutrino astrophysics. The UW group successfully designed and constructed underwater environmental monitoring and acoustical subsystems for DUMAND, including a novel design for an acoustical locating system for which a patent was issued in 1995. The initial deployment operation in 1993 succeeded in laying a shore cable and testing underwater components, but long term data taking was not possible due to loss of funding.

- *JACEE* (Japanese-American Cooperative Emulsion Experiment) - an ongoing US-Japan collaboration directed to the study of the fluxes and interactions of ultra-high energy primary cosmic ray protons and nuclei. The collaboration has been very successful in extending the range of directly-measured cosmic ray fluxes. For the composition up toward the "knee" in the spectrum around 1015 eV, and at present, in the 1-10.0 TeV range, the JACEE measurements are the standard reference. One of our group (Wilkes) serves as US Spokesman for the collaboration. Two students have received Ph.D.s for work on this project and a third student is nearing completion.

In the coming decade a strong concentration of effort will focus on preparation and the start of data-taking at LHC/ATLAS in 2005. During the next three years SLD will be completed and additional faculty will participate in ALEPH. This shift ties in well with more intense preparations and beam tests for the ATLAS muon system. Graduate students will be able to write dissertations on physics analysis topics using ALEPH data and will gain important detector hardware experience by working part of the time on ATLAS detector and simulation problems.

6.1.H *THEORETICAL ELEMENTARY PARTICLE PHYSICS:*

The particle theory group currently consists of seven regular faculty members, Baker, L. Brown, Boulware, Ellis, Nelson, Sharpe and Yaffe, a Research Assistant Professor, Arnold, two post-doctoral fellows, four graduate students engaged in thesis research, and five other graduate students currently involved with reading courses that may lead to their completing a thesis in the group. The group has been supported by the U. S. Department of Energy since 1978, and this agency currently provides annual support of $575,000. The primary research interests of the group involve exploring fundamental and unusual aspects of quantum field theory, together with an ongoing tradition of theoretical work which is directly motivated by, or applicable to, current experiment. A concise description of the research activities of the group during the last decade is presented below.

The faculty of the group has an outstanding record of accomplishment and the group has been able to attract a high caliber of research assistant professors and post-doctoral fellows. Of the 18 young Ph.D.s supported in such positions during the last ten years 14 have moved on to academic positions elsewhere, 9 are in faculty positions, 3 work at research laboratories and 2 have pursues academics careers in related fields. The particle theory group is quite selective in accepting new Ph.D. students, and typically accepts only one or two new students each year. Even with the current difficult job market, our graduating students have a good record of obtaining suitable post-graduate jobs. Of the 12 students who received Ph.D. degrees in the last ten years, 6 are still pursuing academic careers, 1 is at a federal research laboratory, 4 have taken positions in industry and the whereabouts of the twelfth is currently unknown.

Although all members of the group participate in the teaching efforts of the department at all levels, it should be noted that a substantial fraction of the basic graduate classes are taught by group members. This is a natural outcome of the broad research interests of the group in fundamental physics issues. Graduate student teaching is often enriched by previous research experience, as is illustrated by the publication of a book on Quantum Field Theory (Brown) which has become a widely used text. The weekly journal club organized by the particle theory group has, during the past few years, evolved into an informal "topics in field theory" class which consistently attracts a large and highly interdisciplinary audience. Postdoctoral fellows of the group have participated in the teaching activities of the department both at the graduate and undergraduate level.

Members of the group have participated in the activities of other groups in the Physics Department, and they have contributed nationally. There is a long history of collaboration with the experimental atomic physics group that has resulted in many published papers, several of which were written jointly with the experimentalists (Boulware, Brown). At the national level, group members are, or have been, involved in the program committees of national laboratories and physics centers (Boulware, Brown, Ellis, Nelson), and in the editorship of the major US particle physics journal (Brown).

Representative contributions from the past decade's work on field theory include:

- Calculations of electro-weak phase transition properties through two-loop renormalization group improved perturbation theory (Arnold), and next-to-leading order expansions (Arnold, Yaffe)

- Clarification of several aspects of the outstanding problem of baryon violation in high-energy collisions (Arnold, Brown, Yaffe).

- Studies of the viability of electro-weak baryogenesis in minimal extensions of the standard model (Nelson).

- Novel mechanisms for dynamical supersymmetry breaking (Nelson).

- Characterization of the constraints on the asymptotic behavior of perturbation theory generated by renormalization group invariance and analyticity (Brown, Yaffe).

- Studies of the pathologies of interacting quantum field theory on spacetime manifolds with closed timelike curves (Boulware).

- Characterization of the spectrum of cosmological density perturbations produced by unusual models of inflation (Bardeen).

- First-principles derivation of hydrodynamic response and effective kinetic theory in high temperature relativistic field theory (Yaffe).

Recent examples of work directly connected with experiment include:

- Analysis of the effects of Coulombic final state interactions on the shape of the tritium beta decay spectrum near the endpoint (Brown).

- Detailed perturbative QCD predictions of features of quark and gluon jets produced in high energy proton-antiproton and electron-positron collisions (Ellis).

- *Ab-initio* calculations of weak matrix elements *(B_K, ...)* using numerical simulations in lattice QCD (Sharpe).

- Determining consequences of electric-magnetic duality for the long-distance heavy quark interaction (Baker).

6.1.I *EXPERIMENTAL CONDENSED MATTER*

The experimental condensed matter group currently has nine active faculty members, F. Brown, Dash (emeritus), Fain, Ingalls, Olmstead, Seidler, Sorensen, Stern, and Vilches, plus three research associates. Within the Department the experimental group benefits from, and in some cases strongly depends on and collaborates with, the theoretical condensed matter faculty. The experimental group has an extended presence on campus through the appointment of adjunct physics faculty, which includes T. Engel and C. Campbell from Chemistry, V. Vogel from Bioengineering, T. Pearsall from Materials Science and Engineering, and M. Baker from Atmospheric Sciences. Through this extended group, graduate students obtain Physics degrees by taking the required graduate physics classes, the Department qualifying examination, and their general and final examinations with collaborative committees. The enlarged group participates in the regular condensed matter seminar as well as special topical seminars on ice properties, surfaces and interfaces, and very recently nanostructures/nanoscience. The CM experimental group has been an active participant (in recent times through Sorensen, Fain and Ingalls) in the evening MS program.

Faculty changes in the last 10 years have been the retirement (due to then existing regulations) of Greg Dash and the addition of Marjorie Olmstead (from Berkeley) and Jerry Seidler (from NEC at Princeton). Dash has remained extremely active as described below. Fred Brown retired from U. of Illinois and moved to our Department, where he is a professor (without salary). He has been very active and one of the principal organizers of a research team (CAT) designing and building a beamline at the Advanced Photon Source (APS) at Argonne National Laboratory.

At present there are 17 graduate students doing their doctoral work in the physics group, and an additional 5 working with the adjunct faculty. In the last 10 years, 37 UW, 2 Illinois, and 2 Berkeley students have received their Ph.D. guided by the Department faculty. A number of undergraduates routinely do independent study with members of the group, and for the last two years, very good undergraduates from around the country have been in the experimental groups which participate in the NSF funded REU program during the Summer quarter.

A brief summary of research activities in the group follows.

- *Advanced Photon Source* (at the Argonne National Laboratory) - involving F. Brown and Stern to develop a beamline (PNC-CAT) that will allow pioneering research with this intense new X-ray source. New possibilities include using the coherence of the x-rays to image by phase contrast, holography, and speckle contrast. The brightness of the source will allow the development of an x-ray microscope with analytical capabilities, in addition to imaging capabilities. The facility will be in initial operation by mid-1997. Olmstead, Sorensen, Ingalls and Seidler are also actively involved in the facility. (Seidler's position was part of the UW contribution to this initiative.) Outside participants are from Simon Fraser University in Burnaby, BC, Canada, and Pacific Northwest National Laboratory in Richland, WA.

- *Interfacial Melting and Ice Studies* - involving Dash and, most recently Fain in the study of interfacial melting in one, two, and three dimensions. Starting with studies the melting of multilayer Ar and Kr films, interest has now moved to the melting properties of ice under all types of conditions. Members of this group come from the Geology and Atmospheric Science Departments, the Quaternary Research Center, and the Applied Physics Laboratory. Dash's laboratory has been transformed from a traditional low temperature one to a lab dedicated to the study of environmental and carefully grown crystals of ice using a variety of techniques. Extensive contacts with companies involved in environmental remediation fuels and funds part of the research. Fain's interest led to the development of an atomic force microscope facility dedicated to the study of surface melted layers of ice.

- *Physisorbed Films* - involving Fain in the study by low energy electron diffraction (LEED) of physisorbed films. In particular, solid commensurate and incommensurate structures of oxygen, hydrogen, and deuterium were studied, and the effects of electron induced desorption and breakup of hydrogen, deuterium and deuterium hydride were quantified using time-of-flight spectroscopy.

- *Materials at High Pressure* - involving Ingalls in the study of the behavior of materials subjected to high pressure. The main probe was (and is) EXAFS, the work being carried out at the SSRL and NSLS synchrotron facilities. The particular topics addressed include a study of bond angle determination by XAFS using the separable spherical wave approximation, EXAFS experiments at high pressure with small samples, and high pressure studies of iron hydride, iron silicate spinel and sodium nitroprusside.

- *Semiconductors and Semiconductor/insulator Interfaces* - involving Olmstead in research aimed at obtaining atomic level understanding of both the mechanisms of thin film growth and the unique properties of the resultant heterostructures. Given the large interest in interface phenomena, the addition of her laboratory has had a major impact in the breath of topics addressed by the group and in strengthening ties to the chemistry and engineering community.

- *X-ray scattering and DAFS* (diffraction absorption fine structure) - involving Sorensen in the study of surfaces and other systems using X-rays. Sorensen invented the technique now known as DAFS. He demonstrated the existence of an ordered water layer at the surface of electrified interfaces, performed the first successful underwater X-ray crystallography experiment, studied electrochemically deposited monolayers, discovered layer-by-layer surface freezing in liquid crystal films, and, in an experimental-theoretical work which produced three student dissertations, studied layer fluctuations in liquid crystals.

- *Local Structure in Systems With and Without Long Range Order* - involving Stern in studies the mechanism of phase transitions through measurements of local structure. Since interatomic interactions in most cases are short range, a quantitative and even qualitative understanding of how they cause phase transitions requires knowledge of the atomic arrangement of atoms on a local scale. Research by Stern's group has shown that to a surprising extent the local structure is different than the average structure as determined by diffraction. Most of the experimental measurements are done at national synchrotron facilities, with all data analysis done in-house.

- *Films of Quantum Monolayers* - involving Vilches and Dash in the study of ^{3}He, ^{4}He, H_2, D_2, and HD films using a variety of techniques: heat capacity and adsorption isotherms in Seattle, and elastic and quasielastic neutron scattering in collaboration with the group of Michel Bienfait at Luminy, France. Highlights of the research in the last ten years have been the observation of the lowest freezing temperature for a hydrogen monolayer (at 5.74° K) when adsorbed on deuterium plated graphite, and the liquid-vapor coexistence boundary for two-dimensional ^{4}He adsorbed on hydrogen plated graphite.

6.1.J *THEORETICAL CONDENSED MATTER*

The Condensed Matter Theory (CMT) Group has undergone significant change in the last ten years. It has seen the addition of Spivak, and the resignation of Riedel. It now includes five faculty members, den Nijs, Rehr, Schick, Spivak and Thouless. A major change consists in the increased diversity in the interests of the group. In the previous ten year period from 1976 to 1986, critical phenomena and development and application of the renormalization group dominated condensed matter physics. Two-dimensional systems played a special role because the number of interesting universality classes was far larger than in three, and physical realizations of these classes were many. Hence most of the CMT group were working on similar problems, and interacting very strongly with each other and with our experimental colleagues. No single problem has dominated condensed matter theory during the period 1986-96 as had critical phenomena in the preceding ten year period. Consequently, the interests of the group are now far broader than they were previously. The group continues to collaborate with its experimental colleagues and with others outside of the Department. Schick, Spivak, and Thouless are all members of the Nanostructures initiative submitted to the University Initiatives Fund program.

The subject of den Nijs' work is probably the most closely related to our previous interests in critical phenomena and surfaces. To this field he introduced the concept of pre-roughening transitions and of disordered flat phases in crystal surfaces. Using the knowledge of the interrelationships between various physical models for which he is famous, he connected the disordered flat phase to the ground state properties of quantum spin chains, and thus introduced the string order parameter of the so-called Haldane phase. Most recently, he connected the equilibrium models of the *thermodynamics* of crystal surfaces with the Kardar-Parisi-Zhang model of the *dynamics* of growing surfaces. This is part of his current interest in the scaling properties of dynamic processes in 1+1 dimensions. He is supported by an individual grant from the NSF which recently awarded him a special extension for excellence.

The behavior of two-dimensional electron systems has been the subject of much of Thouless' work during this period, particularly the explication of the quantum Hall effect. This has led to a renewed interest in topological quantum numbers in general, a subject on which he is currently preparing a book, and on the motion of vortices in superconductors and superfluids. During this last ten-year period, he was honored with membership in the National Academy of Sciences, the award of the Wolf Prize, and the Paul Dirac Medal of the Institute of Physics. He is supported by an individual NSF grant.

Spivak's work on mesoscopic physics has focused on the behavior of electrons in disordered metals and superconductors. The interests of Spivak and Thouless are probably closer than that of any other two persons in the CMT group, and their interaction has certainly been beneficial, enlivening particularly our seminar series. He was awarded the Hewlett-Packard Prize by the European Physical Society, the Landau-Weizmann prize by the State of Israel, and a Senior Research Fellowship by the Humboldt Foundation. He is supported by an individual research grant from the NSF.

Rehr's work has centered on electronic structure theory, and reflects the Department's strength in X-ray (Stern, Sorensen and Ingalls) and electron spectroscopies (Olmstead). This strength was spurred partly by the pioneering development of the XAFS technique by Stern. Rehr has vastly increased the utility of these spectroscopies by devising new algorithms for calculations of multiple scattering and self-energies in condensed matter. These have been incorporated into a computer code that yields simulations of various X-ray spectroscopies and permits reliable local structure determinations. The code has been licensed by the UW Office of Technology Transfer, and is in use worldwide. He is a Consulting Professor at the Stanford Synchrotron Radiation Laboratory, and Affiliate Staff Scientist at Pacific Northwest National Laboratory. His work is supported by grants from the DOE and NIH.

Previous interest in surfaces and interfaces led Schick to the study of complex fluids, which contain an extensive amount of interface, and to the components of such fluids, such as self-assembling systems of small amphiphilic molecules. This work was summarized in a book with Gerhard Gompper, "Self-Assembling Amphiphilic Systems", written while visiting the University of Munich as a Humboldt Senior Research Fellow. Diblock copolymers and phospholipids are also self assembling, and research on them has led to interactions with the materials science and biological communities. In the summer of 1996 he was co-organizer of the workshop on "Proteins, Membranes, and their Interactions" at the International Center for Theoretical Physics in Trieste. He is supported by an individual NSF grant.

The group retains its previous strength and visibility. In the past ten years eleven students have received Ph.D. degrees while working in the group. Seven more are expected to graduate during the current academic year. Of the eleven who have already received their degrees, nine are employed in work directly related to physics. There have been many post doctoral fellows, several bringing their support with them, and numerous visitors, all enriching the environment of the Department. As a consequence of its greater range of interests, there is less interaction within the group, and between it and our experimental colleagues. However, there is a greater breadth of opportunities for graduate study within it.

6.2 Interactions with Other Academic Units:

As outlined in Section 6.1 many of the research groups directly benefit from their close interactions with faculty in other University units. This is especially true of the relationship with Mechanical Engineering for particle experiment and the collaborations by the condensed matter faculty with members of the Departments of Chemistry, Bioengineering, Materials Science and Atmospheric Science. We also feel that the opportunities for our students to obtain degrees in Physics by pursuing research in the allied fields represented in our Adjunct Faculty adds substantially to our graduate program. Overall we are pleased to be part of a large community of scholars and attempt to make good use of it.

6.3 Private Sector and Government Interactions:

The condensed matter experimental faculty have attempted to regularly make use of funding support from sources other than the usual Federal agencies (DOE, NSF and

NASA). Olmstead has benefited from steady funding from the Japanese New Energy Development Organization while Sorensen has made use of several small grants from commercial firms. While the latter are certainly helpful, they suffer from being small and of short duration. These features do not blend well with an ongoing research program. Both Sorensen and the INT have benefited from a one-time start-up grants from the Murdock Charitable Trust. Since such start-up funds for equipment and other one-time charges are always in short supply at the University, these special allocations can play an extremely important role in getting a program started effectively and are much appreciated.

Under the leadership of Stubbs and Hogan, our astrophysics research has recently benefited from support from the Seaver Foundation, Hewlett-Packard and the Murdock Charitable Trust.

One faculty member, Dash, has recently participated in a private consulting agreement with a commercial firm, the Scientific Ecology Group (SEG) at the same time that SEG had a research contract directly with the Department (again involving Dash).

6 4 Funding:

As noted at the beginning of Sec. VI, Federal funding for research in this Department has been solid during the last ten years (see Figure VI-1 and 2 and Appendix A). The level of growth has generally matched the operations needs of the various research groups. The special initiatives in astrophysics and physics education have been achieved with adequate Federal support. Our major concern is due to the apparently changing funding climate in Washington, DC. While both the NSF and the DOE are facing flat budgets, the DOE, on which we are especially dependent, seems to be under specific attack. We are particularly concerned about being able to provide continuing support for our senior research faculty, who are essential to the efforts in both particle and nuclear experiment.

Internal funding for research activities took a major step forward with the appearance of the so-called "75" (or Research Support Allocation) budgets just at the time of the last report. This money is intended for the support of research and has been particularly useful within the Department. We now receive approximately $200 K per year in this way. Of this amount about 30% goes directly to the grants (prorated on their own levels of activity) and the rest is used for Departmental initiatives. One example is Departmental support of the Advanced Photon Source initiative of Stern. It is also used in matching fund scenarios but only for small amounts. For the last two years the Department has benefited from being able to spend the remainder of the new building fund to outfit its shop and laboratories (both research and instructional). This fund has also allowed the Department to provide for the bulk of the start-up costs of H. Robertson, Seidler, Stubbs and Wilkerson. This pleasant situation is now ending and future experimental hires may face a serious problem finding University support for start-up costs.

6.5 Research Development:

Since this Department is characterized by effective internal communication and is well connected to the outside, both other units on the UW campus and physics departments elsewhere, being aware of exciting new research opportunities has not been a problem. The recruitment of H. Robertson, Stubbs and Wilkerson constitutes an example of our awareness of the future possibilities in two areas of astrophysics. We were able to use the special opportunity afforded by the new building and its buildings fund to provide and equip the required lab space. We used our "time-honored" mortgage scenario to secure (future) faculty positions. However, the special opportunities offered by the new building and the building fund will not reappear for a long time. Likewise our ability to mortgage a position was dependent on having an existing research program in an allied field to help generate the interim salary support. Our ability to pursue future research initiatives in truly innovative directions will require much more creativity.

VII. SERVICE

7.1 University and Professional Services:

Members of the Physics faculty are quite visible in campus-wide service activities. For example, Mark McDermott, the previous Chair of the Department, is currently vice-chair of the Faculty Senate and will be Chair of the Senate next year. There are invariably faculty Senators from Physics and typically Chairs of Senate Councils (*e.g.*, Boulware on the Retirement and Faculty Affairs Councils and Ellis on the Research Council). Physics faculty regularly serve on the Councils of both the College and the Graduate School and on various Search and Evaluation Committees. For three years one Research Faculty member (Wilkes) has been giving lectures on laboratory safety at the annual EH&S seminar for new graduate students. Another faculty member (Henley) serves on the Meany Hall Board.

Beyond the campus, Physics faculty have served on Laboratory Advisory and Review Committees for institutions such as Los Alamos National Laboratory (L. Brown), Fermilab (Ellis) and Lawrence Berkeley Laboratory (Heckel). They have served as editors for Physical Review D (L. Brown) and the Reviews of Modern Physics (Bertsch) and as Associate Editors for the Physical Review Letters (Boulware, Ellis and Sharpe). They serve on steering committees for the American Physical Society, especially on issue of physics education (L. McDermott) and a vast number of organizing committees for specific physics symposia in a large range of specialties. Again no attempt will be made to supply a complete listing of Professional service activities but more details appear in the individual faculty CVs.

In summary, we feel that the faculty of this Department supply at least their fair share of the service needs of both the University and their professional communities.

7.2 Community Service:

The number of opportunities for a physicist to use his/her special knowledge in support of community service seems to be limited. The faculty of the Department are regular speakers in the local schools and occasionally speak to local industry (as H. Robertson did recently at Allied Signal Corp.) but we keep no detailed record of these activities.

7.3 Continuing Education:

The Department offers the Introductory College Physics sequence (Phys. 114, 115, 116) through the Continuing Education Program. The course is taught by a specially appointed faculty member in the early evening. In addition, the Department offers the MS in Applications of Physics program in the evening, which includes many inservice teachers as students.

The Physics Education Group conducts a six-week institute in physics and physical science for up to 40 inservice teachers each summer and a weekly continuation course of that program throughout the academic year.

7.4. Consulting:

Regular consulting arrangements with commercial entities are rare for the faculty in Physics but they do occur, as noted briefly in Section 6.3 in the case of Dash. A much more common scenario are consulting arrangements with government laboratories or other government bodies. For example, L. Brown often consults on various problems at Los Alamos National Laboratory and Fortson consults for the Department of Defense through the committee known as JASON. It is also not uncommon for the more work intensive advisory boards noted in Section 7.1 to be a consulting situation with at least a small honoraria involved. An example is the work of Ellis on the Fermilab Physics Advisory Committee.

One of the most extensive academic consulting programs in the Department is that of L. McDermott. In recent years, she has consulted on education issues for many different institutions. She is on the External Advisory Committee for the Physics Department at the Colorado School of Mines and has been on external review committees for the Physics Departments at the University of Maryland and at the University of California at Irvine. She has also served on the external review committee for the Department of Science Teaching at the Weizmann Insitutute in Israel. She is a frequent consultant on teacher preparation in the sciences and mathematics. She is currently on advisory boards for projects at Harvard, the University of Arizona, the University of Michigan-Flint, and Michigan State University. McDermott is also on advisory committees for undergraduate biology education at City University of New York and for precollege mathematics education at the University of California at Davis.

VIII. EVALUATION

8.1 Faculty:

Faculty are required to have at least one student evaluation of their teaching per year as part of their record. They are, in fact, encouraged to have every course evaluated every quarter. While for many years a Department developed form was used for the student evaluation, since Spring 1996 the official University of Washington student evaluation forms has been used. Additional evaluation is done by the Instructional Quality Committee, which operates on a three year cycle to visit all faculty courses. The Committee produces reports which are discussed with the faculty member reviewed and a separate report is made to the Chair. This record is particularly relevant at promotion and/or merit pay raise times.

8.2 Students:

8.2.A *Undergraduates*:

As stated earlier, the Department does not have specific admission requirements to its major other than the University requirements. Progress, though is followed carefully once the major is declared.

Once a year all majors are required to go through formal advising. Particular signs of poor grades in given courses are carefully reviewed with students at this time. Additional advising is available at all times from the Undergraduate Advisor and the Teacher Education and External Credit Coordinator. All majors near graduation are given a Departmental Exit Poll survey. During 1995-96, 25 out of 32 graduating students returned their surveys. The Exit Poll results are summarized by the chair of the UG committee and analyzed by the UG committee. It is then distributed, with comments, to all faculty. This year an attempt is being made at collecting Advanced Physics GRE scores from our majors who took the exam. From returns so far, we know that in Autumn 1996 at least two students scored in the 900's (the maximum score is 990), but we also know that at least two students scored around 500 (a very poor score for our own admission standards to the Graduate Program). We will pursue this matter, since it is important for us to know
how our students perform on this exam.

An additional monitoring tool was established in 1995-96 with the introduction of a non-mandatory Mentors program. Faculty have volunteered to be Mentors of students and, through the insights of the Mentors, the UG Committee learns of special difficulties and successes students may have, and the general level of knowledge of students in the major.

8.2.B *Evening Masters Program:*

The most significant measure that we have for evaluating the performance of these students is through their grade reports. Action for students with low scholarship is taken in accordance with Graduate School Memorandum No. 16 together with instructions from that unit accompanying its quarterly low scholarship reports to the Department. To a lesser degree the Department reviews timeliness of progress towards the degree, although, since the students in the program are mostly employed full time and have families to support, it is not at all unusual for them to take a temporary leave of absence.

The Department also requires that each student describe, in writing, the project undertaken, as required for the degree, and have on record the concurrence of the advisor. At the time of final oral examination a report on the project is submitted to the Department and a supervisory committee report is filed.

8.2.C *Ph.D. Program:*

Students in the Ph.D. program are evaluated at a number of levels. Entering students are expected to take the first year courses which are stringently graded. Students who do not do well in those courses may be placed on probation and, eventually, asked to leave. Next, students are required to pass a qualifying examination which tests the material in the first year courses as well as undergraduate physics. After that, students must be accepted by a research advisor. This normally follows a trial period during which the student must satisfy the advisor of his or her ability to work in the specific field. Then, the student must pass a General Examination which tests the student's mastery of the basic field of research and preparation for performing the research for the thesis topic. Finally, the student must complete a thesis based on the research and pass an examination of the thesis.

8.3 <u>Curriculum/Instruction:</u>

8.3.A *Undergraduate Program:*

We receive further evaluation of curriculum and courses (or faculty) through our graduating undergraduates exit survey poll, which has a number rating system for all courses in the major plus questions on the curriculum and other matters. We attach a blank exit survey form and a summary result of the most important questions for the last three years as Appendix J.

The Department receives feed back on the activities and opinions of our graduated students from the University's Office of Educational Assessment. Every two years this Office sends out a questionnaire to new degree holders one year after graduation. They are asked to reply to a list of questions of the general variety "How satisfied are you with the UW's contribution to your academic and personal growth in each of the following areas", with responses given on a numerical scale (1="Not at all" to 5 =

"Very") The 1995 survey received replies from about 50% of those contacted. The specific responses were generally in the range 3 to 4, "Somewhat" to "Mostly". Physics BS graduates were more positive than both the average of all physical sciences and the College as a whole on the issues "Understanding and applying scientific principles and methods" (mean = 4.14), "Understanding and applying quantitative principles and methods" (mean = 4.0) and "Assistance of faculty in pursuing your career" (mean = 3.0, so room for improvement). Compared to the rest of the College we have room for improvement on the general issue "Quality of instruction in your major", where our mean response of 3.33 was below the averages for both the entire College and all physical sciences. Just what this means and how to respond is still under consideration.

8.3.B *Graduate Program:*

The Graduate Committee is responsible of overseeing the Graduate Program. The committee consists of the faculty responsible for managing the program with student representation when curricular matters are discussed. The committee meets regularly to review the progress of students, the need for curricular revisions, and other changes of policy.

The survey data from the Office of Educational Assessment also has data from our MS and Ph.D. graduates. The most positive responses are again for the training in scientific principles, quantitative reasoning and problem solving with levels of satisfaction in the 4.3 to 4.9 range (*mostly* to *very* satisfied), well above average for the physical science and the College. On the general "Quality of instruction" question the responses were more positive than for the BS degree holders. The rating from the MS program participants was 3.83 (just below *mostly*), just below the physical science and College averages. The Ph.D. program received a higher 4.22 rating (just above *mostly*) that exceeded the average ratings for all physical sciences and the College. The Graduate School also supplies the Department with data on student satisfaction and other issues obtained from exit questionnaires filled out by students as they apply to receive their degrees. The general results are, not surprisingly, quite similar to the those obtained from the data of the Office of Educational Assessment, with average responses in the 3.6 to 4.4 range. These levels are similar to those for other units in the College.

8.4 Research and Creative Activity:

An evaluation of the Department's relative standing among other U.S. institutions is provided by the results of 1993 study undertaken for the National Research Council.[1] Utilizing a comprehensive program of data gathering from people working in the various academic areas, the study presents relative ranks in most area of academic research. In particular the study ranked departments on "scholarly quality of program faculty" and "program effectiveness in educating research scholars and scientists". In these two

[1] Marvin Goldberg, Brendan Maher and Pamela Flattau, "Resarch-Doctorate Programs in the United States", (National Academy Press, Washington, D.C. 1995).

categories the Department rated 14th and 16.5th (a tie at places 16 and 17). In the last such ranking in 1982 the corresponding numbers were 17th and again 16.5th. We are proud of the substantial improvement in the first category and proud overall of the absolute ranking in both. Many of the Departments rated higher are at private universities with quite different funding structures and student cohorts. At the same time we are constantly working to improve the status of the Department.

Another measure of the quality of the Department is the number of faculty members who receive prestigious prizes and are elected to the various honorary organizations. A brief summary of these two measures is provided as Appendix K, including 24 Fellows of the American Physical Society, 10 Fellows of the American Association for the Advancement of Science, 3 Fellows of the National Academy of Science, 4 Fellows of the American Academy of Arts and Sciences and one Nobel Prize.

Through the two Committees and Associate Chairs, one for the graduate program and the other for the undergraduate program, the Department is continuously reassessing the balance of the relative support for and focus on the two programs. We feel that, although there can occasionally be tension between the two programs as they compete for resources (and there is some general pressure from the University for increased emphasis on the undergraduate program), the mix is generally a positive feature of the Department. The graduate program in physics education has clearly played a positive role in the evolution of the introductory undergraduate sequence while the graduate students in the other research groups often serve as mentors to the undergraduate majors. The graduate students themselves benefit from the opportunity to play the roles of mentor and instructor to the undergraduates.

8.5 Accreditation:

There is no specific accreditation process for graduate programs in physics. General evaluation is described in the previous section.

8.6 Role within region:

The UW Physics undergraduate majors program is the largest in the Northwest and one of the largest in the nation. Given the size of the University of Washington, the Department also services the largest number of non-majors in the Northwest. The only other State program of somewhat similar scope is at Washington State University, which is about one half the size of UW. All other State Universities have Physics majors and offer courses for majors and non-majors. Physics BS degrees are offered at many private colleges and universities in the State, the largest ones being Seattle University, University of Puget Sound, Seattle Pacific University, Whittman College, and Gonzaga University.

The special strength of our Department is that it offers undergraduates a unique opportunity to take courses from distinguished researchers, and to work in front line research projects doing independent study (and sometimes finding hourly employment) in its various research groups. The research interests of the faculty influence and enrich the undergraduate courses, in both the laboratory and the theoretical offerings. The Department offers a full complement of courses to satisfy the most demanding requirements of future high-tech employers or of graduate studies at the best national institutions. This research emphasis is sometimes criticized by undergraduates who cannot, or do not choose to use the research opportunities available. Their belief is that a major State research university will naturally have large classes and impersonal ambiance. We have attempted to address this concern (and its impact on instruction) through the introduction of the Tutorials in Phys. 121, 122, and 123. Our ability to provide this environment is itself a consequence of having a prominent research group in the physics education area. In the tutorials students meet at least once a week in groups of 20 or so with one to three assistants. We hope that with more resources we will offer similar individual attention to students in the non-calculus series, Phys. 114, 115, and 116.

The graduate program also stands out in the region for both the quality and the breadth of the research opportunities offered. (In the national rankings mentioned in Sec. 8.4 Washington State University was ranked 114th and 124th in the two categories.) There is no comparable program north of San Francisco or west of Chicago. It should also be noted that the theoretical condensed matter group plays a special role in the Pacific Northwest, organizing on a yearly basis a northwest condensed matter meeting. The 1996 weekend meeting (the 14th) attracted faculty from the following universities: British Columbia, Simon Fraser, Oregon, Washington State, Central Washington, and Seattle Pacific, in addition to our own.

IX. RESOURCES

9.1 Funding Sources:

91.A *Undergraduate Program*:

Overall State support of the undergraduate instructional program is nearly adequate. However, in some areas the budget cuts of the last ten years have taken their toll. Our most serious concern is the issue of support for Instructional Equipment. As indicated in the Basic Unit Data of Appendix A, the equipment budget was a casualty of the recent cuts. The Department has a very large patrimony of instructional equipment. To thoroughly renew this equipment, even on a 20 year cycle, could cost as much as $50,000/year. Our Department replaced some major deteriorating components and bought some new modern equipment in the last two years thanks to the availability of equipment funding which came with the new building. But this source will not be available again. Also the building funds could not be used to update computing equipment. College supplemental funding has been requested on several occasions to slowly upgrade the instructional laboratory computers and those requests are generally satisfied on a one-time basis. However, a systematic renewal program of all instructional computing equipment will require substantial regular allocations.

The other areas where additional State funds would be very helpful are in the hiring of an additional instructional laboratories technician and in restoring the second of the two lecture demonstration technicians to twelve month employment. The Basic Program Data show that the Staff Budget/Faculty FTE funds ratio has remained essentially constant. This is due to the Department having exactly the same instructional personnel as it did ten years ago, except for M. Andersson replacing G. Ferrara, who retired, and J. Davis being reduced to 10 month employment in one of the budget cuts of recent times. The two introductory laboratory technicians, R. Maxell and M. Andersson, now support all of the sections of Phys. 131,2,3 and 117,8,9 that Maxell and Ferrara serviced ten years ago, plus all the sections of Phys. 131,2,3 (almost double the number) that were added as a consequence of the changes in Phys. 121, 2, 3 described in section 5.C.1. In the upper division labs, J. Stoltenberg takes care of the Electrical Circuits labs (Phys. 334,335), the Optics Lab (Phys. 331), the Modern Physics Labs (Phys. 431, 432, 433), and the Computer Interface Lab (Phys. 434). The Phys. 431 Lab is being upgraded to be offered also as Phys. 576 for graduate students during Summer Quarter (it was already offered once for the evening MS program). The proposed addition of the Introductory Experimental Physics Lab (Phys. 231) and the modification of the Electrical Circuits first quarter to four credits will require additional time sharing of existing personnel, which will leave other tasks uncovered.

It is also worthwhile reviewing the situation with TA support. When the new instructional scheme was implemented in the early 1990s in the calculus-based introductory course with its heavy use of tutorials 16 TA slots were added to the Department allocation (essentially 8 FTE). Budget cuts since then have reduced the allocation by 5. (The effective increase of 11 or about 5.5 FTE explains the increase in this category from 1986 indicated on page 3 of Appendix A.) It would be very helpful to the instructional mission to regain these TAs. We should note that this request is not a call for more graduate student support. There is currently a healthy balance between our efforts to limit the total enrollment in the Ph.D. program to approximately 130 students, our success in finding research based support for our students and the number of TA positions. All of our students are supported in one of the two ways. At the moment at least, any substantial increase in the number of TA slots would mean that we would recruit manpower from outside of the Ph.D. program or recruit our students out of a funded Research Assistantship.

A summary of essentially all of the above requests (and a few more) is contained in the Department's request to the College for the next, 1997-99, biennium which is appended as Appendix L. Note that one request, for a new Fiscal Manager, has already been met.

9.1.B *Graduate Program*:

The primary sources of support for our graduate students are the grants, which support both the students' research and the students themselves. Students typically spend 2/3 of their time in the program supported by research grants. If the current trend of flat budgets for the funding agencies continues, without any recognition of inflation, we will find it increasingly difficult to maintain the current level of support for our Ph.D. students. On the other hand, if we are successful in obtaining more TA positions to meet our instructional needs, as described earlier, any difficulties with student support will be at least partially alleviated.

The resources available to the Department for flexible support of the Graduate Program, particularly for recruitment, are more limited. We typically award four fellowships from three sources, one from the Graduate School, one from the Shell Foundation, and two from the Baumgartner Fund. We are attempting to raise funds to provide another fellowship, but it is a length process. It takes an endowment of approximately $270,000 to fund a singly full year fellowship.

The last source of resources for the graduate program is the State support of the faculty. As described in Section X, current hiring agreements will result in a marked reduction in the size of the faculty at the same time that we are experiencing pressure to devote increased attention to the undergraduate program. These trends constitute a real challenge to the quality of our graduate program.

We recognize that the University cannot replace any decline in federal funding; however, it can address the erosion of the faculty resources devoted to the Graduate Program.

9.2. Resource Trends:

While it is difficult to foresee the future, its seems that at least two features of our funding picture can be predicted for the near future.

9.2.A *Federal Funding:*

Grant monitors for both the NSF and the DOE are currently describing the same near term future. For both, the best cases scenarios involve flat funding with no adjustments for inflation. This suggests a slow but steady erosion of our ability to respond to new initiatives. It also raises a concern about our ability to continue to find support for our Research Faculty. Many of the Department's research activities depend on their contributions and their support is a very high priority. The challenge to the Department is to be more creative in our efforts to identify new sources of funds. In fact, the recent history of the Department suggests that we can respond with new ideas for funding support but it will require continued dedication to the task.

9.2.B *State Funding:*

While one of the "bright" spots in the ten year record of State funding for the Department is the fact that the faculty have received raises, it is important to recognize that the level of these raises has lagged behind our peers. Each year Prof. Neil Fletcher from the Department of Physics at Florida State University performs a National Academic Physics Salary Survey by collecting data on salary levels from physics departments with graduate programs rated by The Chronicle of Higher Education.[1] For 1996-97, he obtained responses from 72 of the 147 institutions. The anonymity of a large number of the institutions who participate is maintained but it is possible to determine average salaries at four of the institutions that are ranked near us in the National Research Council rating mentioned in Sec. 4.3.A. These institutions are the University of Illinois, Urbana, the University of California at Santa Barbara, the University of Maryland and the University of Michigan, which were ranked 8th, 10th, 18th and 19th, respectively, to our 14th. The study by Prof. Fletcher provides a second ranking of institutions according to the weighted average difference from the mean salary (of the sample of 72), weighted and summed over each of the three professorial ranks. The two rankings and the average academic year salary levels at each of the three professorial ranks in the latest data are:

Name	NRC Rank	Salary Rank	Assistant Professor	Associate Professor	Professor
Illinois	8	5	$54,922	$64,738	$90,198
UCSB	10	2	$48,600	$55,325	$101,716
UW	14	60	$47,862	$59,040	$64,377
Maryland	18	16	$51,953	$54,926	$81,754
Michigan	19	17	$54,244	$64,136	$78,374

[1] See the *Chronicle of Higher Education*, September 22, 1995 issue.

Clearly UW salaries are low in almost all comparisons but the difference is largest at the full professor rank, corresponding to 86% of our faculty. The reason for this is easy to understand. While we are forced to hire-in at salary levels that are market driven, fixing our junior faculty salary levels near our peers, the consistently small raises seen at the UW guarantee that the senior faculty gradually fall behind their peers. The resulting difference is substantial, over $20,000 per year on average. While there is generally observed to be a strong correlation between salary levels and the rated quality of physics departments, the UW Department of Physics is clearly an anomaly. It is ranked 14th in quality but its salaries are ranked 60th (out of 72), over $10,000 dollars per year per FTE below the average of all 72 institutions. Interestingly, the other large State university in Washington State, Washington State University, which has a much lower quality ranking, ranks well above us at 47th place in salaries (just $3,814 below the average).

There is another unfortunate feature of our salary distribution that is not clear from the above data but deserves mention. Due to the low number of raises in recent years, the distribution of salaries within the Full Professor cohort is not only low on average but also skewed towards the lower end. The value of the average salary is driven to a large extent by the "high end" tail of the distribution, corresponding to senior hires from other institutions and "competitive raises" to those how have offers from elsewhere. In fact, 19, or nearly one half, of the Full Professors receive an academic salary that is smaller than the average of the more recently hired Associate Professors (the Full Professor median salary is $59,310).

The good news in this situation is that the Department of Physics represents very good value for the State dollar, high relative quality for very low relative salaries. The concern has to be whether, in the context of such large salary differentials, the Department can continue to build on its strengths or if, instead, faculty morale will erode and recruitment initiatives will fail.

9.2.C *Efficiency:*

Given limited State funded, an interesting question is whether we can make more efficient use of the facilities and personnel that we currently have. This is especially important in light of the anticipated 20% increase in enrollments. Here we briefly summarize the results of a study, requested by the College, of possible responses to such an enrollment increase. The Department determined that we could probably increase currently enrollments in the basic service courses (100 and 200 level) by approximately 760 students (or about 8%) by simply improving the registration procedure to fill up current lecture sections (with a corresponding loss in student scheduling flexibility). However, this scenario would require added tutorial and laboratory sections (with fixed, small enrollments) with a resulting requirement for another 18.5 TA slots (about 9 FTEs). The conclusion is that any substantial increase in enrollments will require more resources.

On the positive side, as the University converts to on-line procedures for registration and record keeping, we anticipate a measurable increase in efficiency. For these functions we should be able accomplish more with a fixed number of staff.

X. SUMMARY - Present Conditions and Future plans

10.1 The Department:

10.1.A *Space*

In assessing the present condition of the Department it is informative to look back to the last review report of ten years ago. In that report the highest priority for change was given to the issue of the old Physics building and its inadequacy. The University deserves high marks for responding to that need. The new Physics/Astronomy Building (PAB) is an attractive, state-of-the-art and functional structure. The laboratory space was designed to control, as much as possible, background sources of mechanical vibrations and stray magnetic fields (although we neglected to plan for the electric trolley line on 15th Avenue or the future light rail system under 15th Avenue). Necessary utilities are, for the most part, readily available and the laboratory spaces are designed for flexibility. The instructional spaces are similarly well planned with ready accessibility to the lecture demonstration preparation area from the four large lecture halls. The faculty offices themselves are approximately the same size as in the old building, and are attractive and functional. A strongly positive design feature is the inclusion of the "common spaces" within each of the research areas. These include discussion areas with chalk boards (even the stairwells have boards), group meeting and small seminar rooms. The proximity of faculty offices to other faculty and student offices is also a positive feature. This configuration speaks to another issue in the last report. That report expressed concern about student - faculty communication. That communication has been greatly enhanced by the proximity of the offices in the new building with areas immediately nearby to interact in (it works!). Also, the Physics Study Center (located in the lecture hall building), staffed by TAs and faculty throughout the day, has fostered closer connection between students and faculty. The undergraduate majors have also benefited from a new room of their own in the building, which is available at all times.

The major limitation of the new building is that, due to overall budgetary constraints, it was designed to just accommodate the existing program with essentially no designed-in space for growth or innovation. It was immediately filled to capacity. We also find that the number of small classrooms and seminar rooms for 20 to 30 people is barely adequate. In terms of space, the largest challenge in the next ten years will be responding to the changing research demands of both old and new faculty within the existing facility. Saturation of the current laboratory space will make it difficult to recruit faculty with research interests that require substantial room in the building.

10.1.B *Staff*

The question of staff support, mentioned in the last review report, remains an important issue, both in terms of salary level for the staff and the level of staff support for the Department's activities. Staff salary levels have continued to lag. The demands of our increased efforts to provide challenging instructional laboratory experiences, sophisticated research apparatus, and more complete accounting reports with little change in staff size stretches our support staff to the limit. Counting all names on the autumn 1996 faculty list (Appendix D) we have a regular faculty of 49, 13 professors emeritus, many of whom remain quite active, 9 members of the permanent research faculty, 12 research assistant professors and 28 post doctoral fellows. We instruct more than 3,500 students per quarter and spend some $8 million in grant money per year. However, our administrative support staff (see Figures B-1 and 2 in Appendix B) includes just 4 people in the main office, 3 in fiscal control and 2 in student services, one each to advise undergraduate and graduate students. There are just 5 staff members in instructional support (laboratories and lecture demonstrations), 2 in the Physics Storeroom and 4 to handle all computer support (for a total of 20). While it is difficult to map the staff structure of one Department onto another (boundaries of responsibilities will differ due to history), it is still informative to attempt that exercise. Looking at the Department of Physics at Berkeley, with a slightly larger faculty and much larger graduate program, and at our own comparably sized Chemistry Department, we find the following staff numbers:

	Main Office	Fiscal Control	Student Services	Instructional Support	Storeroom	Computer Support	TOTAL
UW Physics	4	3	2	5	2	4	20
UCB Physics	6	6	3	5	2	1	23
UW Chemistry	10	5	3	5	2	2	27

Approximately half of the time of our computer support people is charged back to the grants as research computing support.

While the differences in the various support functions are not huge, the impact of a single extra individual can be enormous. For example, both UC Berkeley Physics and UW Chemistry have a staff member identified as primarily dedicated to "Outreach" (included in the Main Office category in the table). In our Department this function is covered part-time by various faculty. It is clear that our attempts to raise more endowment support for our graduate students would benefit from another staff member focused on staying in contact with our alumni. Likewise our student services function would be enhanced by a third staff member. While the addition of the new Fiscal Manager position is a major positive step, we still feel that we are understaffed in fiscal control.

10.1.C *Faculty*

What sets this Department apart from those in neighboring institutions and its competition nationally is the strength of its faculty in performing their scholarly activities. We are delighted that the Department has been successful in its new appointments over the last ten years. We have managed to attract our top candidates in essentially all instances. This success came despite competing offers from Caltech and Berkeley, for example, in the case of Stubbs. The appointments have greatly strengthened the faculty and we have successfully responded to new research opportunities. Morale in the Department is quite high and the faculty functions as a department rather than as a collection of independent "baronies". Collaborations that span group boundaries are common. The following is a brief summary of the changes in, status of, and expectations for, each of the main research groups. The various changes in the sizes of the research groups have already been indicated in Figures III-1 and III-2.

ATOMIC:

This group remains one of our most visible areas of experimental research. Hans Dehmelt has been awarded both the Nobel Prize and the National Medal of Science, and he, Van Dyck and Nagourney are very active in trapped ion research. The edm and parity violation experiments of Fortson and Heckel probe physics beyond the 100 GeV scale, which should remain an exciting area. In the last decade the atomic physics faculty has suffered some attrition. Just at the time of the last report we lost Gabrielse to Harvard. More recently, Lamoreaux, a very productive Research Associate Professor, left for Los Alamos. A major challenge to this group is the question of how to proceed past the retirement of Dehmelt. Given its important role, maintaining the vitality of this group into the next decade is a major issue for the Department.

ASTROPHYSICS:

This area of research was selected for growth by the Department in the last ten years and it has done so dramatically. Whereas only Boynton held a joint faculty appointment with Astronomy ten years ago, two new joint faculty positions are now held by Hogan and Stubbs. We have also added both H. Robertson and Wilkerson on the experimental, solar neutrino side. Moving away from conventional particle physics the research of Wilkes and Young is now focused on particle astrophysics, in particular, on solar and astrophysical neutrinos. This general research area also benefits from the work of Bardeen in general relativity, the research of Adelberger and Heckel in gravitation and, generally, our collaborations with the faculty of the Astronomy Department. This is a dynamic research area of great potential that we are solidly involved in.

EXPERIMENTAL CONDENSED MATTER:

In ten years, only Dash has retired and he remains active in research. As recommended by the last review committee, in that period we have added Olmstead and, most recently, Seidler. Thus the group currently has seven faculty members and is highly visible, especially in the areas of X-ray and surface physics. The future possibilities for a leading role at the new Advanced Photon Source at Argonne Laboratory, where Stern is a Beamline Leader, are particularly exciting. However, three of the current faculty (Ingalls, Stern and Vilches) are likely to retire in the next ten years and we must be careful to maintain the level of activity. There is considerable potential here for increased collaborations with our cross campus colleagues in Chemistry and Materials Science and in industry.

THEORETICAL CONDENSED MATTER:

Over the last ten years this group has basically remained constant in size at five, simply exchanging Spivak for Riedel. While Thouless is the most recognized member, all are making substantial contributions to the field in areas ranging from astounding quantum effects to self-organizing systems to sophisticated codes to analyze XAFS data. With the retirement of Thouless expected in the next ten years, a suitable replacement must be identified.

EXPERIMENTAL NUCLEAR PHYSICS:

Of the six faculty in this area ten years ago, four have retired and only two new faculty, H. Robertson and Wilkerson have joined the Department. With the involvement of the experimental nuclear physics faculty in gravitation and weak interaction studies (Adelberger), heavy ion physics (Cramer) and solar neutrinos (H. Robertson and Wilkerson), the future looks active and productive. In last year's DOE review of small University laboratories with accelerators, the Nuclear Physics Laboratory (NPL) reviewed well and funding is expected to remain essentially stable even in the current climate of shrinking budgets. Still there is concern for the future role of the existing accelerator at the NPL in traditional nuclear physics (a concern also noted in the last report). It seems unlikely that the accelerator itself will still be running ten years from now (although a similar opinion was voiced ten years ago). The important issues for the NPL and the Department are the future of federal support for the permanent research faculty at the NPL (3 Professors and 1 Associate Professor) and for the research infrastructure at the laboratory, which benefits many faculty members.

THEORETICAL NUCLEAR PHYSICS:

The theoretical nuclear physics group formed the germ of theoretical physics in the Department. From a group of four members (Haxton, Henley, Miller and Wilets) ten years ago, the group has formally shrunk into a group of three (Bulgac, Miller and Savage), plus two active emeritus members (Henley and Wilets) and a research assistant professor. The group is extremely productive and very visible. The members are especially active in the Institute for Nuclear Theory (which was proposed by the original group) and profit from the considerable intellectual stimulation that the Institute provides. The research activities of the members of this group span a broad area from atomic cluster and many body physics to particle theory, including structure of hadrons, chiral approximations, nucleon-nucleon scattering, nuclear transparency, fundamental symmetries, and other aspects of strong and electro-weak interactions.

INSTITUTE for NUCLEAR THEORY:

The Institute for Nuclear Theory (INT) was established seven years ago by the DOE as its national research center in this discipline, following an open competition. It is a separate entity from the Department of Physics, having the status of a department in the College of Arts and Sciences with distinct budget and personnel functions. The INT is the home department of the three permanent fellows (Bertsch, Haxton and Kaplan), with Physics serving as the appointing department (the seat of tenure). While INT fellows and research assistant professors occasionally teach, the primary mission of the INT is its visitor programs and its research activities. Approximately 250 visitors attend the three INT programs and several workshops held each year, for an average stay of four weeks. As the INT strongly emphasizes the intersections of nuclear physics with particle physics, astrophysics, and condensed matter, its programs and visitors are a source of stimulation to the entire Department.

EXPERIMENTAL PARTICLE PHYSICS:

The experimental particle physics group has been actively involved in major experiments at SLAC, Fermilab and CERN. While there were previously two independent activities funded by the NSF, there is now a single NSF grant funding research at SLAC and CERN. The future lies in the group's participation in ATLAS, one of the detectors being built for the new accelerator - the LHC - being constructed at the European laboratory CERN in Geneva. The group has shrunk over the last ten years from eight faculty members to six with the retirement of both Lord and Williams. The group benefits from three permanent research faculty, of which two have spanned the last ten years. While this area of research has experienced a remarkably exciting ten years with the validity of the Standard Model and the "reality" of quarks ever more apparent, the structure of the field has also evolved towards fewer, larger and more expensive detectors. At the same time overall funding of the area is being squeezed at the federal level creating difficulties for the groups involved in the endeavor. While the scale, duration and distant location of the experiments are not ideally matched to university life, the targets of study, *e.g.*, the source of mass, remain of the highest intellectual interest and the student experience of collaboration in large groups working on state-of-the-art equipment provides excellent career training. The Department must consider how to respond to the aging of the experimental particle physics group and the anticipated two retirements in the next ten years in order to maintain its strength.

THEORETICAL PARTICLE PHYSICS:

The theoretical particle physics group has grown in ten years from five to seven with the replacement of Zee by Sharpe, Nelson and Yaffe. This level of growth is just as recommended in the last review report (responding also to the previous departure of McLerran). The group remains strong in fundamental field theory, in thermal field theory, in electro-weak and supersymmetric modeling and especially in studies of the strong interactions both through lattice calculations and phenomenological studies. More than other groups, particle theory has paid the price of good citizenship with Brown's role for several years as editor of Physical Review D and Boulware's and Ellis' current roles in Department (and College) administration. The next decade will likely see the retirement of at least Baker and Brown. It will be important for the Department to have a plan to keep this theory group vital over the next ten years.

PHYSICS EDUCATION:

The physics education group (PEG) has really grown into its own as a research group during the last ten years. Their role leading the Entry Level Initiative (ELI) to restructure our introductory calculus-based sequence has had a major impact. For the group this has meant having a built-in laboratory for performing instructional studies. For the Department this has meant changes in the way we teach half our introductory students, a change not always easily accepted. Our situation with a research group studying science education actually located in a science department is a "grand" experiment with national implications. Our graduate students now benefit from a more structured and pedagogically effective TA experience. Our research faculty, who elect to teach in this introductory sequence, also receive an early teaching experience with more structure and intellectual support than elsewhere. We are currently searching for an assistant professor in this area and that choice will strongly affect the future of the group. Essential questions for the next ten years for both the PEG and the Department are whether two faculty members is the appropriate number and how we will deal with the anticipated retirement of L. McDermott during that period.

OVERALL FACULTY SIZE:

As indicated by the Basic Unit Data in Appendix A, the faculty size as measured by the Permanent Faculty FTE has been essentially constant at 42.5 to 43 over the last ten years. Actually, as measured by our own internal "head-count" of State-funded faculty the number is more like 42 but still constant over the ten years. This counting exercise is a complex issue due to joint appointments and, more importantly, the fact that this Department has actively used "mortgaged positions" to pre-hire replacements for future retirements. There is, of course, an intervening time period between when the new faculty member is hired and when the mortgaged State funded position becomes available due to the retirement. During this period the new faculty member is funded or "bridged" out of a combination of Departmental (recapture) funds and federal research funds. The faculty in this bridged state form a "queue" waiting for a vacant State position. (They are not typically included in the FTE or State-funded head-count but are counted in the research group discussion above.) Associated with the current queue there is also a second category of mortgaged positions that arose out of the negotiations with the College that made it possible to hire into the queue. When these positions are vacated by retirements, the College intends to recapture them without immediate replacement. The current agreement with the College specifies that out of the next seven retirements (including Dehmelt as a special case) only three will be returned to the Department to provide State funded positions for the faculty in the queue, Wilkerson, Stubbs and Savage (in that order). While the queue has never been a static agreement (*i.e.*, it has typically been changed before its details have been carried out), it is an informative and sobering exercise to view the implications of the current queue for the Department and for its instructional and research missions.

To put this discussion in context Figure X-1 indicates the anticipated rate of retirements for the next ten years assuming that all faculty retire at age 70, a generally conservative assumption. (We have included Dehmelt's retirement arbitrarily in the year 2000.) The dashed line indicates when the current queue ends. Until we reach the dashed line there will be no new hires according to the current agreement.

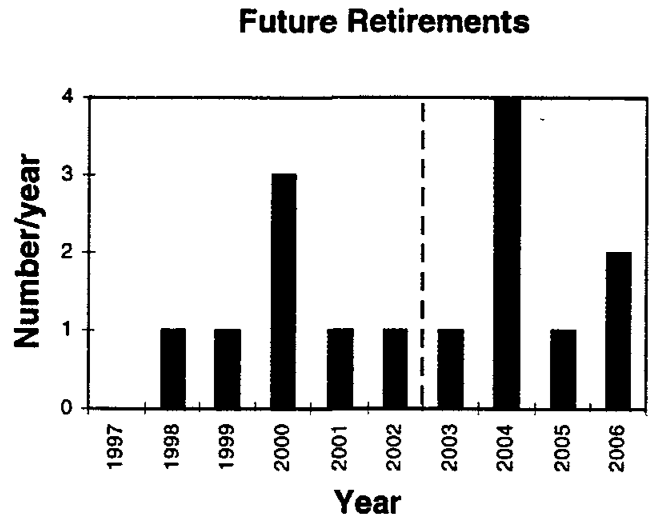

Figure X- 1

We see that the Department is about to enter a period of dramatic shrinkage (see below) and that it will have to energetically recruit faculty just to maintain that reduced size after the year 2002. The Department will need to hire *two* faculty members a year, *every year*, after the year 2002 until around the year 2013 just to maintain itself at the reduced size.

We will argue below that this implied reduced size for the Department is not adequate to carry out its current instructional mission and offers no hope of dealing with the increase in enrollment that is being forecast. Putting that issue aside for now, simply the need to make intelligent selections of quality new faculty for the period after 2002 suggests that we should institute a program of faculty recruitment in the very near future, and certainly before 2002.

We have discussed above the serious impact that the queue (the first seven retirements) will have on the research groups. Especially important are the implied losses, without replacement, of Dehmelt in atomic physics and L. McDermott in physics education.

The impact of the queue on the Department's *instructional* program is also quite damaging. To appreciate this point it is important to understand the effective size of the teaching faculty as a function of time. In this calculation the faculty in the queue count as 0.5 FTE until the time of conversion as they typically teach half of the time. After the conversion they would normally count as 1.0 FTE. Thus the effect on the teaching faculty of a retirement and a subsequent conversion is *not* zero, as one might naively expect, but rather the *loss* of 0.5 FTE! Further, joint Astronomy appointments are counted as 0.5 FTE, even after conversion, as they teach half-time in Astronomy. Thus the conversion of Stubbs from the queue does not change the Physics teaching faculty count at all. The effect of a retirement plus Stubbs' subsequent conversion to fill the retirement will be to reduce the teaching faculty by *1.0* FTE. (Not included in the teaching count is the effectively 2/3 of a teaching faculty member coming from the three INT Fellows who typically contribute to the Department by teaching a total of two courses during the year.) The teaching faculty calculated in this way is somewhat larger than the FTE count and as a function of time looks as in figure X-2.

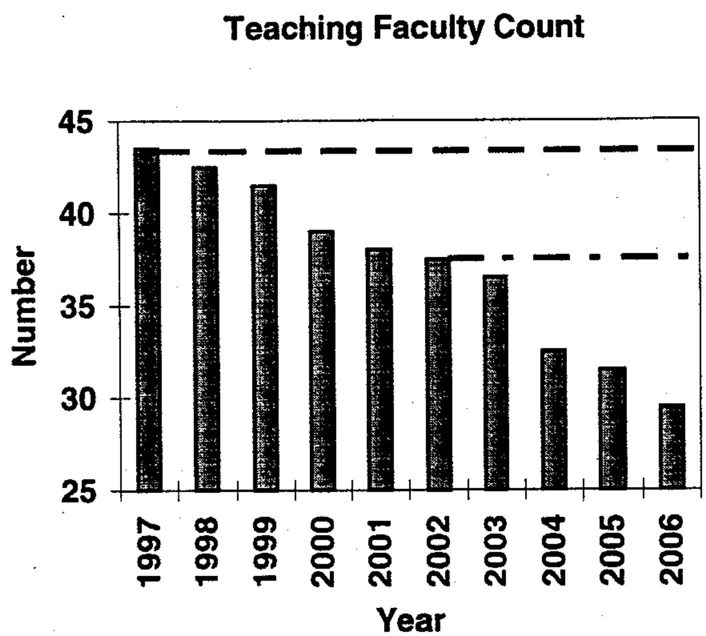

Figure X-2

The current teaching faculty count is 43.5 FTEs (including the position in physics education currently occupied by visitors) and this level of activity is indicated by the horizontal dashed line in Figure X-2. With no new hires before 2003, *i.e.,* during the queue period, this number drops by six to 37.5. This corresponds to seven retirements accompanied by two, non-joint, conversions, which contribute an increase in teaching manpower of just one (0.5+0.5 = 1), for a net change of -6.0 FTE. The resulting level of teaching faculty is indicated by the dashed-dotted line. The graph beyond the year 2002 indicates the effect of the remaining retirements in Figure X-1 if there is no hiring, with the teaching faculty shrinking to 29.5 FTEs (15 total retirements). Of course, the current expectation is that these last positions will be refilled.

Let us focus on the result of the current mortgage plan - the difference between the two dashed lines. At the upper, current level of teaching faculty the Department is barely able to cover what we perceive as our teaching responsibilities. The fact that we can offer at most only one or two quarters of special topics courses each year for both undergraduates and graduates is a serious constraint on the effectiveness of these programs. Even this minor flexibility will disappear as we add the planned new courses (described in the next section of this report). Clearly the scenario suggested by Figure X-2 will lead to substantial reductions in the instructional program. The six lost faculty teaching FTEs correspond to *eighteen* lost quarters of instruction! The one moderating feature in this bleak scenario is that some leave recapture funds, currently used to fractionally support the faculty in the queue, will be released as the queue is emptied. This funding could then be used to hire members of the research faculty, or outside instructors, to fill the empty teaching slots. In this way we might be able to "buy back", on a temporary basis, perhaps 1 or 1.5 of the lost 6 FTEs, assuming satisfactory but inexpensive candidates are available. Still, it seems inevitable that at least one component out of our service courses, our undergraduate major program, or our graduate program will suffer an unmistakable and severe reduction. Note also that this discussion includes no adjustment for the anticipated 20% enrollment increase in the next ten years. Since we feel that this outcome is unacceptable to the mission of the Department and the University, we hope that the College will be able to work with us to define a more positive future, including a more timely and rational retirement replacement plan.

With that disturbing description of coming events for the faculty, let us turn to the current situation for the instructional programs.

10.2 The Undergraduate Program:

10.2.A *Non-major courses*:

The Department offers a substantial complement of courses for non-majors, including additional courses for teacher certification and in-service pre-college teachers, courses which fulfill general distribution requirements or tailored to special interest students, and courses which fulfill requirements and prepare students for admission to other careers. These courses are usually taught by faculty who express a desire to teach them, and are well received by the students. Enrollment has been constant or slightly increasing. The main need at this time is to provide more individualized instruction in the non-calculus Introductory Physics sequence, Phys. 114, 115, 116, where class sizes have steadily increased (many sections to room capacity) while the number and hours of TAs allocated has remained constant or diminished. An experiment is beginning with faculty volunteers to test one section where a lecture/week is traded for a tutorial/problem solving session with 20 students/1 faculty member/week. We expect that an initiative (which will require funding) will be submitted to the College if this test proves successful.

10.2.B *Bachelor of Science program*:

The Department offers a complete and challenging program of study to obtain a BS in Physics, with multiple options available to fulfill individual student interests. It is one of the largest in the Nation. It has an exceptionally strong laboratory program, which is housed in state-of-the-art facilities. Major needs in the future are to obtain steady financial support for equipment renewal, including computers and peripherals, and the restoration of personnel cuts and the addition of one instructional laboratory technician. The anticipated decrease in the size of the teaching faculty will surely impact the breadth of the majors program.

10.3 The Graduate Program:

10.3.A *Evening Masters Program:*

The Evening Masters in Applications of Physics is a strong program which serves a clearly defined need in the community. We have had a recent decline in participation which we believe is due to our weakness in marketing the program. The students are generally working for high-tech companies in the area and pursuing their studies at night so that the question of support does not arise.

When the Evening Masters Program was initiated, we received one position for its support. Discussions with the University's Continuing Education Program suggest that the current enrollment would justify about 1.5 new positions, as well as some operations support. We believe that association with the Continuing Education Program would help us to provide additional support, and that their support in marketing the program would assist in maintaining the enrollment level. Further, we believe that both the Evening Program and the regular Ph.D. program would benefit from having the program listed in the Continuing Education Program catalogue with distinct admission criteria and program requirements.

10.3.B *Ph.D. Program:*

Overall, the Department has a strong Ph.D. program. We are attracting good students and making progress in reducing the time to degree. Most of our students continue to find excellent positions in industry and academia, but we are concerned about the apparent decline in the career opportunities available to recent Ph.D.s. Through various means we are working to keep both our students and our faculty informed of the full range of opportunities which are available, including the non-traditional career paths that some of our previous graduates have followed.

Graduate students are typically supported by teaching assistantships for the first couple of years and by grants thereafter. At present we have sufficient funding to provide this support for all of our students and, even with though budget cutting is a high priority in Washington, DC, we remain confident that we can continue to find that level of support.

As we discussed above, a major concern for the Ph.D. program is the anticipated decrease in the size of the faculty during the next ten years. This will tend to limit both the research opportunities available and our ability to offer a full range of course work. Even before the expected shrinkage we find it difficult to provide many specialized courses on a regular basis. Despite having a large number of students in atomic physics, we only offer the atomic physics course occasionally. We must frequently skip offering mid-level graduate courses such as Nuclear Theory. And sufficient manpower to offer advanced special topics classes is only sporadically available.

Another concern is the availability of recruitment funds for our entering graduate students. We have fellowships from the Graduate School, Shell Foundation, and Baumgartner Fund which enable us to support three students per year. This level of support is not enough to allow us to aggressively recruit outstanding students. It is also well below the fellowship support level typically available at the institutions we recruit against (*e.g.*, we understand that at Berkeley the Department of Physics receives approximately 13 full fellowships each year from the university). We are attempting to obtain additional endowment funds for this purpose and would appreciate assistance the University in reaching that goal.

XI. FUTURE GOALS AND PLANS

In general, the major goals of the Department of Physics are the same as those of the University as a whole: excellence in the generation, transmission, application and preservation of knowledge. The Department should be offering a premier science education to the best undergraduate students from the Northwest United States and highly talented graduate students from around the world. The implication of these goals for our various functions is outlined below.

11.1 *Undergraduate Program:*

Changes that are planned, proposed, and under discussion for the next five years include:

(1) Degrees Offered: We will institute a Minor in Physics program. While the Minor is not a new degree, this program will bring Physics into the expanding group of Departments offering such an option within the University. The Minor in Physics will be awarded to those students who take the freshman and sophomore calculus-based physics sequence followed by three or four additional courses along one of three options: the physics instruction option, the experimental physics option and the mathematical physics option. As many students in allied fields in science and engineering already take the majority of these courses, the aim is to provide them with specific, formal credit for this facet of their education. We are convinced that a firm grounding in physics constitutes a strong basis for careers in many other fields. We expect the Minor program to start in Summer or Autumn, 1997.

(2) Curriculum Content: During 1994-96 the UG Committee studied, and in 1996 proposed and the Department approved, a slight revision of the curriculum for majors, to occur gradually during the next several years. One issue addressed is the desire to provide a serious laboratory experience for science majors as early as possible in their education. A second and similar concern is for early exposure to computational methods. To these ends a sophomore Introduction to Experimental Physics course (Phys. 231) will be taught for the first time in Autumn 1997 and a sophomore Introduction to Computational Physics course (Phys. 232) will be taught for the first time in Spring, 1998. We are also restructuring the Electrical Circuits Labs (Phys. 334 and 335) to provide an enhanced emphasis on digital circuits, including an introduction to digital circuits in the first quarter. The first quarter course credit will be increased from 3 to 4 and, at the same time, the requirement for the BS that students take both Phys. 334 and 335 will be reduced to only Phys. 334. The restructured course will be taught for the first time in Winter, 1998, if faculty time for the restructuring is available. The goal of the credit changes is to both recognize the enlarged content of Phys. 334 and to free some credits to allow us to make the Phys. 232 course a requirement. The Senior Lab in Applications of Computers to Measurement will also be enhanced with an infusion of the latest models of personal computers.

For the non-science undergraduate the Department currently offers several courses that overlap with studies in other areas such as fine arts, music and sports. With an apparently rising level of awareness of scientific and technology issues in the regional press and the Northwest community overall, we anticipate an increasing demand for such courses. We are prepared to respond to what we hope will be a need for more general courses where students can experience serious scientific argument with only a modest amount of mathematics.

(3) Methods of Instruction: Working with individual instructors, members of the Physics Education Group are exploring ways of introducing some of the techniques used in the tutorials (collaborative learning, conceptual emphasis, semi-socratic questioning, *etc.*) into courses that are more advanced than the calculus-based introductory sequence. Pretesting, development of new curriculum materials, tutorials, and assessment are being tried in the Thermodynamics course (Phys. 224), Relativity (Phys. 311), and in the Introduction to Quantum Mechanics course (Phys. 324 and 325). It is still too early to tell if these efforts will lead to a modification of the methods of instruction traditionally used in these and other courses.

The Department is also exploring the possibility of offering courses through Distance Learning. At the introductory level, we are considering a course based on the Phys. 114, 115, 116 series (the algebra-based university physics course). This may be a new course or an adaptation of an existing course offered by another institution. The University has extensive experience and the necessary facilities for the development of distance learning courses and is highly interested in entering this field. The high quality of our lecture demonstration facility (most of the demonstrations have been recorded and are available on video discs) and our laboratory courses will help facilitate this development program.

(4) Interdisciplinary efforts: The Department is involved in two experimental inter-disciplinary teaching experiments. The Physics Education Group has been investigating difficulties that students encounter in applying concepts from introductory physics in their subsequent studies in engineering. Members of the group are collaborating with individual instructors in Engineering 210 (Statics) and Engineering 230 (Dynamics) in the development of tutorial materials to help students improve their ability to apply what they have learned in physics to problem-solving in engineering. The Department is also experimenting with a biophysics course to introduce physics majors to this field of research.

(5) Number of students admitted to the program annually: We expect the number of physics majors increase at least as rapidly as the anticipated increase in the total University enrollment. This trend is not likely to be followed nationally, but the University of Washington is the premier institution of higher education for a very large corner of the continental United States. The number of students who will participate in the Minor in Physics program is not predictable at this time.

11.2 *Evening Masters Program:*

The Evening Masters program in "Applications of Physics" is a robust, diverse program, fulfilling a large range of needs. We are currently considering ways to further enhance the program. One possibility would be to make it more professionally focused, turning out graduates with more specific commercial viability in a range of specialties, for example, physics education, condensed matter technology, *etc.* Such a program could perhaps be joint with other related departments and local industry. While the original program was directed primarily at engineers and scientists working in local high-tech R&D, many students are now from the software industry and k-12 education.

Another way to enhance the program would be offer an even more general MS degree with more daytime students, some perhaps recognized as explicitly planning to continue on to the Ph.D. Such a program could conceivably help supply graduate teaching assistants for whom there appears to be an ever increasing demand by the department.

In whatever direction the program goes, it will continue to provide a valuable and appreciated service to the community and it would seem that the Department should strive to obtain more official recognition and support for offering such an option. This could be achieved by formalizing the program within the University, either as a separate regular graduate degree program or, more likely, as part of the University's Continuing Education Program. We are currently seriously evaluating the latter approach.

11.3 *Ph.D. Program:*

Our Ph.D. program has to respond to a number of conflicting demands. We want our students to be broadly educated in physics, so that they can work effectively on a wide variety of problems and respond intelligently to changing opportunities throughout their careers. We want them to have acquired the necessary tools of the trade: theoretical, computational, and experimental, through a combination of course work and independent study. To produce a successful dissertation, students must complete a significant piece of original research. They should understand the nature of scientific investigation and discovery. They should have sufficient accomplishments as graduate students that they are attractive candidates for postdoctoral or other initial positions. They should contribute substantially to the programs which provide their financial support, whether this is a teaching program or a research grant. In the process they should master the skills needed for effective teaching, research and management. Ensuring that students obtain this breadth of education during the course of their graduate study is an ongoing a challenge.

We have recently taken some modest steps to fine tune the balance described in the preceding paragraph. We have introduced a new course at the end of the first year (Phys. 511) which is intended to show how theoretical ideas developed in other courses are used in current experimental contexts. Our impression is that the course is succeeding in its intended goals, but, unfortunately, only about half the first year students took it last year. We have converted one quarter of our classical mechanics course into a course on numerical methods which is to be taken in the second year and is being taught this winter quarter for the first time. It is intended that the students become familiar with basic numerical methods used by both experimentalists and theorists. We also expect that this course will provide students who pursue careers outside academic and research physics with a strong background. Other changes are contemplated, but have not yet been discussed by the full faculty.

We have agreed to encourage faculty to provide Research Assistantships for first year students, at the expense of pushing more senior students back into teaching positions, but we have not yet implemented this. We hope that this will remove some of the pressure from first year students, and give them a more realistic view of what a Ph.D. program is primarily about. We are making sure that students who are not yet members of a research group have faculty advisors whom they see at regular intervals. The Graduate Program Coordinator is reviewing applications to take the General Examination, and, where necessary, reminding committees to see that the candidates have fulfilled our declared course requirements (which are drawn up in a very flexible form). The Graduate Program Coordinator has also been following up on those cases revealed in annual reports where progress towards the degree is either unusually slow, or where intentions declared in a report have not been followed through. In some cases this seems to have led to an increased rate of progress.

We think it would be desirable to broaden students' education by requiring them, in the third or later years, to take at least one course outside their main field, either in another area of physics, or outside physics. We would like to encourage committees to take a more active role in the education of students, ensuring they look at their research projects in a broader context.

11.4 *The Faculty:*

The prospect of bringing no new faculty into the department for the next six years not only hampers our ability to meet our core mission of teaching and research -- it also risks taking us out of the mainstream of physics. It is vital to the long term health of the department that we constantly refresh ourselves, bringing in new ideas and science along with new people. It is particularly important that we bring in young people. By the year 2002 the age distribution in the Department will mean that all of our faculty graduated from college before our typical undergraduate was born.

Our department has risen to national eminence because of the creative new research directions established by our faculty. The Department has earned a reputation for cleverness and innovation, and is widely considered to be on a rising curve. This situation has come about because we have enjoyed good university support, and because our faculty has recognized opportunities and acted on them, generally putting the good of the Department ahead of more selfish goals. The results include our forefront role in high precision atomic physics, where our faculty helped lead a renaissance in this field. In nuclear physics the faculty supported the establishment of the INT, with its vision that the future of the field depended on its rich intersections with particle physics, astrophysics and condensed matter, as well as the new directions at the NPL, where neutrino physics and precision tests of symmetries now lead the program. Most recently, in condensed matter experiment the department has strongly supported a new initiative to do material research at the very short wavelengths of the latest generation of light sources.

As in other rapidly moving fields, an essential component of preparing for the future involves identifying and exploring new research directions. There is concern at the University that we are entering a period of diminishing resources for research. Despite this, we believe we can continue to offer the University new research directions that will justify their support: to fail to do so will put in jeopardy the gains achieved in the last 30 years. While the following list is far from complete, the faculty are actively exploring directions such as the following:

- An attractive possibility is to build on the Department's current strength in atomic physics. Two avenues are being explored. The first is to build a group in the area of neutral atom traps and the laser manipulation of atoms and molecules, and, at the same time, to forge a connection with the biotechnology programs at the University that use these techniques. Interest in such an initiative has been expressed by members of the faculty in Molecular Biotechnology, Biochemistry, and Physiology and Biophysics. The second avenue is the creation of a center for fundamental precision measurements to capitalize on and enhance the strength and uniqueness of the existing program. Such a center could serve as an umbrella for the gravity, single ion, and atomic parity and edm research in the Department.

- Another possibility is to enhance our existing initiative in astrophysics, which has been marked by the arrival of Hogan and Stubbs during the past decade. The technical revolution that is occurring in astronomy and astrophysics is unprecedented: new technology telescopes, COBE, the Hubble Space Telescope, massive gravitational wave detectors (*e.g.*, LIGO in our own neighborhood), deep underground neutrino observatories, and satellite-bound detectors such as GRO are allowing us to probe the galaxy at wavelengths, at distances, and on time scales never before achieved. We could strengthen our investment in this area by moving into new areas that complement our gravitational lensing, neutrino, and theory efforts. Because of NASA's declared interest in deeper connections with university researchers, we see opportunities for new funding in this subfield.

- There is increasing interest in Biophysics, an interest whose origins lie in the changing patterns in both biology and physics. On the biological side, the focus has turned to the smaller scales inherent in molecular biology. On the physicist's side, there has been a growing body of work, particularly in condensed matter physics, focused on the larger scales evidenced in complex fluids, such as polymers. In addition, new microscopes, such as the Scanning Tunneling Microscope and the Atomic Force Microscope, and other technologies, such as laser tweezers, have permitted the study of biological systems in the physicist's laboratory. The increasing overlap of these realms is evidenced by work in physics departments on such subjects as the conformation of membranes, the mechanical response of DNA, the explication of molecular motors, and the folding of proteins. Studies of such systems are inherently interdisciplinary, a point of strength at the University of Washington, which has always had a commanding presence in the biological sciences. This interdisciplinary nature is reflected in the proposed University Initiative in Nanoscale Science, which includes faculty from the departments of Bioengineering, Chemical Engineering, Material Science, the Medical School, Chemistry, and Physics. A biophysics effort in the Department of Physics would be able to benefit from the existing programs on campus, serve the increasing number of students attracted to this area, and establish the Department in an field which is exciting and clearly growing.

- The extraordinary increases in computer power, with CPU speed and storage capabilities increasing by a factor of 100 per decade, is affecting every branch of physics, as well as the way physics is communicated. The Department has the basic building blocks in place from which a larger and more cohesive effort in numerical many-body physics could be launched: we have a strong presence in lattice gauge theory, and substantial many-body expertise in condensed matter and at the INT. The Department is currently a major partner in a proposal to the DOE Academic Strategic Alliance Program that also involves Astronomy, Applied Mathematics, Chemistry, Statistics, the INT, the Center for Molecular Biotechnology, Mechanical Engineering, and Computer Science and Engineering. Major points emphasized in the proposal are galaxy formation, MHD simulations of supernovae and in turbulent relativistic jets, solar system evolution, and the materials properties of large atomic systems. Strong university support for interdisciplinary efforts and national initiatives in computer-intensive research again make this an attractive area for growth.

Building on our successes of the past and on a lively spirit of innovation, we envision an even more productive future both in the areas that we currently serve and in new directions yet to be selected. The Department will work with the College and the University to help transform that vision into reality.