Department of Physics 2018 Self-Study

Natural Sciences Division of the College of Arts and Sciences
University of Washington, Seattle Campus

Degrees Offered:
Bachelor of Science in Physics
Minor in Physics
Master of Science in Physics
Doctor of Philosophy (PhD)

Year of last ten year review: 2008
Five year interim review: 2013

Department Chair: Blayne Heckel

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Submitted on September 21, 2018

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Part A

Section I: Overview of Organization

Mission and Organizational Structure

The Department of Physics contributes to the mission of the University by providing a solid and enriching education for our students; by making lasting contributions at the forefront of human understanding, and by communicating the excitement of science to our fellow citizens.

The Physics Department is one of the 5 large departments within the Natural Science Division of the College of Arts and Sciences (CAS). The department includes the Center for Experimental Nuclear Physics and Astrophysics (CENPA), the Institute for Nuclear Theory (INT), and the Physics Instrument Shop. Physics is home to 61 faculty-title employees (including 36 tenure track FTE supported by the CAS), 55 Professional and Classified Staff, 18 Postdoctoral Research Associates, about 180 graduate students, and about 450 undergraduate physics majors. Department faculty are listed in Appendix C. During the 2017-18 fiscal year, we provided over 53,000 student credit hours (SCH) of instruction and had research grant awards in excess of $21M. In the 2018 US News & World Report, the department was ranked 22nd in the nation. Faculty awards include 2 Nobel Prizes, 1 Wolfe Prize, 11 inductees to the National Academy of Science, and the Melba Phillips Medal for physics education research.

Degree Programs: The department has 4 degree programs: Bachelor of Science in Physics, Minor in Physics, fee-based Master of Science in Physics (Professional Master's), and Doctor of Philosophy (PhD). Table 1 shows enrollment and graduation patterns for each degree program.

Table 1: Enrollment and Graduation Patterns

Academic Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Undergraduate										
B. S. Degrees Awarded	54	57	69	83	102	108	110	132	141	173
Minors Awarded	12	13	10	13	16	8	8	12	12	15
Enrolled Majors (Spring)	249	254	292	345	382	385	405	458	426	452
Professional Masters										
M.S. Degrees Awarded		7	11	7	12	11	6	12	15	7
Enrolled	18	25	39	41	35	33	41	38	44	28
Doctoral										
PhD Awarded	15	22	20	13	14	19	24	17	25	17
Enrolled (Autumn)	140	136	137	143	152	145	153	145	142	151

Academic and Non-Academic Services: Budgetary and staff oversight is the responsibility of the department Administrator. Bi-weekly meetings between the Chair, Assistant to the Chair, Administrator, and IT Director provide good communication about current and anticipated administrative issues. Appendix A shows the Organizational Chart for the department staff.

Academic advising and student services are provided by 4 staff members: a Graduate Academic Counselor, an Undergraduate Academic Counselor, a Program Coordinator and a Program Assistant. Oversight of the academic advising is provided by the Student Services Committee which includes both faculty and staff. Two staff members support the introductory lab program and a staff of 2 supports our lecture demonstration facility. A staff of 4 provides IT support to the department (shared with the INT and Astronomy Department). The Physics Instrument Shop is a self-sustaining unit that includes 4 instrument makers and a glassblower.

It is our assessment that the physics staff is highly capable and productive, but that the department is under-staffed. Apart from inevitable retirements (including the department Administrator this autumn), turnover of department staff is remarkably low. We lost our main office receptionist position to past budget cuts, and we are in need of a staff member to handle donor relations, tracking of our degree recipients, and preparation of a department newsletter. "Workday," the new university personnel system has added very significantly to the workload of key staff members and may impact our ability to retain our current staff. The upcoming revision of the University finance system will add to these pressures.

Governance: Issues associated with the department operations, instructional programs, and faculty hiring are discussed at monthly faculty meetings, presided over by the department Chair. The Chair and three Associate Chairs, one each for the undergraduate program, graduate program, and research program comprise an Executive Committee whose role is to vet motions (both policy and appointment/promotion) that will be presented to the faculty, and to advise the Chair on decisions not requiring a faculty vote. The Executive Committee is also responsible for faculty merit reviews; the committee is augmented by additional members when raises beyond the 2% standard merit are authorized. Most of the business of the department is carried out in committees, listed in Appendix D. All faculty members are assigned to several committees and are expected to contribute constructively. Committees oversee our programs and make recommendations that typically become motions to be voted upon by the faculty.

Student representation is provided on committees whose purviews overlap with student issues. An external Professional Master's Advisory Board provides advice for the fee-based Master of Science program and about the skills that students need in the workplace. An external Frontiers of Physics Public Lecture Committee supports our public lecture series. Faculty participation on UW Senate committees and monthly meetings of the Chairs of the Natural Science Division departments provide information from other academic units. It is our assessment that the shared governance in the department works well.

Budget & Resources

Appendix B shows the budget of the department over the last 3 biennia. The department receives funds from the CAS in state budgets (GOF, DOF, & LOF), from endowment and royalty income, from an instructional lab fee budget, from the fee-based Professional Master's Program, and from research grants and contracts. The state budget growth reflects salary increases over this time period. The carry-forward on the state funds are unexpended committed faculty hire start-up funds. The lab fee budget derives funds from students enrolled in our instructional labs ($35 - $50 per student per academic quarter). This fund pays the salaries of the staff who manage the labs as well as providing funds for equipment and supplies. The Professional Master's Program generates, on average, a $70k annual profit for the department, used to bridge the salary of a tenure track faculty member. Royalties from physics education research publications are used to bridge the salary of another tenure track faculty member, and this year we are forced to support one lecturer on indirect cost return funds.

The department Chair and Administrator work together to monitor the budgets and ensure the best use of the funds. In 2018, the state budget of the department was cut by $130k, split between operations funds and TA positions.

The Physics Department does not have a strong record for raising funds from external donors. In recent years the department has been working closely with the advancement staff of the CAS to elevate our fund-raising capabilities. Until 2016, the department's primary connection to the outside world was through a Visiting Committee of local leaders from industry and a small number of alumni. The Visiting Committee was useful as an advisory board, but it was never able to spearhead our efforts to identify potential donors and generate outside interest in the department. At that time, Professor David Kaplan met with a local retiree who was interested in physics and the meeting resulted in a donation to the department to create a public lecture series for exciting topics in physics. The Visiting Committee was disbanded and an active subset of the committee joined with Professor Kaplan and other faculty members to form a Frontiers of Physics Public Lecture Series Committee. The lecture series has been a success. With invaluable help from the advancement team of the CAS, 5 public lectures have been presented by highly prominent speakers including 3 Nobel Prize laureates. Receptions and dinners associated with the lectures have identified a growing list of people who may be interested in providing support to the department. Going forward, we need build on our initial successes and nurture the contacts that we have been able to make.

Priority areas for fund raising include:

- Graduate fellowships for the recruitment and continued support of graduate students. Currently, the department has $6M of endowment for graduate student support.
- Endowed Professorships to recruit and retain outstanding faculty. The department currently has two (partially) endowed professorships.
- The establishment of a Thouless Institute for Quantum Materials to both capitalize on the recent Nobel Prize awarded to David Thouless and foster research in the area of quantum materials. See Appendix K for more information.
- The establishment of an Institute for Quantum Information and Computing to unify the efforts across campus in this emerging field. See Appendix L for more information.

It is clear that improving our ability to raise external funds needs to be a priority for the department. We have never had the resources to employ a staff member to produce an annual newsletter and to track and remain in contact with our alumni. We hope to partner with other departments that have the same deficiency to share the cost of an advancement staff member. In the meantime, the Graduate Academic Counselor of the department, Catherine Provost, is organizing an alumni association of local graduates of our PhD program. As we learn from this alumni association, we will be able to assess whether something similar can be done with our undergraduate degree recipients.

Unit Diversity

The Physics Department shares the commitment of the University to strive for a diverse faculty, staff, and student body, and to ensure welcoming and respectful learning environments. It is well known that the representation of women and underrepresented groups (URG) in physics is among the lowest in any STEM field. The problem continues to be a "leaky pipeline" whereby fewer women and URG students choose to pursue physics at each stage of their

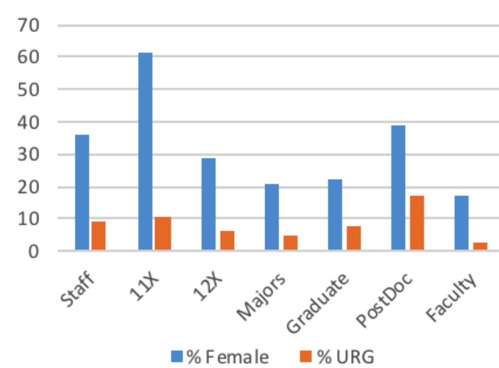


Figure 1: Diversity Overview for UW Physics

academic careers. The pipeline is distressingly empty when it arrives at UW Physics: for example, of roughly 1800 students choosing to take calculus-based introductory physics last year, only 3 self-identified as black females. Figure 1 shows the current fraction of women and URG in the department. 11X (life science majors) and 12X (pre-engineers) are the introductory physics courses. More detail on the program diversity is in Appendix E. The fraction of women in our majors program, PhD program, and our faculty are all slightly above the national averages in these areas (data for postdoctoral research associates was unavailable). It is evident from the data that diversity in physics remains a challenging problem.

Steps we have taken to improve diversity include:

- Offering Physics 101, a course to prepare students from disadvantaged backgrounds to be successful in introductory physics, and working with the Office of Minority Affairs & Diversity to populate the class.
- Sending department representatives and recruitment material to meetings of the National Society of Black Physicists and the Society for Advancement of Chicanos/Hispanics and Native Americans in Science.
- Providing funds to send undergraduates to the annual American Physical Society (APS) Conference for Undergraduate Women in Physics (CUWiP).
- Hosting the APS CUWiP both in the past, and again in 2019.
- Hosting an APS Climate Site Visit in November 2018, to solicit suggestions for interventions or changes that can address practices that may limit or reduce participation by women and underrepresented groups.
- Adding a town hall style meeting in place of the first colloquium of the year to discuss department goals for the year and to allow all members of the department to bring forth concerns they may have.
- Using endowment funds, ARCS and GO-MAP fellowships to enhance diversity in our graduate student body.
- Incorporating inclusive best practices on faculty search efforts

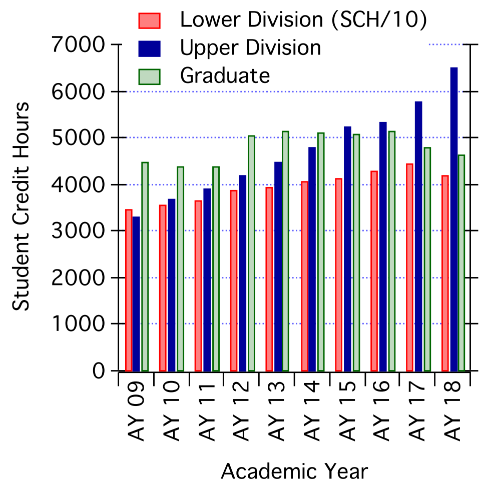
We believe that we are following best practices for the recruitment of women and URG to our graduate program and faculty. Appendix E also presents our diversity plan. Our primary problem is lack of resources. The competition with other institutions, also under pressure to increase diversity and often with resources to do so, is intense. In 2017, our graduate recruitment led to only 1 woman in an entering class of 31 students. In 2018, we redoubled our efforts to recruit more women and underrepresented students and we unexpectedly received a gift from an external donor of $130k for graduate fellowships. We were able to use that fellowship money to recruit 11 women and 1 URG student, in a class of 29 students, to enter our program in 2018. When resources are available, we can be successful.

In 2016, we made a generous faculty offer to Liuyan Zhao, who was the top candidate in a search in the field of experimental condensed matter physics. UW was her first choice, but her spouse held a tenure track position in Statistics at another institution and needed a similar position at UW. There was a time when the central administration at UW was able to provide support for strategic hires (such as when David and Margaret Thouless were recruited to UW), but no longer. The Office of the Associate Vice Provost for Faculty Advancement was unable to help. The only help the department received was advice from the Office of the Dean to forward the spouse's CV to other department chairs and hope for the best. Three other R1 institutions were able to provide tenure track positions to both Liuyan and her spouse; our offer was declined. Even with additional resources, increasing the diversity within our program will be a major challenge for the department in the coming years.

We have found that we are more successful recruiting female and URG faculty when searches are allowed to make multiple hires. In the last 10 years 3 female and 1 URG faculty were hired under these circumstances, while 2 additional offers to female candidates were made, but turned down.

Section II: Teaching & Learning

Figure 2. Enrollment Growth



Our instructional program serves many constituencies, ranging from non-science majors fulfilling a distribution requirement to doctoral students gaining specialized knowledge. The Bachelor of Science in Physics offers degree options in applied physics, biological physics, comprehensive physics and teacher preparation, as well as a minor in physics; the Master of Science in Physics is a flexible evening program aimed at working professionals, and our Doctor of Philosophy in Physics offers an option to obtain a dual-titled degree in Physics and Nanotechnology & Molecular Engineering. We provide introductory physics at five different levels that serve a variety of constituencies across campus and encompassing over 45% of those entering UW as freshmen: a one-quarter course for non-science majors (Phys 110), an inquiry-based quarter for students interested in STEM, but arriving at UW needing pre-calculus (Phys 101), a year-long algebra-based sequence serving primarily life scientists (Phys 114-5-6, referred to as 11x), a year-long calculus-based sequence (Phys 121-2-3, referred to as 12x) serving engineers and physical scientists (7% of whom go on to major in physics) and a year-long honors sequence (Phys 121H, 122H, 123H) that serves students in the university honors program or those who wish to see the introductory material at increased depth (20% go on to major in physics).

To meet the needs of this diverse instructional program, on average 43 classroom courses are taught each academic quarter. Lecture track faculty teach two courses per quarter while tenure track faculty teach one course per quarter.* Appendix F provides a list of the courses offered by the department along with the number of sections and the enrollments for both 2009 and 2018.

The migration of students to STEM fields has led to a significant growth in our instructional program over the past decade. The number of student credit hours (SCH) taught annually in the department has increased in the past decade, from 42,500 in 2009 to over 53,000 last year. As illustrated in Figure 2, upper division undergraduate credit hours have doubled, while lower division credit hours have increased by about 25%, driven by a nearly 50% increase in calculus-based mechanics (Phys 121); the graduate program has been stable.

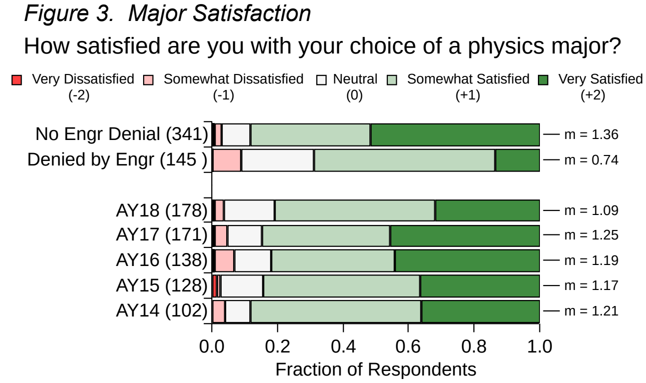
* Exceptions are INT senior fellows, who are funded by the Department of Energy, one quarter teaching release for the chair of the Graduate Admissions/Recruiting Committee, two quarters release for the Director of CENPA, and one quarter release per year for Assistant Professors in their first three years.

Our physics education research group is actively involved in developing and evaluating curricula incorporated into our instructional program. Pre-test and post-test data are regularly reviewed and curricula are modified in response. Concept-focused tutorials and interactive lectures developed at UW form a vital constituent of our introductory courses, and have been implemented across the country. We also benefit from being the test bed for newly-developed tutorials at the 300-level that help students learn advanced concepts in electricity and magnetism and in quantum mechanics. We are building on recent physics education research, both at UW and elsewhere, to develop better practices that promote equity and inclusion in physics instruction.

The department takes evaluation and assessment seriously. An Instructional Quality committee observes and evaluates each faculty member on a rotating three-year cycle (more frequently for junior faculty). Student evaluations are required in at least one course each academic year, and this autumn we will initiate an opt-out system that will automatically order online evaluations for each course. Both peer and student evaluations are consulted during the merit review and promotion process and are also considered when making teaching assignments. The Introductory Physics committee conducts a separate survey on course structure and content.

Overall feedback on the undergraduate program is obtained from the Senior Exit Survey, which seniors are required to fill out when applying for graduation. These data are reviewed by the Student Services and Majors committees to inform changes in the program. Figure 3 shows high levels of satisfaction with students' choice of a physics major, although those who report choosing physics as a back-up major after being denied entrance to engineering are significantly less satisfied than those who did not. There is no significant variation with graduation year. Starting in Autumn 2018, the College of Engineering is admitting freshmen directly to the College (DTC) and telling other students they are not likely to be able to major in Engineering; we cannot predict the impact of DTC on the physics major, but are hopeful it will decrease the disappointment expressed by these students. Appendix F shows Exit Survey evaluations of the value of our majors courses. Based on these data, we made, for example, the 200-level *Particles & Symmetries* class optional for the applied and biophysics tracks, and reassessed the required seminars 294 and 494-5-6.

Figure 3. Major Satisfaction



Introductory Physics

The largest components of the department's instructional program are the introductory physics sequences: roughly 40% of faculty teaching assignments and 60% of teaching assistant hours support these courses and their associated laboratories and tutorials. On average, 15 lecture sections are taught each academic quarter in the two large physics auditoria (with access to our lecture demonstration collection). The lectures are accompanied by 90 sections of introductory physics labs (serving both classes) and 70 tutorial sections (serving 12x). Over the past decade, we have accommodated a 15% increase in lecture sections, 8% increase in labs (fewer 11x students are taking its non-required lab) and a 36% increase in tutorials. While the most recent year shows a drop in the 12x population, the number of enrolled UW freshmen expressing an interest in STEM dipped slightly in 2017, but is 7% larger this year, which will likely continue the upward pressure on the introductory sequence. Courses aimed at non-science majors have seen decreasing enrollment except for a new course on sustainable energy sources. Several faculty who have been teaching these courses recently retired, and newly assigned faculty are revamping them to make them more relevant to a diverse audience.

The introductory sequences aim to afford an overview of physics while also teaching the key transferable skills of problem solving and mathematization. We have hired four full time lecturers in the last three years, based on national searches. One is supported by a CAS faculty line, two are supported by our Professional Master's Program (but teach in the intro physics sequences), and one is supported by a combination of faculty leave recapture and indirect cost return. It is our intention that these positions will be long term (and promotable) as 2/3 of our introductory physics students are taught by lecture track faculty. Our lecturers have all been trained in evidence-based teaching through the UW's Center for Teaching and Learning. Having a consistent set of instructors with some common training has allowed us to make major changes to the introductory classes over the last three years, with most classes now using evidence-based practices. In conjunction with the department's physics education research (PER) program, we have now implemented interactive lectures into the algebra-based classes. These materials have previously been shown to have a significant positive impact on student learning in the calculus-based classes.

Our lecturers have developed extensive materials to share with faculty who do not regularly teach these introductory courses. This has lowered the barrier for additional faculty to adopt an evidence-based teaching style. Less class time is spent giving a traditional lecture, and more time devoted to engaging the students with a think-pair-share model, where students are first asked to think about a question on their own before small group discussion. Finally, a group is selected to share their discussion with the class, and instruction is then focused around those discussions.

An ongoing effort that we expect to complete within two years is restructuring the introductory labs. The goal of this overhaul is to de-emphasize specific physics content in favor of learning general skills such as how to design an experiment, how to assess experimental results, and how to work effectively in groups. These skills are better aligned with what has been shown to be a primary benefit of labs, and with future career skills likely to be relevant for most students.[†]

Finally, our excellent lecture demonstration facility continues to play an essential role in introductory physics instruction. Demonstrations engage the students and, when integrated well into the curriculum, they are shown to increase student learning.

Undergraduate Physics Majors & Minors Programs

The undergraduate physics major has undergone dramatic changes in the past decade. As shown in Figure 4, the annual number of graduates has essentially tripled, from 54 in 2008-09 to 175 in 2017-18. In 2015-16, we graduated 1.6% (134/8440) of all physics bachelors in the U.S., one of only three U.S. institutions with more than 100 graduates. Our recent rate of growth is two to three times that of our comparison populations: national physics bachelors, UW Engineering bachelors, other UW STEM bachelors, and UW freshmen interested in STEM.

[†] See "Phys 21: Preparing Physics Students for 21st-Century Careers," Joint Task Force on Undergraduate Physics Programs, Paula Heron and Laurie McNeil, Co-Chairs (www.compadre.org/JTUPP/docs/J-Tupp_Report.pdf)

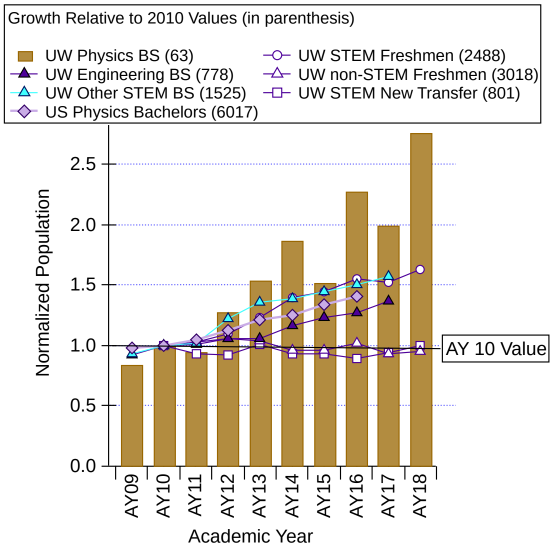


Figure 4. Normalized Growth of Physics Bachelors and Comparison Populations.

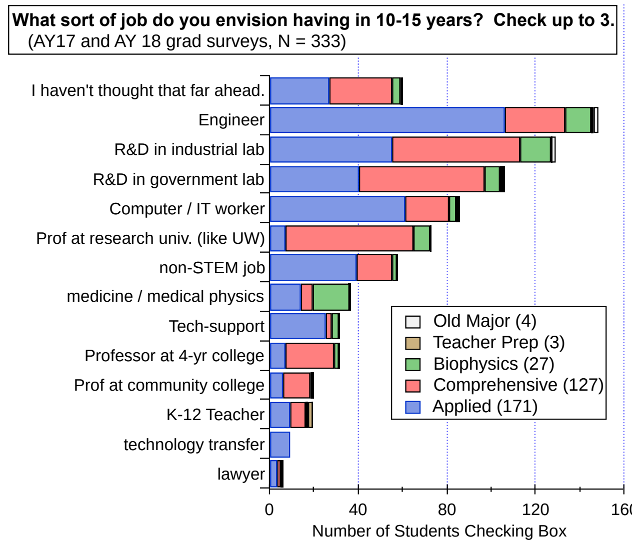


Figure 5. Physics undergraduates career goals. Average # of checked boxes = 2.3.

A significant reason for the size of our physics major is the flexibility of our program to help students prepare for a wide range of careers. Physics students learn how to solve complex problems and apply mathematical models to the world, which are highly transferable and applicable skills. Figure 5 shows the results of an exit survey question on career goals. In view of the diverse career goals of our undergraduate population, in 2011 the Department instituted four distinct degree options, or "tracks" as well as a physics minor. The four tracks – Comprehensive Physics, Applied Physics, Biological Physics and Physics Teacher Preparation -- share a two-year common base of physics and math, and differ in the focus of their electives.[‡]

The Comprehensive track (45% of majors in Sp18) is aimed at students who wish to pursue graduate study in physics or a related field; it requires most of the 300-level core physics courses, plus advanced laboratories. The Applied track (44% in Sp18) is aimed at students who will pursue a technical job with their bachelor's degree, with required courses in laboratory data analysis and computing reducing the number of math-intensive physics courses. The Teacher Preparation track (1.5% in Sp18) requires students to take courses developed by our physics education group. The Biological Physics track (7% in Sp18) prepares students for careers or further schooling in biological physics or other biomedical disciplines, and requires introductory chemistry and biology plus a course in biophysics.

Much of our recent growth has been in the Applied Physics track. This reflects the position physics has held as a back-up major for students who arrive at UW interested in engineering. Exit survey data reveal that about half of our Applied Physics (114/221) and Biophysics (19/39) graduates applied to and were rejected from one or more departments in UW Engineering before declaring a physics major; this contrasts with only 5% (10/184) of those in the Comprehensive track reporting rejection from engineering. The Biophysics track is also popular with transfer students who have completed introductory chemistry, biology and physics at community college.

[‡]Specific requirements may be found at https://phys.washington.edu/major-requirements.

Until 2016, there were no entrance requirements for the physics major. A significant number of students declared a physics major without ever intending to take physics, many of whom left UW without a degree due to poor scholarship, and many students were under-prepared for upper-division coursework. To alleviate these problems, physics applied for and became a "minimum requirement, non-competitive" major. To set evidenced-based admissions criteria, we sought early predictors of eventual graduation or failure through a transcript review of students who had recently taken our required 200-level mathematical methods course. This class is not offered at local community colleges and is a prerequisite for 300-level electrodynamics and quantum mechanics. Our goal was to identify students exhibiting a mismatch between their skill set and the physics major as early as possible, and to help them either acquire those skills or select a major for which they are better suited. We also require that students develop a graduation plan as they declare to avoid an identified problem of drifting through the major. The criteria for transcript-based admission, as well as the petition process for those not meeting the criteria, are at https://phys.washington.edu/declaring-major.

Initial data from the new major admissions criteria are promising. Figure 6 shows the number of students who spend only one quarter as a physics major (hatched) has decreased, as has the number of majors dropping out of the university (red). Our retention rates from declaration (blue) to graduation (brown) have also significantly improved since we created the four degree options. The next step is to implement a major continuation policy based on satisfactory progress. The policy has been developed and approved by the physics faculty; it will work its way through the appropriate reviews at the College and University level this academic year.

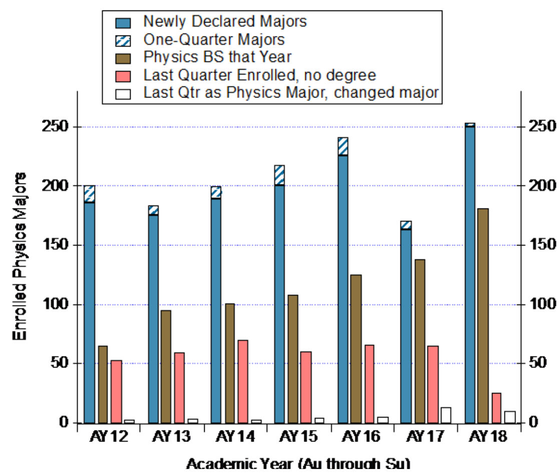


Figure 6. Net change of physics majors each academic year.

The increase in the major population has changed the classroom environment for our physics majors. It is qualitatively different to take thermodynamics, quantum physics, and electro-dynamics in a class of 30-40, where the professor can at least recognize everyone, if not learn each name, versus a class of over 150, where students may both feel and act as though they are anonymous. Our conceptual tutorials in the 300-level *Electricity & Magnetism* and *Quantum Mechanics* classes give students a group of 20-25 with a TA for one hour per week, build community, and provide avenues to form study groups. However, the 200-level courses are large classes without break-out sections, and are in great need of additional support. Currently available resources provide only about 10 minutes of teaching assistant time per student-week, including all grading of homework and exams, plus any office hours or review sessions. These 200-level gateway courses to the major can be especially intimidating as a first physics course for students transferring from community college, who can have a hard time joining study groups formed earlier, during the 12x labs and tutorials, or meeting new people in a huge class. Nonetheless, exit surveys of our BS degree recipients indicate a high degree of satisfaction with our majors courses, as shown in Appendix F.

Another significant curriculum issue is the capstone experience: students are required to complete three credits where they independently apply physics outside the classroom or participate in a (1 credit/qtr) seminar where students present on current topics in physics; students in the Teacher Preparation track are required to do a teaching practicum with a research focus. Ideally, each student would have the opportunity to experience physics as a creative and contemporary endeavor, working closely with a faculty member. However, the fraction of graduating students reporting difficulty in finding a research experience has been increasing in recent years, now at 17%; about half report having participated in research before they apply for graduation. Of 2017-18 graduates, about a quarter of graduates fulfilled the capstone requirement with three credits of senior seminar, about 35% with only research or teaching in physics, and an additional 5% with a mix of the two. The remaining third of graduates satisfied the capstone requirement with an experience outside the department, with Astronomy, the Applied Physics Lab, and Earth and Space Sciences the most common hosts. The supervision of undergraduate research is not evenly shared throughout the physics department: in the past three years, 6 faculty members supervised over half the undergraduate physics research credits, and only 8 of over 260 students have been supervised by a theorist. A list of physics majors presenting at the Mary Gates Undergraduate Research Symposium for the past three years may be found at https://phys.washington.edu/undergrad-research-symposia, which shows that many students are supervised outside the department.

Physics Student Services has undergone several changes to accommodate the increase in majors. We still have only a single Undergraduate Academic Counselor, although the Graduate Academic Counselor now spends a portion of her effort helping advise undergraduates on graduate school admissions and working to increase diversity in our undergraduate program. In Autumn 2016, the department hired a Student Services Program Assistant to take over many non-advising activities previously handled by the academic counselors. The Student Services Area was rearranged to create both a welcoming foyer and a space for the UFA to hold regular office hours. This has both increased communication between the UFA and the academic counselors, and made the UFA more approachable to students. The UFA handles academic advising, major declaration petitions, degree requirement substitutions, transfer course equivalencies and any other actions that require faculty permission; she also is liaison to the Society of Physics Students and writes and analyzes annual surveys of our majors and monitors undergraduate statistics. In addition to advising available all year through the Student Services office, the department holds Annual Spring Advising prior to the opening of Autumn registration, wherein students meet with a faculty member. Students are told this is required, but the requirement is not enforced due to a lack of resources.

Our chapter of the Society of Physics Students (SPS) was deemed "outstanding" by the national organization in 3 of the past 4 years. SPS holds weekly *Lunchbox Seminars* with the colloquium speaker, typically attended by 10-15 students and the UFA. Besides helping students learn about new developments in physics, these weekly sessions provide an avenue for informal feedback to the UFA. SPS sponsors a number of events throughout the year, including lab tours, research symposia, and social events. It tends to attract the subset of majors who are graduate school bound, and one goal is to expand the range of students participating. A new organization, *Undergraduate Women in Physics @ UW*, was launched last spring.

The UFA hosts several informational meetings each year. A meeting for grad-school-bound juniors and seniors has been held in late October for a number of years. Three years ago, we added a Career Panel in February for students aiming to join the workforce after graduation. With the new major requirements, we instituted an information session for prospective majors in the autumn, and last spring held a similar session during an evening class of Physics 12x. We held our first orientation for new majors in Autumn 2017, and will continue this practice.

The College of Arts and Sciences will start admitting freshmen directly to the Natural Sciences Division in Autumn 2020 (DTD). The impact of Direct-To-College and Direct-To-Division admissions on the physics major is difficult to predict. Hopefully, students will choose a physics major earlier in their studies, instead of waiting through one or more engineering admissions cycles. The most common reason reported by graduating students as to why it took more than four years to complete their physics degree is "I changed majors or declared a major late" (50% of students giving at least one reason, 37% of all students). We also hope that DTC/DTD will decrease number of majors who report resentment on our graduation surveys about the "bait-and-switch" of admission to UW and their inability to major in engineering or computer science.

Professional Master of Science

The Professional Master of Science Program in Physics (PMSP) provides a track to the MS degree in Physics for part-time evening students. It is the only terminal master's degree program we offer; PhD students may obtain an MS degree as part of their progress toward a PhD, but full time graduate students are not admitted solely to pursue an MS degree. Our professional masters is also the only terminal MS in physics offered in Washington State. The primary goal of this program is to broaden and extend the physics education of scientists and engineers having BS degrees who work in local industry, and increase connections between the regional tech community and our department. We have about 40 students in the program at any given time.

At the time of its inception in the 1970s, the Evening MS degree program was state supported. State support became inadequate to maintain quality, and since 2009 our PMSP has been administered as a fee-based, self-supporting program, one of over 100 degree programs managed by UW Professional and Continuing Education (PCE), a division of UW Continuum College. All academic aspects: admissions, requirements, curriculum, and standards, are determined entirely by the Physics Department while PCE handles registration, tuition collection, and administrative support. As a self-supporting program, we can expand our resources to meet expanding enrollment and are not dependent upon state funding. Our policy is to keep the PMSP tuition rate per credit hour at the same level as the resident graduate tuition charged by UW's state-supported degree programs.

Originally, most PMSP students were employees of Boeing. Boeing remains a significant source of PMSP students through their Learning Together Program, which pays tuition for qualified employees and provides promotions and raises for employees completing an advanced degree. Today our student body comes from many sources, including employees of other regional tech companies (some of whom also offer their employees tuition aid and other forms of support), engineers, teachers, military personnel, and people who simply want to learn more physics. An increasing number of applicants are recently-graduated BS students in physics, math and engineering who want to enter the job market with a more advanced degree.

Our admissions process is deliberately inclusive, recognizing the fact that most engineering and physical science BS degree programs include material overlapping courses taken by physics majors. Our applicants are often interested in moving out of routine bachelor's level technical jobs into more creative R&D work. An applicant is admitted if their undergraduate transcript indicates decent grades in physics or physics-equivalent courses - a 3.0 (B) average in relevant courses. In addition, we ask applicants to provide a statement of purpose. This is not an essay contest, but is used to ensure that the applicant's goals and expectations mesh with our program's capabilities.

Each student must successfully complete at least 36 graduate credits. A minimum of 18 credits of graded classes are required, and must include three designated core courses. Elective classes on a wide variety of topics are offered each quarter (except summer). All evening classes are taught by members of the department faculty, most of whom lead grant-supported research groups. Our PMSP students tell us that a major attraction of this program is that courses are not taught by temporary part-time instructors, but by full time university faculty. The ability to work with leading-edge researchers is another important attraction.

Each class meets two evenings per week, with a typical class size of 15 to 20 students. All lecture courses may be attended online, via Zoom conferencing software provided by PCE. We encourage students to attend in person whenever possible, but online sessions are recorded and may be reviewed at any time. As traffic in the Seattle area worsens, many of our students now prefer to attend online, and instructors teach some class sessions online only. We have also begun admitting students from outside the Seattle area, after ensuring they understand the limitations of fully online class participation.

Students may arrange independent study courses with any faculty member. They may also (with prior approval) take physics-relevant courses (400 and above) in other departments such as Astronomy, Chemistry, Electrical Engineering, etc. (PCE handles registration and tuition collection for such courses and coordinates with the other department, so our program receives revenue for students taking these classes.)

A final independent study project is required of all students, on a topic of their choice, supervised by a physics faculty member or adjunct faculty member (i.e., UW physics faculty whose primary appointments are in other departments). Students may work with a faculty mentor's research group, or find a faculty member to supervise a topic of personal interest. The topic may be related to the student's employment, provided a faculty member is available to supervise and the employer agrees that the student's report must be public information.

After completion of credit requirements and submission of a written report on the independent study project, students receive the MS degree after passing an oral exam before a committee of two or more faculty members. More information on the program is available at: https://www.physicsmasters.uw.edu.[§]

Our biggest challenge going forward is improving the marketing of the program so that we can maintain, or preferably grow, the student enrollment. In recent years, the PMSP program has generated net annual revenue for the department varying between $40k to $120k.

PhD Program

The Physics Doctoral program aims to ground students with broad physics knowledge as well as guide them to sufficient depth in a particular area to contribute significantly to the advancement

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[§] We also have a LinkedIn group, https://www.linkedin.com/groups/6523919 of knowledge. These aims are evaluated through the Masters Review, General Exam, Dissertation, and Final Exam.

The Physics Graduate PhD program has a typical enrollment of 150 students. Incoming class size varies from year to year, but is usually in the range of 23-28 students. This pattern has been stable over many years and is set by the size of the faculty, the level of research funding, and the number of teaching assistantships. Students in good standing are fully funded by research or teaching assistantships (RA's or TA's), or by outside fellowships. Most graduate students enter our program with a TA appointment and transition to an RA appointment in their second or third years.

About 20% of our physics graduate students pursue PhD research with adjunct faculty. The UW provides a rich environment for inter-disciplinary research with a large number of physics PhD's holding faculty positions in departments across campus. Many students working with adjunct faculty are pursuing research involving biological processes or astrophysics.

The international student component in our graduate program has been stable over the years at about 20%. Such students represent about 1/3 of all graduate applicants each year. Undergraduate preparation in these students is often at a higher level than in the US, but cultural and language barriers can easily inhibit success in our program making the selection process a difficult task.

Diversity, Admissions and Recruitment: Our program currently includes 3 Native Americans, 1 African American, 8 Hispanic Americans, 6 ARCS fellows,[**] and 7 NSF fellows. Over the last 9 years, we made significant progress on increasing the gender diversity of our graduate student population; currently 22% of our graduate students are female. The national average for physics PhD's earned by women remains low, at about 20%. See data in Appendix E.

We restructured our admission and recruiting process in 2010 with the goal of increasing the fraction of female graduate students to above the national average. Since then, 20-29% of the students in our graduate program have been female. Maintaining our current gender balance represents a struggle. Competition from other top physics departments is significant and we suffer from endemic disadvantages such as low TA/RA stipends (about $28k/yr for our TAs, compared to $34k/yr for NSF graduate fellows) and high living expenses. We have limited endowed resources to fund special recruiting fellowships. We are grateful to the ARCS Foundation for supporting our diversity efforts in the form of 2-3 ARCS fellowships annually. Diversity is a priority at UW, but that has not translated into tangible central support for graduate recruitment.

The recruitment of graduate students is a department-wide effort that begins with the Graduate Admissions/Recruitment Committee, consisting of 8-10 faculty members representative of the various research opportunities offered by our department. We admit about 100 students from an applicant pool of 500-600. About 40 of the most promising and responsive admitted students are invited to attend our Visiting Weekend, a two day event in early March during which students visit research labs, meet with faculty in small groups, lunch with current graduate students, and join a department-wide dinner in the Walker-Ames Room of Kane Hall.

[**] ARCS = Achievement Awards for College Scientists, recruitment awards to increase the participation of underrepresented groups in our graduate program.

Beginning Research: Graduate students are admitted to the department as a whole, not directly into a specific research group, unlike some other disciplines on campus. Students often select their PhD adviser during the first year, but it is not uncommon to switch or join research groups in the second year or even later. We offer a special 1 credit course in the autumn of the first year*, Introduction to Research* (Phys 528), in which faculty summarize their research. The next quarter, in winter, all first-year students are required to sign-up for at least one credit of *Independent Research* (Phys 600), attend group meetings of at least one research program, or start a reading project with a specific faculty member. Research typically starts in earnest late in the first year, and by mid-way through the second year most students are engaged in research which will eventually lead to their PhD. The first-year course schedule has flexibility to allow students to move sooner or later into research by deferring some core classes to their second year. More details can be found on our WEB site, https://phys.washington.edu/phd-program .

The transition into graduate school poses several barriers that can necessitate considerable mentoring and individual advising. These include adjusting to a new environment at the UW, the demands of the required 1st year courses, and the transition from structured course work to performing original research. We provide two levels of advising and mentoring during the first year. Each student has a peer mentor, a second or higher-year graduate student. They meet informally and also twice each quarter as a group during "peer mentor tea". Every graduate student has also a first-year academic faculty adviser. This faculty adviser continues in that position until the student has found a PhD adviser and formed a Supervisory Committee. One faculty member of the supervisory committee takes on the role of Faculty Mentor, willing and able to serve as adviser or confidant on issues beyond the thesis specific research. More details of our mentoring program see, https://phys.washington.edu/advising-and-mentoring-program .

Master's Review: In 2011, we made fundamental changes to our Qualifying Exam, responding to the view that the stress induced was not commensurate with its educational value. Our current alternative, the Master's Review (MR), includes Master's Review Exams (MRE's) which are the final exams of four first-year courses: *Statistical Mechanics* in the autumn, *Electro-Magnetism* and *Quantum Mechanics* in the winter, and *Classical Mechanics* in the spring. The Exam Committee works with the course instructor on the preparation and grading of exams. Students who pass all 4 automatically pass the MR. Students who pass 3 of 4 MREs have their progress reviewed by a Master's Review Committee (MRC) at the start of their 2nd year; they pass the Master's Review if they have demonstrated established research. An overwhelming majority of students do pass the Master's Review by this point.

Students who fail in their first attempt to pass the MR participate in a special *Qual-Prep Course* offered in their second year. Enrollment in this course is typically below 8, allowing individual tutoring. Except in special circumstances, e.g., students with an especially weak undergraduate program preparation, the deadline for students to pass the MR is the end of their 2nd year. This somewhat complex hybrid review format has proven to work reasonably well in practice. The few students who do not succeed typically combine weak course work performance with an inability to establish a research home after two years in our program. Such students have the option to leave the program with a thesis-based Master's degree.

Figure 9 shows the status of students in the graduate program, organized by entry year, with colors indicating progress in the program. The red bars represent students who have not yet passed our Master's Review (the Qualifying Exam). This includes the entire 2018 incoming class,

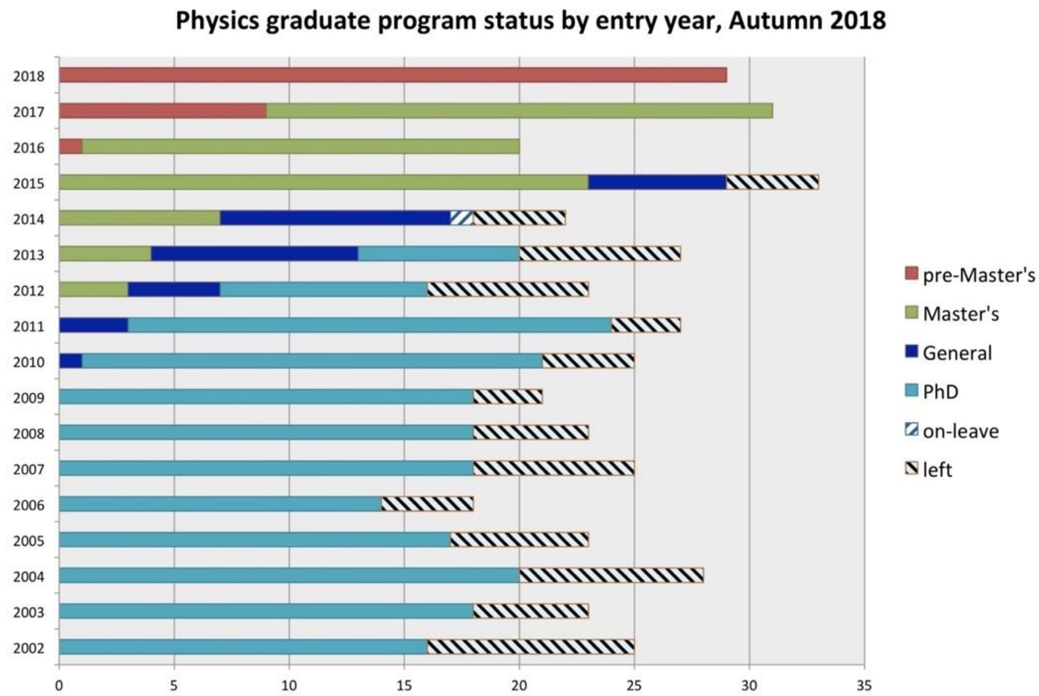

Figure 9: Progression of graduate students towards a PhD.

part of the 2017 class, and occasional students from earlier years who entered the program with gaps in their undergraduate. Green bars represent students who passed the MR but not yet the General Exam; purple bars represent students in between the General Exam and Dissertation Defense Exam; blue denotes students who received their PhD; hashed bars denote students who left without a physics PhD (including some students who transferred to a different doctoral program).

Graduate Curriculum: We offer a wide array of graduate courses beyond the first year core classes. These include annual offerings such as quantum field theory and solid-state physics, biannual offerings like atomic physics and general relativity, plus several special topics courses every year. The number of special topics courses has decreased as the undergraduate teaching load has increased. We view our broad course offerings as essential for providing adequate breadth and depth in physics graduate education. Students are expected to take all courses directly related to their PhD research area plus at least two courses that are clearly distinct from their own field of expertise. The graduate committee periodically reviews our course offerings and proposes changes (such as a recent recommendation to split *Numerical Methods* into distinct theoretical methods and statistical data analysis offerings).

Time to Degree and Outcomes: Our average time to the PhD has decreased a bit, approaching 6.0 years from about 6.3 a decade ago, but this data are noisy. We are beginning to see evidence that our Master's Review process is contributing to this decrease by allowing students to begin research earlier in the program. The number of students leaving our program without a UW Physics PhD fluctuates year by year, but averages about 18%, consistent with the national average. This number includes students who transfer and successfully complete a PhD elsewhere (e.g., 3 students went with Professor Dam Son when he moved to Chicago). Under the current system it is unusual for any student to drop out during the first year; almost all students earn at least a Master's degree. Reasons some students drop out in later years are diverse and complex, but high paying jobs in the software industry often play a role.

While individual faculty members track the careers of their former PhD students, the department does not have good database tracking all students. We are working to remedy this. The general trend in post PhD employment continues to evolve. Many of our graduate students remain in academia and reach faculty positions at top universities, but a growing number of our PhD's move immediately, or after a short postdoc, into the software industry, not only at large companies like Google, Microsoft, and Amazon, but also at many small startups. Programming is easily learned but the mathematical foundations, problem solving skills, and independent thinking that a Physics PhD provides continue to be highly sought after.

Our elected Physics Graduate Student Council provides feedback and advice to the department about issues that affect our graduate program. The student-run Career Development Organization hosts an annual workshop with representatives from industry and national labs.

It is our assessment that our graduate program is strong, although we continue to look for ways to provide more support for our students.

Section III: Scholarly Impact

The UW Department of Physics has a record of world class contributions in many areas of physics. This distinguished history includes ground-breaking work on precision measurements of trapped ions, recognized by a Nobel prize (Dehmelt, 1989), studies of phase transitions and low temperature physics, key advances in quantum field theory and inflationary cosmology, short range tests of gravity, many contributions to nuclear and particle physics, the elucidation of topological effects in condensed matter systems, also recognized by a Nobel prize (Thouless, 2016), and foundational contributions to physics education research, recognized by the AAPT Phillips medal (McDermott, 2013). Department faculty, postdocs, and students have received numerous additional awards and honors. Selected recent honors are listed in Appendix G.

At present, the department has noteworthy strength in nuclear physics and physics education research. In nuclear physics, the department has two DOE-funded Centers of Excellence, the Institute for Nuclear Theory (INT), described in Appendix H, and the Center for Experimental Nuclear Physics and Astrophysics (CENPA). CENPA is devoted to precision tests of fundamental physics; current efforts include leadership or major involvement in efforts to directly detect dark matter (ADMX, DAMIC), measure the neutrino mass (KATRIN, Project-8) and muon anomalous magnetic moment (Muon *g*-2) to unprecedented precision, and search for neutrinoless double beta decay (MAJORANA, LEGEND).

An emerging area of strength in the department is condensed matter experiment, with particular emphasis on novel properties of two-dimensional and layered materials. Several of our condensed matter faculty have become a core component of the NSF funded Material Research Science and Engineering Center led by UW Chemistry, and a DOE funded Energy Frontier Science Center led by Columbia. A few more synergistic hires in this area should achieve the critical mass needed to lead similar centers in the future.

For many years, this department has been one of the top U.S. physics departments in terms of the number of physics Bachelor degrees awarded. While many of our Ph.D. graduates and postdocs have chosen to move into hi-tech industry, government lab, or teaching positions, a great many have pursued successful careers in academia (see Appendix G).

Currently funded research projects are listed in Appendix I. The amount of interdisciplinary research within the department has grown substantially during the past decade. Six of our faculty hold joint appointments with other departments or units (Materials Science and Engineering, Electrical Engineering, Bioengineering, and the Institute for Learning and Brain Sciences), and six of our faculty hold adjunct positions in other departments (Chemistry, Astronomy, EE, Microbiology). In addition, we have 20 adjunct faculty whose primary appointments are in other departments (including Physiology and Biophysics, Chemistry, Electrical Engineering, Material Sciences and Engineering, Earth and Space Sciences, Aeronautics and Astronautics, Radiology, Applied Mathematics, Oceanography). Roughly 20% of our graduate students choose to pursue research with our adjunct faculty.

As one would expect, a huge fraction of contemporary physics research, in this department and elsewhere, is highly collaborative. Most research publications involve authors from multiple institutions working in collaborations ranging from a few people to thousands. Mentoring students to work effectively in collaborative efforts is an important part of modern education.

We strive to help new faculty establish their research program as well as develop or improve their teaching skills. UW provided startup funding allows new faculty to begin building a lab and supporting students or postdocs for a limited period before securing external funding. Assistant professors are given reduced teaching and service assignments during their first three years. Peer teaching evaluations (in addition to student evaluations) are performed annually, and faculty are encouraged to consult with the UW Center for Teaching and Learning, and with our local physics education group. Teaching in the introductory physics courses (in which all new faculty must demonstrate effectiveness at some point) are team efforts, with much mentoring of faculty new to the system. Every assistant professor has a collegial review committee with which they meet annually to discuss progress, challenges, and expectations for the future. And the chair meets annually with all promotable faculty to discuss progress and expectations.

Section IV: Future Directions

Experimental research in the department underwent substantial renewal during the past decade, with over a dozen hires of state-funded tenure-track faculty. Most of these hires supported new experimental activities within CENPA or were part of our effort to build strength in condensed matter physics. Collectively, our recent faculty hires have been extremely productive in research, responsible for much of the recent growth in the department's total research funding (up over 40% in the last six years, now exceeding $21 M/yr). Looking forward, our experimental faculty have a healthy demography with only two or three of our most senior experimental faculty likely to retire during the coming decade.

On the theoretical side of the department, the next ten years will be a period of major renewal. Nearly all state-funded tenure-track theoretical faculty, eight in total, are expected to retire (or depart) during the next decade. This includes all current particle theory faculty, all but one state-funded nuclear theorist, and half of our condensed matter theorists. The maintenance of a balance between theory and experiment is essential to the continued success of the department, not only for excellence in theoretical physics, but also as a necessary component for the recruitment and training of students, the teaching of our graduate courses, and the creation of synergistic interactions between experimentalists and theorists essential for much cutting-edge research.

Vision

The upcoming period of turnover of theoretical faculty provides an opportunity to assemble the talent and expertise needed to address many of the most compelling questions in contemporary physics, and to achieve greater diversity in the faculty as a whole. Crafting a clear vision of future research priorities is always challenging, but two broad themes encompass much of what we believe should constitute major research efforts within the department in the coming decade. These are:

Quantum Materials and Quantum Information: This thrust includes a wide variety of work, both experimental and theoretical, whose common thread involves efforts to understand highly entangled, strongly correlated or strongly coupled systems. These efforts include:

- The very active field of two-dimensional and layered quantum materials in which it is possible to tune many parameters (composition, doping, strain, ...) and produce materials with remarkable properties like topological insulators, superconductors, Weyl metals and strongly correlated phases such as electronic nematics.
- Study of exotic phases of matter such as quark-gluon plasma, the dense gluonic state produced in electron-ion collisions, and high density nuclear matter, whose equation of state is central to understanding neutron star properties. Over the coming decade, it is likely that electromagnetic and gravitational wave observations of neutron star binary systems will lead to unprecedented insight into properties of dense nuclear matter.
- Study of engineered many body systems realized in trapped atomic systems, where it is possible to manipulate directly the effective interactions between atoms and probe the resulting dynamics. For example, it is now possible to create lattices of trapped atoms with interactions which mimic some of the most important, and incompletely understood, models of strongly correlated electrons, thereby creating “quantum simulators” for systems which cannot be effectively studied on classical computers.
- Elucidation of possible topological phases of matter, their properties, and their realization in both theoretical models and real materials. In the last decade many new topological materials have been found, including the recent discovery in this department of the 2d topological insulator phase in monolayer tungsten ditelluride. The non-locality inherent in these materials has implications for encoding quantum information in a decoherence-free manner, as well as connections to the study of anomalies in quantum field theory, making this a vibrant area at the intersection of condensed matter and particle theory.
- Study of the deep structure of consistent quantum field theories, dualities between gravitational and non-gravitational theories, and connections between quantum information and gravity. The discovery of gauge/string (or AdS/CFT) duality has made clear that fundamental questions about black hole information loss and quantum gravity are directly related to aspects of entanglement and quantum information in non-gravitational quantum field theories.

Physics Beyond the Standard Model: The search for new physics beyond the standard model remains a vital endeavor. Observations of non-zero neutrino masses, dark matter and dark energy are compelling indications of the incompleteness of the current standard model of particle physics. It is not possible to predict whether the most significant breakthroughs will come from high energy accelerator experiments producing new particles, high precision measurements detecting small departures from standard model predictions, terrestrial dark matter detection experiments, or astrophysical observations of the early universe. The department has longstanding and ongoing efforts in all these endeavors. Participation in complementary searches for new physics, particularly where there are opportunities to play a leadership role, must continue to be pursued. Such efforts include:

- High precision tests of fundamental properties. This is a long-standing specialty of CENPA, with experiments ongoing and in development measuring neutrino mass (KATRIN, Project-8), the muon anomalous magnetic moment (Muon *g*-2), neutrinoless double beta decay (MAJORANA demonstrator, LEGEND, Selena), and probing short distance gravitational forces. The coming decade will see results from KATRIN and muon *g*-2, the start of the ton-scale phase in the search for neutrinoless double beta decay, and undoubtedly new starts and progress on other innovative experiments.
- Dark matter direct detection. The second generation axion dark matter experiment ADMX, located at the University of Washington, has reached unprecedented sensitivity and could discover, or exclude, one of the leading theoretical candidates for the nature of dark matter. The UW is also leading the detector design and construction of the next-generation DAMIC-M experiment searching for light (sub-GeV) dark matter, with orders-of-magnitude improved sensitivity over previous experiments in this mass range.
- Collider physics at the LHC. The UW is part of the ATLAS collaboration, with emphasis on searches for new physics in Higgs production and for unusually long-lived new particles. The next decade will see the turn-on of the high luminosity upgrade at the LHC, greatly improving the sensitivity of new physics searches. The UW group is involved in needed detector and computing upgrades, and is pursuing machine learning techniques to maximize discovery potential. The UW also leads an effort to build a surface detector (MATHUSLA) sensitive to ultra-long-lived new particles and is part of a related proposal for a forward search detector (FASER) sensitive to very light long-lived particles.
- Radio cosmology, using arrays of radio telescopes (currently MWA and HERA) to try and observe the formation of the earliest stars and galaxies. The coming decade should see major advances in our understanding of early structure formation and the imprint of dark energy as new optical facilities (LSST) and radio arrays (SKA) come online.
- New physics phenomenology. The formulation of alternative possible models of beyond-standard-model physics, examination of constraints on such models implied by all current experimental or observational limits, and the exploration of novel signatures which may be experimentally tested in the foreseeable future, are all essential contributions to the search for new physics.
- Technology development for gravitational wave observatories (LIGO and LISA).

Outside these Thrusts: The above delineation of two broad research thrusts suffers from the same defects as most other attempts of broad categorization; not everything fits neatly. In particular, biological physics and the statistical modeling of biological processes is an area in which the department has invested in recent years. This area is likely to grow in importance in the coming decade, and is part of the very extensive UW involvement in neuroscience, biomedical research, and genomic “big data.” In addition, the department has a long-standing and continuing effort in physics education research focused on examining how people learn, structure, process, and apply models of the physical world, and incorporating insights emerging from this work into new instructional strategies. (See Appendix J for more information.) Insights from this research have led to significant changes in the teaching of introductory physics both in this department and elsewhere. Ongoing work is exploring alternative teaching strategies in introductory physics labs and upper division courses.

Priorities

To achieve the above vision of a broad and well-balanced research enterprise, in the face of a wave of upcoming retirements, the department will need to add numerous new faculty over the coming decade. In our view, the most critical priorities are the following:

Condensed Matter Experiment: We must fulfill the remaining commitment, made as part of a retention offer to X. Xu, to further strengthen condensed matter physics within the department. This will entail several additional experimental hires. Bringing into the department expertise in techniques such as angle resolved photoemission spectroscopy and scanning probe microscopy, complementary to those employed by our current condensed matter faculty, would be especially valuable. Building a strong synergistic experimental condensed matter effort, with the critical mass necessary to lead major research collaborations and attract the strongest students and postdocs, is a central component of our quantum materials and information thrust. We hope to fulfill this commitment in, at most, the next two years.

Strongly Correlated Systems: From high temperature superconductors to dense nuclear matter to quark-gluon plasma, understanding strongly correlated systems poses one of the most compelling challenges in theoretical physics. It lies at the heart of our quantum materials thrust. In the past couple of decades, the most important and exciting breakthroughs driving progress in theoretical physics have originated in areas that straddle traditional field boundaries. In particular, a strong cross-fertilization between condensed matter theory and fundamental high energy physics has led to advances in both fields. For example, quantum anomalies, originally discussed in high energy theory, have become prominent in condensed matter in the development of the field theory of fractional quantum Hall systems, and more recently in describing many novel materials such as topological insulators, Weyl metals, and a plethora of new 2D electronic phases in double-layer graphene. More broadly, condensed matter theory as a whole is moving in the direction of quantum field theory, which is used to describe a variety of strongly correlated electronic systems. Likewise, insights from condensed matter have been useful in exploring other areas such as topological features in dense nuclear matter and aspects of heavy ion collisions.

Given the breadth and stature of our current theory faculty, we have a window of opportunity to identify and recruit truly exceptional candidates who will advance this fundamental and fascinating field. In support of this effort, and in honor of our emeritus colleague David Thouless, the department would like to create a *Thouless Institute in Quantum Matter,* with endowed support for new faculty, postdocs, and students, and dedicated to fostering beneficial interactions among theorists and experimentalists working on different aspects of quantum matter. (See Appendix K for more information.)

Quantum Information: The manipulation and exploitation of quantum superposition and entanglement is under intense study, both for reasons of fundamental interest and hoped-for utility in applications ranging from cryptography to computing. The NSF, DOE, private foundations (Simons), and major corporations (Microsoft, Google) are all investing substantially in this area. In the quest for a usefully scalable quantum computing architecture, many different physical implementations of qubits are under investigation (superconducting circuits, arrays of trapped ions or neutral atoms, nitrogen vacancy centers in diamond, Majorana modes on nanowires). At the same time, basic theoretical questions abound, involving both fundamental conceptual issues and practical utility. For example, how do information-theoretic bounds relate to constraints from causality in consistent quantum field theories? How can quantum information bounds shed light on physical processes involving entropy generation, thermalization and equilibration? How does the evolution of quantum entanglement resolve the black hole information loss puzzle? Can one understand the emergence of spacetime, and gravity, starting from quantum information? Will quantum computers in the foreseeable future, with relatively modest numbers of qubits and limited operation fidelity, actually be useful for studying physical theories of interest? For which theories and with what algorithms? Significant progress has been made on several of these questions in recent years, and we believe this is an extremely promising area for future work.

Our ability to build a leading effort in quantum information theory will benefit from our current strength in quantum field theory, the complementary effort in quantum materials, existing interest and activity in quantum information within the department and elsewhere at the UW, and the proximity of related efforts at Microsoft Research. To help foster growth in quantum information science at the UW, the department proposes creation of an interdisciplinary *Institute for Quantum Information and Computing*, supporting research in this area and serving to bring together researchers across campus, and from local industry, who are studying aspects of quantum information and computing. (See Appendix L for more information.)

Data-Driven Theory: The coming decade will see an avalanche of data from new experiments and observations. Regardless of whether one considers the largest collaborations generating "big data," small laboratory scale experiments, or mid-sized efforts in between, maximizing the information extracted from modern experiments typically involves an interplay between experimentalists and theorists who work on the methods and models needed to interpret experimental results or observations. This is true across the discipline, from studies of novel materials to collider physics, dark matter experiments, and neutrino, gravitational wave, and optical studies of extreme astrophysical events. To achieve our vision of robust strength in searches for physics beyond the standard model, and in quantum materials and information, it is essential for the department to have theorists (or "phenomenologists") who work at the interface between theory and experiment, proposing new searches, examining data, building models, and exploring possible interpretations. Such work may involve large scale computation (e.g., simulations of large scale structure formation or neutron star collisions, or calculations of hadronic corrections to muon g-2), or modest calculations combined with the creativity and imagination needed to recognize previously unexplored possibilities. A healthy research portfolio for the department requires theory faculty with the expertise and interest needed to engage with current and forthcoming experimental data.

Summary

These hiring priorities in strongly correlated materials, quantum information, and data-driven theory, taken together, constitute a major rebuilding of theoretical physics in the department. With eight state-funded theoretical faculty, as well as two senior fellows of the INT, likely to retire or depart in the near future, achieving the above vision with a healthy balance between theory and experiment necessitates upwards of 10 new theoretical hires with broad synergistic interests and expertise matched to the areas described above.

Institutional investment of a relatively modest number of faculty lines, allowing us to fill existing and upcoming vacancies in a timely manner, would create an outstanding Physics department with broad and well-balanced strengths. The stature and expertise of current faculty gives us a window of opportunity to identify and recruit truly exceptional new faculty. Seizing this opportunity to achieve the above vision would substantially improve the national and international ranking of the department, moving us into the top tier of US Physics departments. We strongly believe that such a hiring effort is best done via searches authorized to make multiple hires in a given search. This greatly increases the odds of identifying, and successfully recruiting, truly exceptional candidates.[††]

Part B: Unit-Defined Questions

Question 1. Instructional Program

Our instructional program is one of the largest in the nation for physics departments: 2500 students register for introductory physics instruction each academic quarter, 500 physics majors receive instruction in our majors program, and 190 students receive instruction in our graduate programs. We provide 129 physics courses each academic year to meet our instructional needs. Looking forward, we would like to ensure that we are using our resources efficiently to provide the best instruction we can to prepare our students for their career paths.

Please assess the quality and standards of our instructional programs.

- *Are resources being used efficiently in our introductory physics program?*
- *Do the physics major "tracks" serve the needs of our students?*
- Research experience is a capstone requirement for our majors, yet our research programs cannot accommodate our large student population. The senior seminar course is our alternative to lab experience. *Is the senior seminar an adequate capstone experience? Are there other capstone experiences that we should be considering?*
- *What steps should be taken to minimize the damage to our instructional program from anticipated budget cuts?*

Additional Discussion

The enrollment growth in our instructional programs placed significant stress on the department, both in scheduling new sections and finding enough instructors. In fact, much of the last decade was spent accommodating the growth rather than focusing on curriculum development. By scheduling additional introductory lab sections, reducing labs from 3 to 2 hours (with on-line pre- and post-lab submissions), and giving multiple annual offerings of our core major's courses in larger lecture halls, we were able to increase our instructional program without turning any students away. An unintended and unfortunate consequence of our larger class sizes is that a physics major may now earn a degree without ever having the opportunity to

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[††]Moreover, authorization to make multiple concurrent hires has been found to significantly affect diverse hiring: https://www.insidehighered.com/news/2015/05/01/new-report-says-cluster-hiring-can-lead-increased-faculty-diversity, https://www.insidehighered.com/advice/2018/07/19/advice-deans-department-heads-and-search-committees-recruiting-diverse-faculty.

take a physics class with less than 60 students. Even more serious are the consequences for our capstone courses. A decade ago, we were able to provide most majors with laboratory research experience while those who opted instead for the senior seminar were in a classroom with 10 to 15 other students. Currently, we can only provide research experience to only a portion of our majors (although some find such experience elsewhere on campus). Our senior seminar courses, limited by the number of teaching faculty, have been offered in sections with up to 30 students each, diminishing the amount of time that faculty can interact with students and the length (and depth) of the student presentations.

Teaching more sections without a corresponding increase in the number of teaching faculty has forced us to reduce the number of liberal arts courses that we offer from a historical average of 5 to our current offering of just 2: PHYS 110, *Liberal Arts Physics,* and PHYS 217, *Energy Futures*. We have also been forced to reduce the number and frequency of special topics course offerings for our majors and graduate students.

Looking forward, we intend to expand our efforts to employ evidence based teaching strategies in our classrooms and instructional labs. To the best of our abilities, we will continue to accommodate all students in need of introductory physics. Our target for Direct-Admit to the Natural Sciences Division of the College of Arts and Sciences is to graduate 120 physics majors each year. This decrease from our current size should relieve some of the stress on our capstone courses. Once enrollments stabilize, we will need to assess the effectiveness of the large class sizes in our core major's courses and the effectiveness of our capstone program.

Question 2. Faculty Research

Faculty hiring decisions within the department inevitably force a choice between strengthening existing research groups versus moving into new research directions. In the last 10 years, we have invested heavily in experimental condensed matter physics and when possible have hired into existing research groups. We failed to make strategic hires in cosmology, astrophysics and other areas of theoretical physics.

Please assess the research portfolio of the department.

- *Does the committee have advice about how research fields should be prioritized in the future?*
- *Is the balance between experimental and theory programs healthy or should that balance evolve as we move forward?*
- During the last decade, the university has incentivized the creation of joint positions between the Physics Department and departments within the College of Engineering. *Does the committee assess these investments to have been successful and to have strengthened our research program? Should more or less emphasis be given to such positions in the future?*

See information from Sections III & IV and Appendices K & L

Question 3. Department Climate

Please assess the department atmosphere and levels of job satisfaction experienced by students, faculty and staff. Please provide advice on best practices to increase the recruitment, retention and satisfaction of members of underrepresented groups in our department.

See information in the main text and in Appendix E.

Question 4. Department Budget

State support for the department is in decline; TA support is regularly in jeopardy, faculty count has been reduced, the Physics/Astronomy Building is aging and there are no plans for renovation, offices have been lost to the Astronomy Department, and the Physics/Astronomy Library was lost to the Computer Science Data Science Studio. Perhaps most importantly, support for new initiatives is shrinking. For example, we have been unable to leverage the astonishing success of a Nobel Prize for David Thouless into any tangible benefit to the department.

- *Are there untapped resources or fund raising activities that we are neglecting?*
- *Can the committee suggest new ways for the department to interact with the administration to avoid further decline?*
- UW's brand of Activity Based Budgeting, which requires the College of Arts and Sciences to survive on tuition income alone, makes it impossible for the Physics Department to ever "pay its way" (cover its costs) within the College. *Please assess the pros and cons of a possible Physics Department petition to move to the College of Engineering.*

Additional Discussion

Table 2 shows the breakdown of faculty positions by title as of the start of Autumn Quarter, 2018. Numbers in parentheses are the FTE supported by the College of Arts and Sciences.

Table 2: Faculty Positions by Rank

Tenure Track		Research Track		Lecturer Track	
Assistant Prof.	7 (4)	Assistant Prof.	4 (0)	Lecturer	5 (1)
Associate Prof.	8 (6.17)	Associate Prof.	2 (0)	Senior Lecturer	1 (1)
Full Prof.	30 (25.7)	Full Prof.	2 (0)	Principal Lecturer	1 (1)

Unlike in 2008, when only one faculty member held a joint appointment with another department (Astronomy), currently five faculty members hold joint appointments with departments in the College of Engineering, and one with the Institute for Learning and Brain Science.

Figure 11 shows the current age distribution of the department's faculty. Taking age 70 as a typical age for retirement, it is apparent that for the next 10 years, to maintain our current faculty count, the department will need to fill on average 1.5 positions per year. Between 2008 and 2018, the department filled 21 tenure track vacancies (including 3 within the INT), 2 Lecturer vacancies, and hired 2 additional Lecturers.

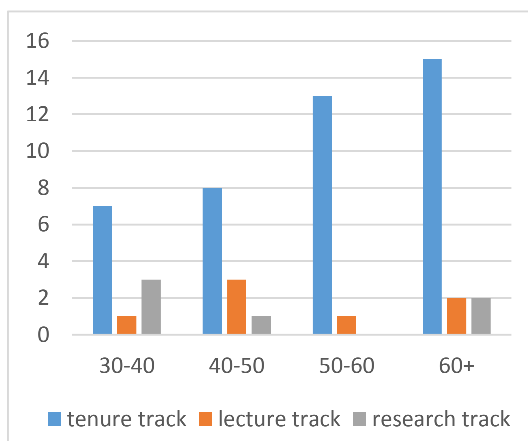


Figure 11: Faculty age distribution

In 2008, the College of Arts and Sciences (CAS) provided 40.5 FTE for tenure track physics faculty and 3 FTE for lecture track faculty. In 2018, the 3 lecturer lines are still supported but the CAS currently supports only 36 tenure track lines. In the past 3 years, 3 tenure track vacancies have gone unfilled and a 4th new position for the department (as part of a faculty retention package) remains unfilled. The reduction in state support for faculty who teach our courses has forced the department to find non-CAS funds (from the Professional Master's program and Royalty Research funds) to pay for 8 quarters of instruction each year. This is likely to be unsustainable and, as discussed above, our instructional program cannot accommodate such a cut to our course offerings. Looking forward, we have no clarity on the plans of the CAS for the size of the physics faculty. Three years ago, the plan was to maintain the department at a stable level of 39 tenure track FTE.

It is clear that the department has been a loser under the university's Activity Based Budgeting (ABB) plan. Artificially low in-state tuition rates and the relatively expensive cost of physics degrees make it impossible for the department to finance itself on tuition revenue alone (even with the largest undergraduate program in the nation). Like engineering departments, some support from state funds is necessary to augment the tuition revenue. At the same time, the CAS, whose budget comes primarily from tuition revenue, has chosen to invest in those departments who, unlike physics, do generate net revenue. How the CAS (or central administration) chooses to address the mismatch between the funds needed to support a competitive physics program and the tuition revenue derived from physics SCH is the most serious issue facing the department going forward. The department is willing to move to a College that does receive significant state support, if that is what it takes to remain competitive.

Question 5. Department Rank

The department has dropped in rank in the US News and World Report from #20 in 2008 to #22 in 2014.

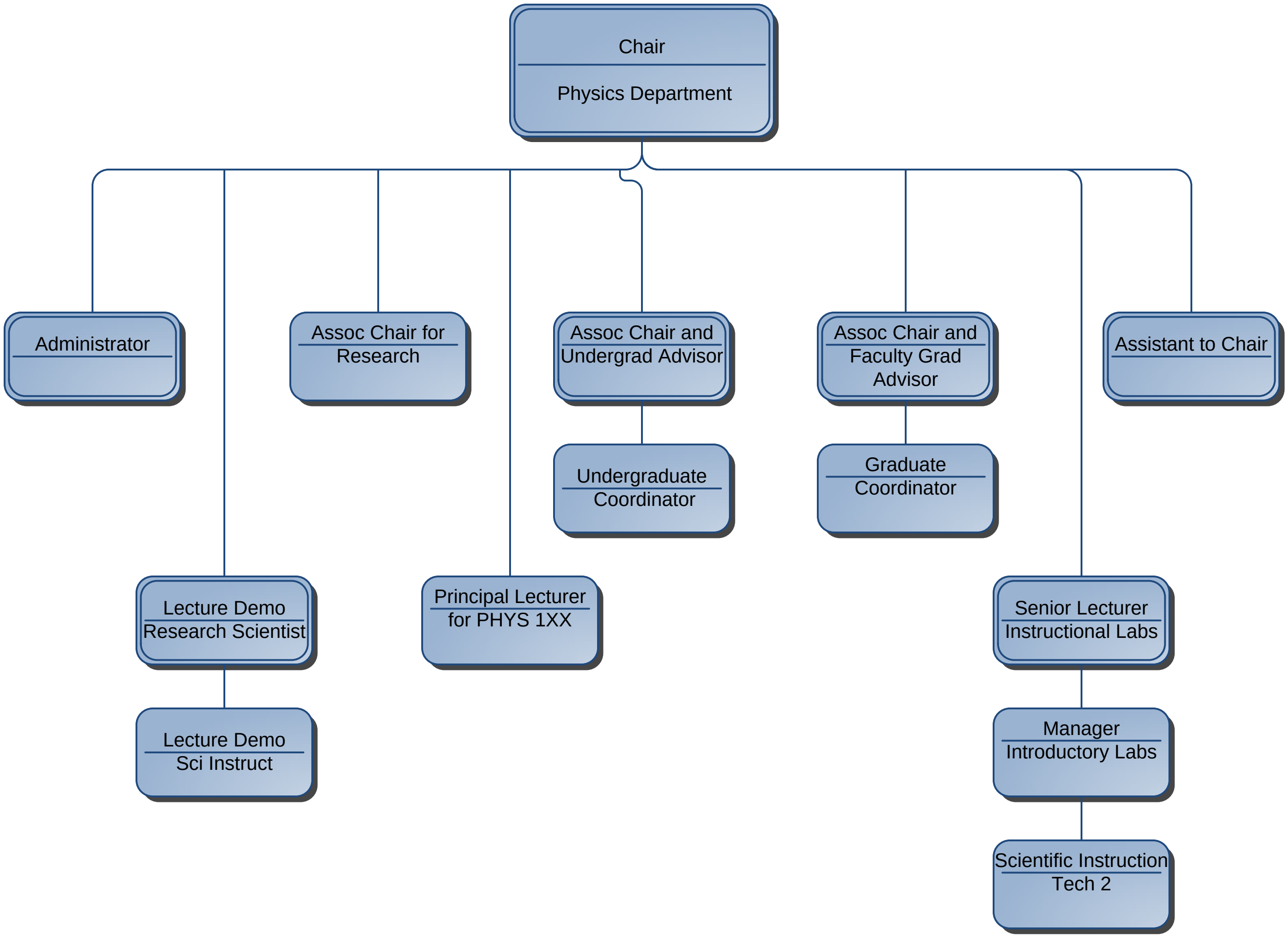
- *Other than limited resources, can the committee identify further reasons why we are failing to keep parity with departments that were once our peers?*
- *Please provide advice on steps that we should be taking to reverse this trend.*

Additional Discussion

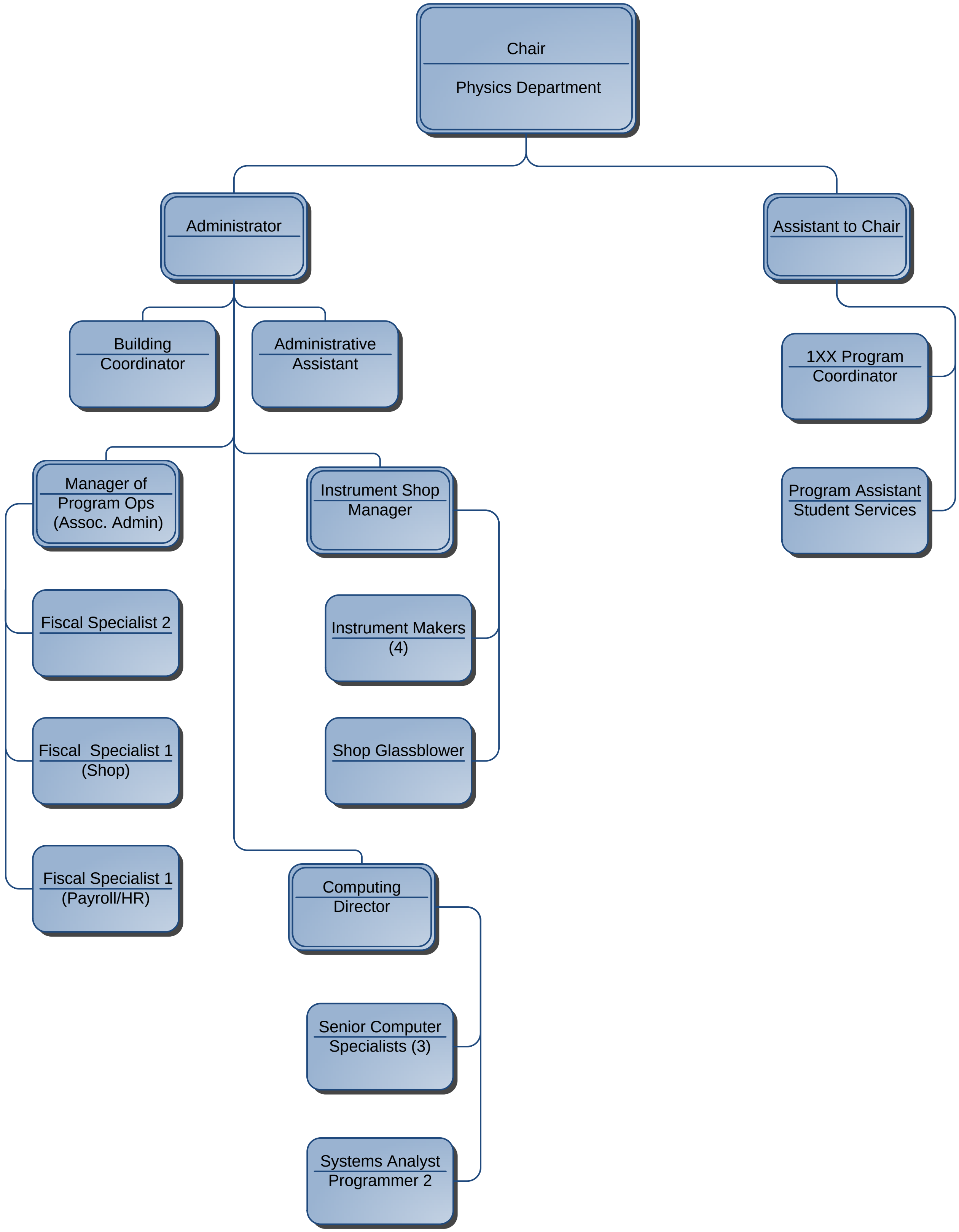
The research activity of the department continues to be among the highest in the university. We appreciate the support of the College (and at times, the central administration) in making often expensive faculty hires possible. Looking forward, our plan builds upon the successes of the last decade, but requires that we be able to fill existing and future faculty vacancies in a timely manner. A second tier Physics Department should not be acceptable at this university.

Part C: Appendices

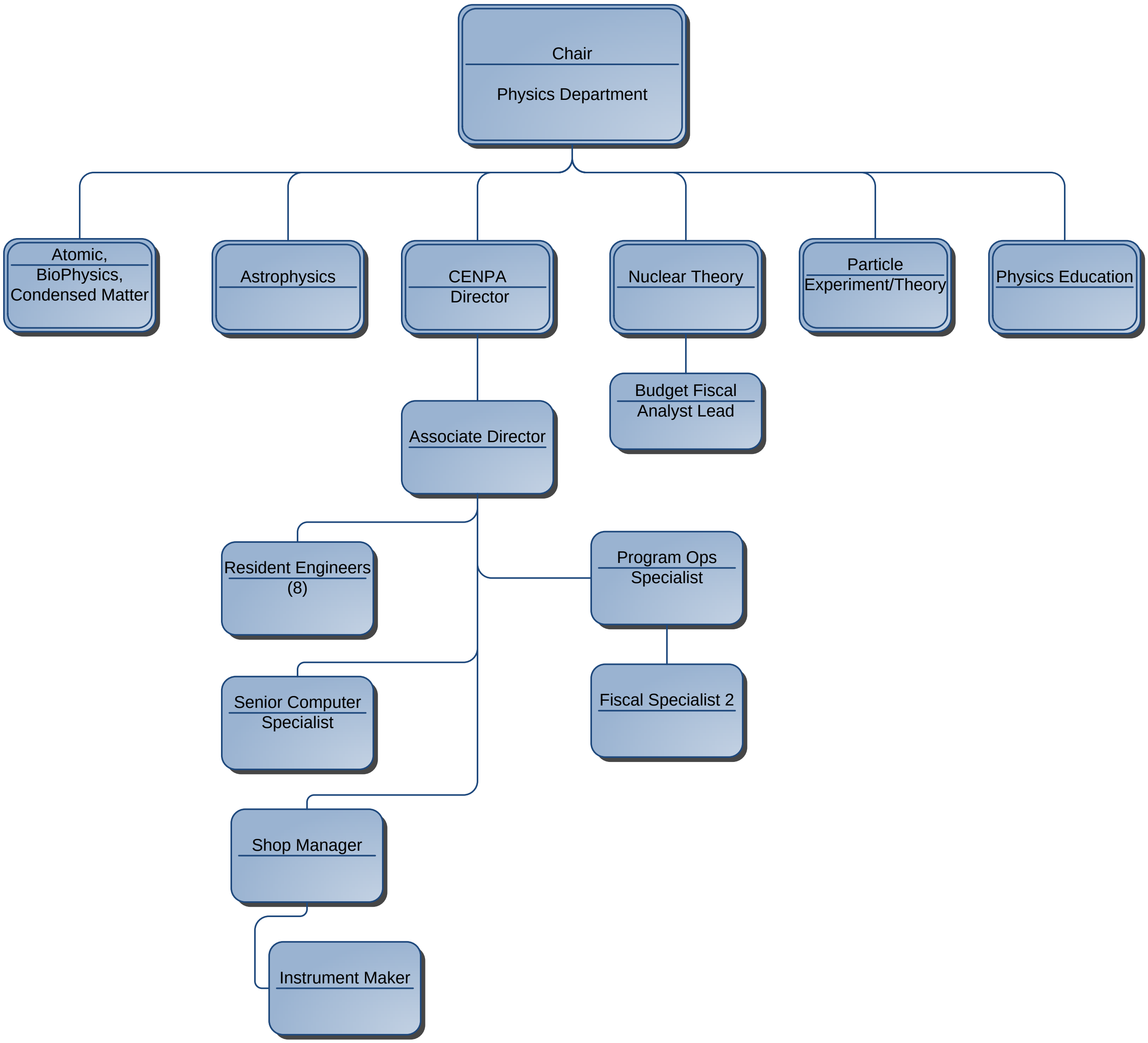
Appendix A: Organizational Chart



Reporting to the Chair



Reporting to Staff



Research Reporting

Appendix B: Budget

Biennium	2011 (July 1, 2011 through June 30, 2013)		2013 (July 1, 2013 through June 30, 2015)		2015 (July 1, 2015 through June 30, 2017)	
Income	**Budget Amount**	**Carryforward**	**Budget Amount**	**Carryforward**	**Budget Amount**	**Carryforward**
GOF*	15,947,539	0	16,926,169	0	18,622,119	0
DOF**	2,807,009	1,441,071	2,866,615	1,409,970	3,084,674	1,536,755
LOF***	2,536,972	1,330,246	2,303,850	1,357,424	1,760,174	1,147,525
Total	**21,291,520**	**2,771,317**	**22,096,634**	**2,767,394**	**23,466,967**	**2,684,280**
Expenses						
Operations	527,036	(3,185)	446,022	(11,994)	543,975	(30,686)
Faculty Salaries	8,629,410	27,235	9,215,899	(22,803)	9,868,226	0
Staff	1,961,617	(5,578)	2,139,600	(3,572)	2,112,551	(69,009)
TA Salaries	1,638,115	(18,473)	1,970,444	40,510	2,561,255	83,499
Benefits	3,191,361	12,805	3,154,204	655	3,536,112	(2,640)
Start-up	4,702,494	2,758,513	4,632,486	2,764,598	4,168,618	2,703,116
Cost Sharing Commitments	641,487	0	537,979	0	676,230	0
Total	**21,291,520**	**2,771,317**	**22,096,634**	**2,767,394**	**23,466,967**	**2,684,280**
Income						
Master's in Physics	638,353	77,856	713,923	199,596	725,670	122,042
Expenses						
Salaries / Benefits	451,429		443,340		462,653	
Operations	16,325		20,235		38,993	
Overhead	92,743		50,753		101,983	
Total	**560,497**		**514,328**		**603,628**	
Income						
Lab Fee Budgets	788,092	189,894	690,319	163,915	723,615	54,268
Expenses						
Salaries	302,850		307,828		291,949	
Equipment / Supplies	295,348		218,576		377,398	
Total	**598,198**		**526,404**		**669,347**	
Income						
Gifts & Endowments	1,312,735	700,582	1,028,388	713,080	1,399,650	798,481
Grants, Contracts, Royalties	45,370,409	12,500,273	46,118,112	14,176,349	49,517,718	12,567,247
Expenses						
See narrative						

* GOF: State appropriations (tax support) and operating fee revenue (portion of tuition)
** DOF: Research Cost Recovery (RCR)
*** LOF: Provost matching funds

Appendix C: Information About Faculty

Faculty CV's are available at: https://phys.washington.edu/2018-cvs

A list of Adjunct & Affilate Faculty is available at:

https://phys.washington.edu/physic-department-adjunct-affiliate-faculty

Academic Appointee	Current Appointments	Rank
Kas, Joshua J.	Primary: Physics	Acting Assistant Professor
Monahan, Christopher John	Primary: Physics	Acting Assistant Professor
Schaarschmidt, Jana	Primary: Physics	Acting Assistant Professor
Venkateswara, Krishna Raj	Primary: Physics	Acting Assistant Professor
Chavarria, Alvaro Eugenio	Primary: Physics	Assistant Professor
Chu, Jiun-Haw	Joint: 2/3 Physics, 1/3 Clean Energy Institute	Assistant Professor
Fidkowski, Lukasz Michal	Primary: Physics	Assistant Professor
Fu, Kai-Mei C	Joint: 2/3 Physics, 1/3 Electrical Engineering	Associate Professor
Majumdar, Arka	Joint: 1/3 Physics, 2/3 Electrical Engineering	Assistant Professor
Rybka, Gray	Primary: Physics	Assistant Professor
White Brahmia, Suzanne	Primary: Physics	Assistant Professor
Blinov, Boris	Primary: Physics	Associate Professor
Detwiler, Jason	Primary: Physics	Associate Professor
Hsu, Shih-Chieh	Primary: Physics Adjunct Associate Professor, Electrical Engineering	Associate Professor
Li, Mo	Joint: 1/3 Physics, 2/3 Electrical Engineering	Associate Professor
Morales, Miguel F	Primary: Physics Adjunct Associate Professor, Astronomy	Associate Professor
Wiggins, Paul A	Joint: 2/3 Physics, 1/3 Bioengineering Adjunct Associate Professor, Microbiology	Associate Professor
Al-Binni, Usama A	Primary: Physics	Lecturer
Messina, Donna Lee	Primary: Physics	Lecturer
Smith, David Patrick	Primary: Physics	Lecturer
Tolich, Kazumi	Primary: Physics	Lecturer
Tolich, Nikolai	Primary: Physics	Lecturer
Efimov, Vitaly	Primary: Physics	Lecturer Emeritus
Pedigo, R. Daryl	Primary: Physics	Principal Lecturer
Pengra, David B.	Primary: Physics	Senior Lecturer
Robertson, Charles E.	Primary: Physics	Senior Lecturer Emeritus
Andreev, Anton	Primary: Physics	Professor
Beane, Silas R.	Primary: Physics	Professor
Bulgac, Aurel	Primary: Physics	Professor
Cobden, David	Primary: Physics	Professor
Den Nijs, Marcel P	Primary: Physics	Professor
Garcia, Alejandro	Primary: Physics	Professor
Goussiou, Anna	Primary: Physics	Professor
Gundlach, Jens	Primary: Physics	Professor
Gupta, Subhadeep	Primary: Physics	Professor
Heckel, Blayne R.	Primary: Physics	Professor

Heron, Paula	Primary: Physics	Professor
Hertzog, David	Primary: Physics	Professor
Kaplan, David B.	Primary: Physics	Professor
Karch, Andreas	Primary: Physics	Professor
Lubatti, Henry J.	Primary: Physics	Professor
McDermott, Lillian C.	Primary: Physics	Professor
McLerran, Larry	Primary: Physics	Professor
Miller, Gerald A.	Primary: Physics	Professor
Nelson, Ann	Primary: Physics	Professor
Olmstead, Marjorie A.	Primary: Physics Adjunct Professor, Chemistry	Professor
Reddy, Sanjay K.	Primary: Physics	Professor
Rosenberg, Leslie	Primary: Physics Adjunct Professor, Astronomy	Professor
Savage, Martin J.	Primary: Physics	Professor
Seidler, Gerald T.	Primary: Physics	Professor
Shaffer, Peter S.	Primary: Physics	Professor
Sharpe, Stephen R.	Primary: Physics	Professor
Spivak, Boris	Primary: Physics	Professor
Watts, Gordon T.	Primary: Physics	Professor
Xu, Xiaodong	Joint: 2/3 Physics, 1/3 Materials Science & Engineering Adjunct Professor, Electrical Engineering	Professor
Yaffe, Laurence G.	Primary: Physics	Professor
Adelberger, Eric G	Primary: Physics	Professor Emeritus
Baker, Marshall	Primary: Physics	Professor Emeritus
Bardeen, James M	Primary: Physics	Professor Emeritus
Bertsch, George F.	Primary: Physics	Professor Emeritus
Boulware, David G	Primary: Physics	Professor Emeritus
Boynton, Paul E	Primary: Physics	Professor Emeritus
Brown, Lowell S	Primary: Physics	Professor Emeritus
Burnett, Toby	Primary: Physics	Professor Emeritus
Chaloupka, Vladimir	Primary: Physics	Professor Emeritus
Cook, Victor	Primary: Physics	Professor Emeritus
Cramer, John G	Primary: Physics	Professor Emeritus
Ellis, Stephen D	Primary: Physics	Professor Emeritus
Fortson, E. Norval	Primary Physics	Professor Emeritus
Halpern, Isaac	Primary: Physics	Professor Emeritus
Haxton, Wick C	Primary: Physics	Professor Emeritus
Ingalls, Robert L.	Primary: Physics	Professor Emeritus
Rehr, John J.	Primary: Physics	Professor Emeritus
Robertson, R. G. Hamish	Primary: Physics	Professor Emeritus
Rothberg, Joseph E.	Primary: Physics	Professor Emeritus
Schick, Michael	Primary: Physics	Professor Emeritus
Sorensen, Larry B.	Primary: Physics	Professor Emeritus
Thouless, David J.	Primary: Physics	Professor Emeritus
Van Dyck, Robert S.	Primary: Physics	Professor Emeritus
Vilches, Oscar E.	Primary: Physics	Professor Emeritus

Wilkes, R. Jeffrey	Primary: Physics	Professor Emeritus
Fertl, Martin	Primary: Physics	Research Assistant Professor
Hoferichter, Martin	Primary: Physics	Research Assistant Professor
Kaspar, Jaromir	Primary: Physics	Research Assistant Professor
Roggero, Alessandro	Primary: Physics	Research Assistant Professor
Stroberg, Ragnar	Primary: Physics	Research Assistant Professor
Enomoto, Sanshiro	Primary: Physics	Research Associate Professor
Taulu, Samu Juhana	Primary: Physics	Research Associate Professor
Doe, Peter J.	Primary: Physics	Research Professor
Kammel, Peter	Primary: Physics	Research Professor
Snover, Kurt A	Primary: Physics	Research Professor Emeritus
Storm, Derek W	Primary: Physics	Research Professor Emeritus
Trainor, Thomas A.	Primary: Physics	Research Professor Emeritus
Weitkamp, William G	Primary: Physics	Research Professor Emeritus
Troy, Steven B.	Primary: Physics	Teaching Associate

Appendix D: Physics Department Committees

Instructional

Introductory Physics	Oversees the introductory physics program
General Education	Oversees courses aimed at non-science majors
Summer Session	Determines course offerings and instructors for the summer program
Majors Curriculum	Oversees the courses in the physics majors program
Undergraduate Advising	Faculty assigned for annual meetings with physics majors
REU	Research Experience for Undergraduates (NSF grant)
Student Services	Oversees various graduate and undergraduate services
Graduate Curriculum	Oversees the courses in the graduate PhD program
Graduate Advising	Both graduate advising and mentoring
Masters Review	Determines who passes the graduate qualifying criteria
Graduate Exam	Ensures that graduate course final exams are appropriate for satisfying the graduate qualifying criteria
Graduate Admissions	Determines who gets admitted to the graduate program
Graduate Visiting Weekend	Organizes a recruitment event for admitted students
Professional Masters	Oversees the graduate Professional Masters program
Instructional Quality	Responsible for teaching peer evaluation of faculty

Department Business

Awards	Determines the recipients of annual department awards
Building Aesthetics	Responsible for building art/displays
Colloquium	Invites speakers for the weekly department colloquium
Diversity and Climate	Addresses diversity and climate issues that arise
Executive	Advises the department chair
Safety and Security	Oversees compliance with UW safety requirements

Committees, Cont.

Faculty Search	Appointed as needed when searches are approved
Technical Services	Oversees department shops
Physics Frontiers Lecture	Advancement and public lecture series
Website	Oversee the department website

Single Assignment

Course Assignment	Determine faculty teaching assignments
Chilled Water	Liaison for issues with the building chilled water system
ASE Advisor	Oversee academic student employee contract compliance
CDO Advisor	Aid the graduate Career Development Organization
Giessen Liaison	Aid the German exchange program with Justus Liebig University Giessen
PGSC Advisor	Advisor to the Physics Graduate Student Council
SPS Advisor	Advisor to the department chapter of the Society of Physics Students

Appendix E: Physics Diversity Plan and Data

The UW Physics Department is committed to increasing the representation of minorities in Physics, and in the past few years has made significant strides towards our goal of becoming one of the most inclusive and diverse Physics departments in the country.

Over the past several years, the Physics department has made a major push to improve the inclusiveness of our department and increase the recruitment and retention of minority and women graduate students. Efforts have included:

- A revamped graduate recruitment process focused on quickly identifying excellent women and URG applicants, personal contact with faculty in their area of research, and bringing these applicants to the department's visiting weekend.
- Strengthening our student and faculty mentoring programs. All students have both student and faculty mentors during the first two years of graduate school, and after progressing to candidacy a faculty mentor that is separate from their research advisor.
- National outreach to increase the number of qualified minority applicants.

The results have been very positive with the number of women entering our PhD program jumping from 5% to 25%, and the recruitment of a couple of high profile minority students, including two Native American students.

Diversity Plan

Our efforts include:

Current recruitment (1). In the past few years we have heavily focused on improving our national visibility within the minority physics community, including:

- Presence at the Seattle the Society for Advancement of Chicanos/Hispanics and Native Americans in Science meeting, and participation on the local organizing committee. The department hosted a recruiting table, laboratory tour, and lunch table during the UW visiting day and shared a recruiting table at the convention center with Astronomy.
- Contacted all of the minority students on the McNair name exchange to encourage them to consider graduate school at the University of Washington.
- Full redesign of our department webpage to better attract students.

In addition to our efforts to recruit students for our PhD program, UW is the largest source of physics majors in the country. More than 1% of all US undergraduate physics majors are from UW, and every year we send students to the elite graduate programs in the country. Thus our efforts to increase the representation of women and minorities in our undergraduate population has a significant impact on the national diversity of the field. Specific efforts include:

- Presentations to the undergraduate advisors to make sure women and minority students are not steered away from calculus based physics (precluding majoring in engineering or the hard sciences).
- Community college transfer programs, including "Physics Day" lab tours and panel discussions for community college students and an innovative community college research program for transfer students.
- Active involvement in undergraduate research symposia.

- Frequent volunteering and outreach by our graduate students and faculty, including Burke Museum “Girls in Science” summer camp, panel presentations at the Undergraduate Women in Physics Conference, and QuarkNet Master classes for middle school students.

Efforts to increase matriculation (2). A key goal for the department has been increasing the yield of admitted graduate students. We typically matriculate ~28 students into the PhD program a year, and have made significant strides in the last four years in increasing our diversity.

- The department guarantees full support for students in good academic standing throughout their graduate career (tuition and stipend).
- We quickly identify women and minority students we wish to recruit, and have a faculty member personally contact each of them to discuss our program and invite them to visiting weekend. Lodging for visiting weekend is supported by the department.
- Visiting weekend is held over two days in March for ~35 prospective students, and the weekend is organized by our current graduate students. Standard events include: pick up by our students of prospective students at the airport, a brief introduction to the department’s broad research (60 faculty and 25 adjunct faculty), a poster session on current research hosted by our students to talk about their current research, 3 meetings with research groups of the applicant’s choosing, a department dinner (~125 participants), a panel discussion on graduate life by our students (no faculty or staff allowed to attend), two laboratory tours, an introduction to the physics TA program, a diversity panel, and student led tours of Seattle.
- Each prospective student is contacted after visiting weekend by one of our graduate students, and often a faculty member. Minority and women candidates are often contacted by multiple people.
- For high profile recruits who cannot attend visiting weekend, we will organize individual tours.
- We carefully allocate fellowships like GO-MAP and available recruiting funds in an effort to recruit a diverse student body.

Future recruitment efforts (3). Our approach has been systemic—by improving the departmental environment and student support for all of our graduate students we both improve the experience for all of our students and specifically increase the desirability of our program to women and minority students. It is because of our inclusive approach that we’ve been able to recruit some high profile minority students away from more prestigious institutions. Our students are our best ambassadors. As detailed above we have involved our students in every aspect of recruitment, from attending national conferences, to hosting the department’s visiting weekend, to following up with prospective students after they visit.

A recent goal has been to increase the number of undergraduate minority physics majors with the research experience and academics to succeed in graduate school—whether they apply to UW or somewhere else—via our REU program, our community college outreach efforts, and the diversity of our own undergraduate physics majors.

Retention (4). The department endeavors to provide a supportive and collaborative environment for our students. Specific efforts for enhancing retention include:

- Every incoming graduate student is matched with a student mentor, with regular group and individual meetings.
- Formal faculty mentoring throughout their graduate careers, including a dedicated faculty mentor for first year students and an excellent staff graduate advisor.
- Guaranteed financial support for all students in good academic standing.
- Annual career day to help make contact with industry employers.

- Strong contacts with other departments to encourage interdisciplinary dissertations—a significant number of our graduates work with advisors outside the department.

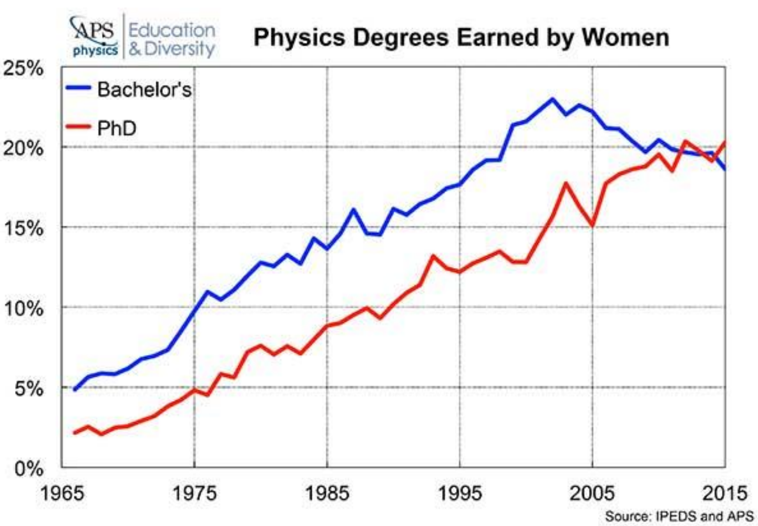
Inclusiveness (5). Inclusiveness is of course a systemic issue, and must be approached as such. We have:

- Expanded the charter of the diversity committee to include the entire departmental environment.
- Improved our harassment training for incoming graduate students in consultation with faculty from the Women's Studies Department.
- Hosted "Elevating Excellence and Leadership in Physics: The Power of Diversity" by Mónica I. Feliú-Mójer
- Hosted a Gender Workshop for physics graduate students by one of our students.
- Participation by graduate students in faculty meetings and departmental standing committees including curriculum, graduate, diversity, 100 level physics course coordinating, ASE, and events.
- An active Graduate Student organization that is involved in both the academic and social aspects of student life. For example our students organize a monthly volunteer event in the local community (Goodwill Glitter Sale, public libraries, science fairs, etc.)

Commitment to funding students (6). The Physics Department guarantees full support for students in good academic standing throughout their graduate careers, and will provide matching funds for any GOP or GO-MAP diversity fellowships. Fellowships allow students to accelerate their graduate careers and are a key part of our efforts to recruit some of the best minority students in the country. While we do not have the name recognition of Harvard or Stanford, by leveraging our breadth of research and inclusive, supportive atmosphere we have been successful in recruiting students when we've been able to match their financial offers.

Physics Degrees Diversity Data

The American Physical Society reports on national trends in diversity for Physics majors and PhD's. The following example graph addresses national gender diversity https://www.aps.org/programs/women/resources/statistics.cfm .

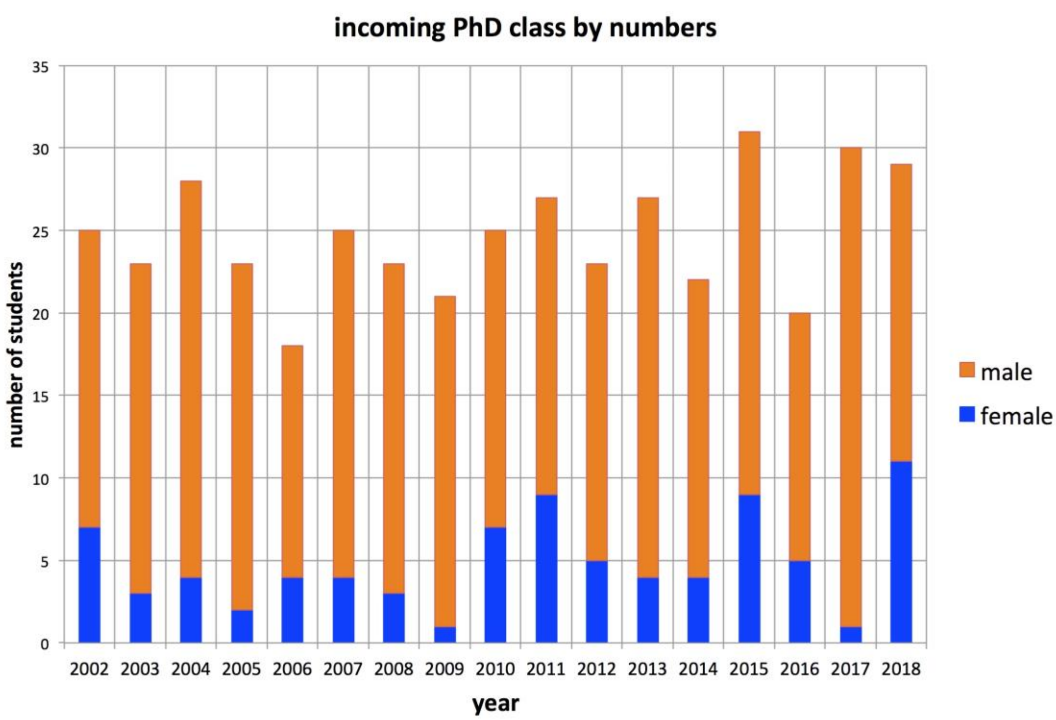


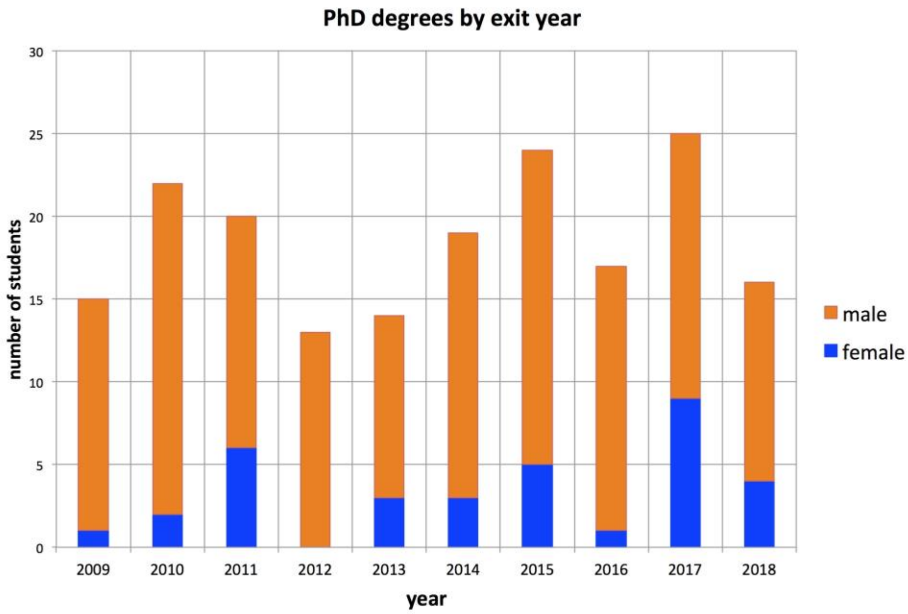
The fraction of UW graduates in the Physics major with a first generation college degree was 24% in 2016-17 (the last year for which data are available). The proportions of women and minorities (URG = black, Hispanic, pacific-islander and native American) are similar to 10 years ago, while the fraction of international and US-born Asian students has increased dramatically (both were 4% in 2009).

Table. Undergraduate Diversity Snapshot AY 17-18

	Total	Male	Female	Int'l	US Asian	URG	Female URG
Algebra-based Mechanics	1085	424 (39%)	661 (61%)	98 (9%)	310 (29%)	118 (11%)	63 (6%)
Calculus-based Mechanics	1805	1244 (69%)	561 (31%)	395 (22%)	222 (36%)	124 (7%)	36 (2%)
Sophomore Math Physics	278	217 (78%)	61 (22%)	66 (24%)	37 (13%)	13 (5%)	5 (2%)
Junior E&M II	208	161 (77%)	47 (23%)	42 (20%)	31 (15%)	11 (5%)	3 (1.5%)
Physics Graduates	175	140 (80%)	34 (19%)	34 (19%)	24 (14%)	10 (6%)	1 (0.5%)
UW Engineering Graduates	825	593 (72%)	231 (27%)	139 (17%)	166 (20%)	62 (8%)	11 (1.3%)
National Physics Graduates		80%	20%			12%	

Gender diversity has been a focus point in our graduate student recruiting for the last decade. The following graphs illustrate that we outperform the above national averages, but also shows that doing so represents a constant struggle with competitive Physics Departments.



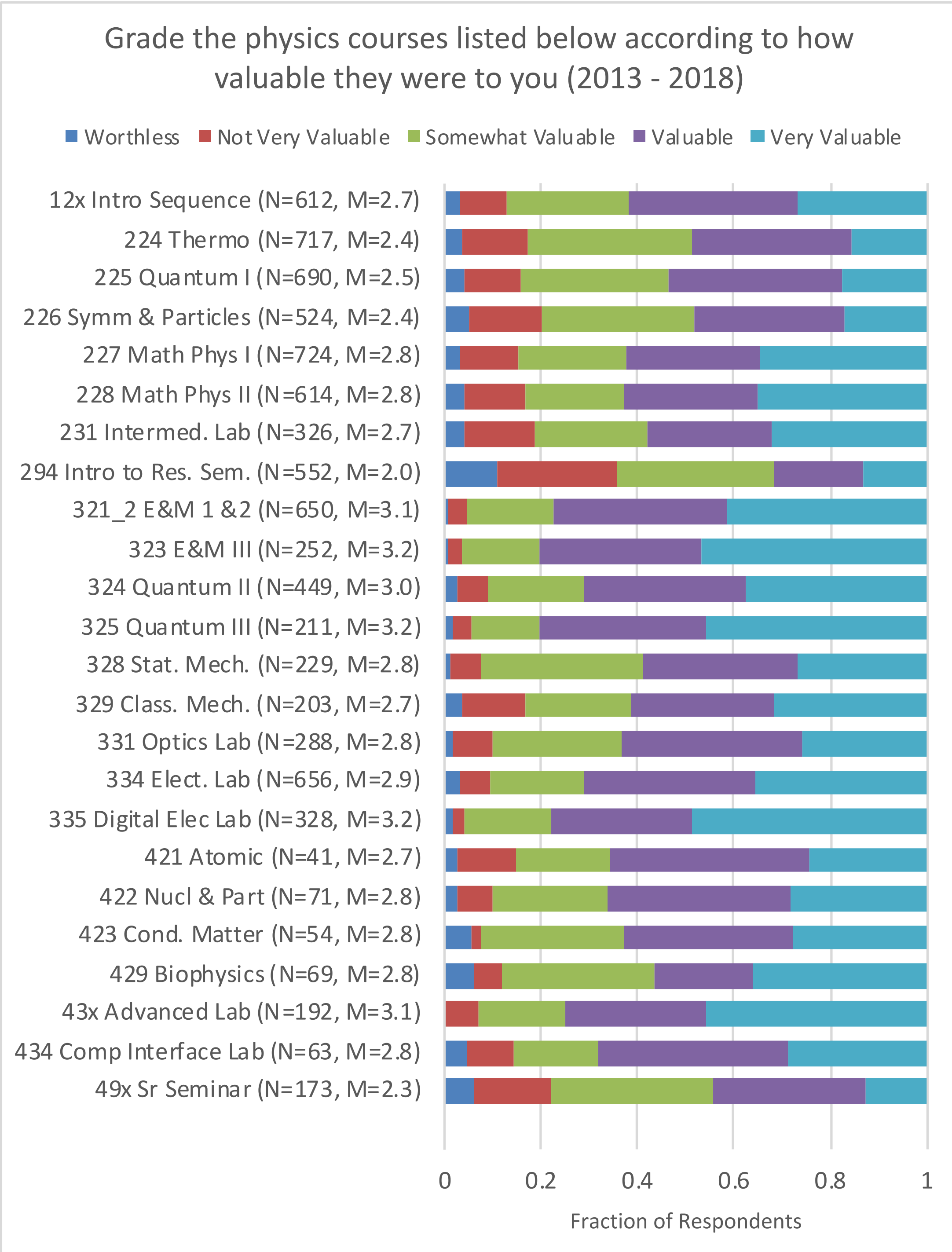

PhD degrees by exit year
number of students
0
5
10
15
20
25
30
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
year
male
female

Appendix F: Course Offerings and Course Surveys

Undergraduate Course Offerings		Sections/ Acad Year	Faculty Qtrs/ Acad Year	Total Acad Yr Enrollment	Su 2009 Enrolled	Sections/ Acad Year	Faculty Qtrs/ Acad Year	Total Acad Yr Enrollment	Su 2018 Enrolled
Course	Topic	2009				2018			
Non-Scientists Courses									
101	Intro Physics By Inquiry					0.5	0.5	16	
110	Liberal Arts Phys	1	1	195		1	1	42	
207	Physics of Music	1	1	69		1	1	44	
214	Light and Color	1	1	38					
216	Science and Society	1	1	50					
41x	Physics by Inquiry for In-service Teachers	3	1.5	45	21	3	1.5	39	
Introductory Level Physics									
114	Algebra-based Mechanics	7	7	1111	78	7	7	1050	53
115	Algebra-based Fluids and Electrodynamics	5	5	873	73	6	6	896	66
116	Algebra-based Waves, Optics and Quantum	4	4	480	59	4	4	553	55
121	Calculus-based Mechanics	8	8	1267	73	11	11	1715	103
122	Calculus-based Elecrtrodynamics	8	8	1085	53	9	9	1472	78
123	Calculus-based Waves, Optics and Heat	6	6	838	81	7	7	1193	86
121T	Tutorials for Mechanics	60	0.6			83	0.6		
122T	Tutorials for Electrodynamics	51	0.6			68	0.6		
123T	Tutorials for Waves, Optics and Heat	40	0.6			54	0.6		
217	Energy Futures					1	1	62	
Intermediate Level Physics									
224	Thermal Physics (Includes statistical)	3	3	141	18	2	2	272	46
225	Quantum Mechanics 1 (two-state systems)	2	2	93	19	1	1	189	66
226	Symmetry and Particles (w/ special relativity)	1	1	28		2	2	193	
227	Math Methods 1 (Linear Alg, Diff Eq, Vector Calc)	2	2	118		2	2	2	
228	Math Methods 2 (Fourier/Laplace, PDE, complex anal)	2	2	81	51	1	1	139	75
311	Undergraduate General Relativity	1	1	38					
Upper Level Physics Lectures									
321	Electrodynamics 1 (electrostatics, dielectrics)	3	3	96		2	2	263	
322	Electrodynamics 2 (magnetostatics, wave eqn)	2	2	64		1	1	167	55
323	Electrodynamics 3 (EM radiation, retarded potentials)	1	1	29		1	1	75	
324	Quantum Mechnics 2 (wave mechanics, H atom)	1	1	38	32	1	1	108	35
325	Quantum Mechanics 3 (pertub. theory, interactions)	1	1	34		1	1	76	
328	Statistical Mechanics (partition function)	1	1	15		1	1	77	
329	Classical Mechanics	1	1	9		1	1	68	
407	Phys by Inquiry for Future Teachers 1 -mechanics	1	1	10		0.5	0.5	4	
408	Phys by Inquiry for Future Teachers 2 - E&M	1	1	11		1	1	14	
409	Phys by Inquiry for Future Teachers 3 - waves	1	1	9		1	1	20	
421	Atomic & Molecular Physics	1	1	8		1	1	21	
422	Nuclear & Particle Physics	1	1	8		1	1	17	
423	Condensed Matter Physics	1	1	17		1	1	16	
424	Advanced Classical Mechanics	1	1	11					
429	Biological Physics	1	1	15		1	1	40	
451	Issues for Ethnic Minorities and Women in STEM	1	1	7					
Laboratories									
117	Introductory Mechanics Lab	41	1.5	834	72	31	1.5	683	37
118	Introductory Heat,E&M Lab	31	1.5	644	60	28	1.5	584	46
119	Introductory Waves Lab	19	1.5	382	55	20	1.5	442	40
121Z	Introductory Mechanics Lab	69	1.5	1267		78	1.5	1715	
122Z	Introductory Heat,E&M Lab	52	1.5	1085		65	1.5	1472	
123Z	Introductory Waves Lab	41	1.5	838		52	1.5	1193	
231	Intermediate Laboratory (incl 1 hr lecture)	1	1	14		5	1	77	66
331	Optics Laboratory (incl 1 hr lecture)	2	1	44		5	1	88	
334	Electronic Circuits Lab 1 (incl. 2 hr lecture)	3 + 2	2	79	22	8	1	163	50
335	Electronics Circuits Lab 2 (incl. 2 hr. lecture)	2	1	26	31	7	1	135	
431	Condensed Matter Physics Senior Lab	1	1	14		2	1	32	18
432	Atomic Physics Senior Lab	1	1	18		2	1	38	
433	Nuclear Physics Senior Lab (incl. 1 hr lect)	1	1	15		2	1	24	
434	Data Acquisition Lab	2	1	20					
Seminars									
294	UG Introduction to Research Seminar	1	1	41		1	1	241	
485-6-7	Senior Honors Seminar	1.5	1.5	28		3	1.5	26	
494-5-6	Senior Seminar	1.5	1.5	32		9	4.5	195	
Supervised Independent Study and Research									
401-2-3	Graded UG Independent Study / Teaching practicum			99				7	
499	Undergraduate Research							145	
TOTAL		493	97.3	12411	798	596	96.3	16103	975

Graduate Course Offerings

Course	Topic	2009 Sections/ Acad Year	2009 Faculty Qtrs/ Acad Year	2009 Total Acad Yr Enrollment	Su 2009 Enrolled	2018 Sections/ Acad Year	2018 Faculty Qtrs/ Acad Year	2018 Total Acad Yr Enrollment	Su 2018 Enrolled
Graduate Required Classes									
501-2-3	TA Training	3	1.5	75		1	1	75	
505	Classical Mechanics	1	1	25		1	1	41	
513	Electrodynamics 1	1	1	25		1	1	29	
514	Electrodynamics 2	1	1	23		1	1	30	
515	Electrodynamics 3	1	1	22		1	1	27	
517	Quantum Mechanics 1	1	1	25		1	1	29	
518	Quantum Mechanics 2	1	1	25		1	1	31	
519	Quantum Mechanics 3	1	1	24		1	1	28	
524	Statistical Mechanics 1	1	1	26		1	1	29	
528	Graduate Introduction to Research	1	1	18		1	1	33	
Graduate Elective Classes - currently annual									
511	Contemporary Physics	1	1	19		1	1	6	
525	Statistical Mechanics 2	1	1	7		1	1	26	
567	Cond Matt-Grad 1	1	1	11		1	1	12	
568	Cond Matt-Grad 2	1	1	7		1	1	7	
557	High Energy - Grad	1	1	12		1	1	15	
560	Nuclear Theory	1	1	9		1	1	8	
570	QFT 1	1	1	18		1	1	19	
571	QFT 2	1	1	15		1	1	10	
572	QFT 3	1	1	3		1	1	6	
576	Preparation for the Qualifying Exam					1	1	6	
Graduate Elective Classes - Currently on Rotation Basis									
506	Numerical Methods					1	1	14	
507	Group Theory	1	1	26					
550	Atomic - Grad	1	1	7					
554	Nuclear Astro								
555	Cosmology					1	1	11	
564	Gen Relativity - Grad	1	1	18					
558	High Energy - Grad	1	1	3					
561	Nuclear Theory -2	1	1	9					
Evening Masters Classes - Currently Annual									
441	QM - Evening	1	1	14		1	1	23	
543	E&M 1 - Evening	1	1	21		1	1	11	
Evening Masters Classes - Currently Bi-Annual									
541	QM Apps - Evening					1	1	17	
544	E&M 2 - Evening	1	1	12					
Evening Masters Classes - On Rotation (3 each year)									
530	Laser Physics								
536	Acoustical Physics								
542	Numerical Methods	1	1	11					
545	Optics					1	1	5	
546	Condensed Matter Physics	1	1	15					
547	Research Electronics								
421	Atomic Physics					1	1	10	
575A	Radiation and Detectors					1	1	13	
575B	Medical Imaging								
Special Topics Classes									
576/8	Special Topics	6	6	45		5	5	42	
Supervised Independent Study and Research									
E600	Evening MS Research			33				41	
600	Graduate Research (pre-General Exam)			226				270	
800	Dissertation Research			139				102	
TOTAL		37	35.5	968		33	33	1026	



Results of senior exit survey. Mean is calculated on a scale where Very Valuable = 4, Worthless = 0. The survey is typically taken 6 months prior to graduation, so upper-division electives are underrepresented here.

Appendix G: Selected Recent Awards, Honors & Placements

Awards and Honors

faculty:

2018	Majumdar, Arka	Alfred P. Sloan research fellow
	Nelson, Ann	APS Sakurai prize
	Chu, Jiun-Haw	Alfred P. Sloan research fellow
	Sharpe, Stephen	Southgate fellowship of Adelaide University
	Miller, Gerald	Southgate fellowship of Adelaide University
	Miller, Gerald	Rothchild fellowship of Hebrew University
	Efimov, Vitaly	APS Faddeev medal
2017	Chu, Jiun-Haw	Moore Junior Fellow of Materials Synthesis
	Chu, Jiun-Haw	AFSOR young investigator award
	Miller, Gerald	Shaoul Fellowship of Tel Aviv University
	Robertson, Hamish	Honarary DSc, McMaster University
2016	Hsu, Shih-Chieh	DOE early career award
	Karch, Andreas	APS fellow
	Thouless, David	Nobel prize in Physics
	Xu, Xiaodong	UW Innovation award
	Detwiler, Jason	Breakthrough prize in fundamental physics
	Doe, Peter	Breakthrough prize in fundamental physics
	Enomoto, Sanshiro	Breakthrough prize in fundamental physics
	Robertson, Hamish	Breakthrough prize in fundamental physics
	Tolich, Nikolai	Breakthrough prize in fundamental physics
2015	Cobden, David	APS fellow
	Fidkowski, Lukasz	Alfred P. Sloan research fellow
	Fu, Kai-Mei	Cottrell scholar award
	Majumdar, Arka	Intel early career award
	Majumdar, Arka	AFSOR young investigator award
	Shaffer, Peter	APS fellow
	McLerran, Larry	APS Herman Feshbach prize
	McLerran, Larry	Doctorate Honoris Causa, Jagiellonian University
	McDermott, Lillian	GIREP medal
	Kaplan, David	fellow, American Academy of Arts and Sciences
2014	Xu, Xiaodong	Cottrell scholar award
	Xu, Xiaodong	IUPAP young scientist prize
	Yaffe, Laurence	Alexander von Humboldt research award
	Spivak, Boris	Joseph Meyerho professor, Weizmann Institute
2013	Kaplan, David	National Academy of Science member
	McDermott, Lillian	AAPT Melba Newell Phillips medal
	Detwiler, Jason	DOE early career award
2012	Bardeen, James	National Academy of Science member
	Fu, Kai-Mei	NSF career award
	Nelson, Ann	National Academy of Science member
	Savage, Martin	Alexander von Humboldt research award
	Wiggins, Paul	NSF career award
	Xu, Xiaodong	NSF career award
	Xu, Xiaodong	DOE early career award

2011	Wiggins, Paul	Alfred P. Sloan research fellow
	Xu, Xiaodong	DARPA young faculty award
	McLerran, Larry	Honorary PhD, People's Republic of China
2010	Spivak, Boris	Alexander von Humboldt research award
2009	Gundlach, Jens	APS fellow
	Gupta, Subhadeep	NSF career award
	Morales, Miguel	NSF career award
	Gupta, Subhadeep	Alfred P. Sloan research fellow
	McLerran, Larry	J. Hans D. Jensen prize, Heidelberg University

postdocs:

2017	Frojdh, Per	UW 1996	Emmy award for video coding
	Schaibley, John	UW 2013-2016	AFSOR young investigator award
2016	Jarzynski, Christopher	UW 1994-1996	fellow, American Academy of Arts and Sciences
	Kiburg, Brendan	UW 2011-2012	Wilson fellow, FNAL
2015	Tan, Shina	UW 2006-2008	APS fellow
2014	Stewart, Iain	UW 2002-2003	Simons investigator
	Tan, Shina	UW 2006-2008	NSF career award
	Arnold, Peter	UW 1992-1996	APS fellow
2013	Hornig, Andrew	UW 2010-2013	LANL Director's fellowship
	Stewart, Iain	UW 2002-2003	APS fellow
2012	Beane, Silas	UW 2002-2003	APS fellow
	Romatschke, Paul	UW 2006-2010	Alfred P. Sloan research fellowship
2011	Starinets, Andrei	UW 2002-2004	Maxwell medal and prize
2010	Bedaque, Paulo	UW 1996-2001	APS fellow
	Hammer, Hans	UW 2004-2005	APS fellow
	Tan, Shina	UW 2006-2008	APS George E. Valley prize
2009	Jarzynski, Christopher	UW 1994-1996	APS fellow
	McLaughlin, Gail	UW 1996-1998	APS fellow
	Narayanan, Rajamani	UW 1995-1997	APS fellow

students:

2018	Davoudi, Zohreh	2014 PhD	Kenneth G. Wilson award in lattice gauge theory
	Seyler, Kyle	2018 PhD	Millikan postdoctoral fellowship, Caltech
	Kico, Natalie	current	Microsoft Research fellowship
	Briceno, Raoul	2013 PhD	DOE early career award
2017	Briceno, Raoul	2013 PhD	Kenneth G. Wilson award in lattice gauge theory
	Johnson, Cameron	2016 BS	NSF graduate fellowship
	Wagman, Michael	2017 PhD	Pappalardo fellowship, MIT
	Gruszko, Julieta	2017 PhD	Pappalardo fellowship, MIT
2016	Goodhew, Lisa	current	NSF graduate fellowship
	Fieseler, Charles	current	NSF graduate fellowship
	Stryker, Jesse	current	NSF graduate fellowship
	Wu, Sanfeng	2016 PhD	Pappalardo fellowship, MIT
	Beardsley, Adam	2015 PhD	NSF postdoctoral fellowship
	Harvey, Sarah	2015 BS	NDSEG graduate fellowship
2015	Walker-Loud, Andre	2006 PhD	Kenneth G. Wilson award in lattice gauge theory
2014	Walker-Loud, Andre	2006 PhD	DOE early career award
2013	Totorica, Sam	2012 BS	NSF graduate fellowship
	Grabowska, Dorota	2016 PhD	NSF graduate fellowship

2012	Karin, Todd	2016 PhD	NSF graduate fellowship
	Thomas, Nicole	2014 PhD	Intel PhD fellowship
2011	Luzum, Matt	2010 PhD	APS dissertation award in nuclear physics
2010	Jones, Aaron	2015 PhD	NSF graduate fellowship
	Spitzer, Chris	2009 PhD	AIP Congressional fellowship
	Walsh, John	2010 PhD	LHC-TI fellowship, UC Berkeley
	Zurek, Kathryn	2006 PhD	NSF career award
	Drut, Joaqin	2008 PhD	LANL Director's fellowship
2009	Chesler, Paul	2009 PhD	Pappalardo fellowship, MIT
	Khramov, Alexander	2013 PhD	NSERC graduate fellowship

Student and Postdoc Placements

postdocs:[1]		**current position**
2016-2018	Schlichting, Soren	faculty, University of Bielefeld
2015-2018	Aleksey Cherman	faculty, University of Minnesota
2015-2018	Cai, Xinghan	faculty, Shanghai Jiaotong University
2015-2017	Liu, Chang-hua	faculty, National Tsing Hua University
2014-2018	Mehtar-Tani, Yacine	staff scientist, BNL
2013-2016	Schiabley, John	faculty, University of Arizona
2013-2016	Buchoff, Michael	staff scientist, LLNL
2013-2016	Pober, Jonathan	faculty, Brown University
2012-2015	Holt, Jeremy	faculty, Texas A&M University
2012-2015	Passante, Gina	faculty, California State University Fullerton
2012-2015	Cid, Ximena	faculty, California State University Dominguez Hills
2011-2016	Parno, Diana	faculty, Carnegie Mellon University
2011-2016	Rompotis, Nikolaos	faculty, University of Liverpool
2011-2014	Kaminski, Matthias	faculty, University of Alabama
2011-2014	Moroz, Sergej	faculty, Technische Universitat Munchen
2011-2014	Steiner, Andrew	faculty, University of Tennessee
2011-2013	Knecht, Andreas	staff scientist, Paul Scherrer Institute
2011-2012	Sun, Dong	faculty, Peking University
2010-2012	Winter, Paul	staff scientist, ANL
2010-2012	Yamamoto, Naoki	faculty, Keio University
2010-2010	Rosati, S	staff scientist, INFN Rome
2009-2014	Lin, Huey-Wen	faculty, Michigan State University
2009-2012	Gezerlis, Alexandros	faculty, University of Guelph
2009-2011	Stetcu, Ionel	staff scientist, LANL
2009-2010	Platter, Lucas	faculty, University of Tennessee
2008-2011	Cloet, Ian	staff scientist, Argonne National Lab
2008-2011	Wrede, Chris	faculty, Michigan State University
2008-2011	Hoyos, Carlos	faculty, University of Oviedo
2007-2009	Duan, Huaiyu “Mike”	faculty, University of New Mexico
2007-2009	Gazit, Doron	faculty, Hebrew University

1 Includes term-limited Research Assistant Professors.

2007-2008	Nishida, Yusuke	faculty, Tokyo Institute of Technology
2006-2014	Forbes, Michael	faculty, Washington State University
2006-2010	VanDevender, Brent	staff scientist, PNNL
2006-2009	Lahde, Timo	staff scientist, Juelich Nuclear Physics Institute
2006-2008	Tan, Shina	faculty, Georgia Tech
2006-2010	Romatschke, Paul	faculty, University of Colorado
2005-2009	Mal, Prolay Kumar	faculty, NISER, India
2005-2008	Piai, Maurizio	faculty, Swansea University
2005-2007	Herzog, Chris	faculty, SUNY Stony Brook
2005-2007	Melconian, Dan	faculty, Texas A&M
2005-2007	Lee, Christopher	staff scientist, LANL
2005-2007	Sadaghiani, Homeyra	Faculty, Cal Poly Pomona
2005-2006	Schwenk, Achim	faculty, Technische Universitat Darmstadt
2005-2006	Rupak, Gautam	faculty, Mississippi State University
2004-2007	Vuorinen, Aleksi	faculty, University of Helsinki
2004-2007	Lunardini, Cecilia	faculty, Arizona State University
2004-2006	Lin, C.-J. David	faculty, National Chiao-Tung University
2004-2005	Hammer, Hans	faculty, Technische Universitat Darmstadt
2003-2006	Jalilian-Marian, Jamal	faculty, Baruch College
2003-2006	Wingate, Matthew	faculty, Cambridge University
2003-2004	Bender, Michael	director, Centre d'Etudes Nucleaires de Bordeaux
2003-2004	Nogga, Andreas	staff scientist, Juelich Nuclear Physics Institute
2002-2010	Schlamminger, Stephan	staff scientist, NIST
2002-2008	Detmold, William	faculty, MIT
2002-2004	Starinets, Andrei	faculty, University of Oxford
2002-2004	Erlich, Josh	faculty, William and Mary
2002-2004	Bogner, Scott	faculty, Michigan State University
2002-2003	Stewart, Iain	faculty, MIT
2002-2003	Nollett, Kenneth	faculty, Sand Diego State University
2002-2003	Hanein, Yael	faculty, Tel Aviv University
2001-2011	Stetzer, Mackenzie	Faculty, University of Maine
2001-2004	Katz, Emmanuel	faculty, Boston University
2001-2004	Kovchegov, Yuri	faculty, Ohio State University
2001-2003	Formaggio, Joseph	faculty, MIT
2001-2003	Tuchin, Kirill	faculty, Iowa State University
2000-2004	Weiner, Neal	faculty, NYU
2000-2004	Kovchegov, Yuri	faculty, Ohio State University
2000-2002	Moore, Guy	faculty, Technische Universitat Darmstadt
2000-2001	Strickland, Michael	faculty, Kent State University
1999-2003	Beane, Silas	faculty, University of Washington
1999-2003	Kaplan, Lev	faculty, Tulane University
1999-2001	Chacko, Zacharia	faculty, University of Maryland
1999-2001	Sabella, Mel	faculty, Chicago State University
1999-2000	Brown, David	staff scientist, LLNL
1999-2000	Hanhart, Christoph	staff scientist, Juelich Research Center
1998-2001	Schmidt, Ulrich	faculty, Heidelberg University
1998-2001	Reddy, Sanjay	faculty, University of Washington
1998-2000	Parreno, Assumpta	faculty, Barcelona University
1998-2000	Phillips, Daniel	faculty, Ohio University

1997-2000	Kumar, S. Prem	faculty, Swansea University
1997-2000	Papenbrock, Thomas	faculty, University of Tennessee
1996-2001	Bedaque, Paulo	faculty, University of Maryland
1996-2000	Hagino, Kouichi	faculty, Tohoku University

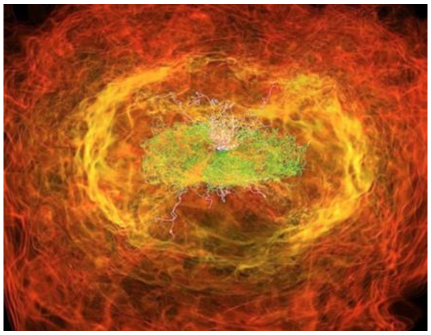
students:

2016 PhD	Wu, Sanfeng	faculty, Princeton University
2015 PhD	Jones, Aaron Mitch	staff scientist, Hughes Research Laboratories
2015 PhD	Kasirga, Serkan	faculty, Bilkent University
2014 PhD	Davoudi, Zohreh	faculty, University of Maryland
2014 PhD	Hansen, Maxwell	staff scientist, CERN
2013 PhD	Briceno, Raul	faculty, Old Dominion University
2011 PhD	Bolton, Daniel	faculty, Colorado State University
2011 PhD	Nicholson, Amy	faculty, University of North Carolina
2010 PhD	Paik, Steve	faculty, Santa Monica College
2010 PhD	Deyo, Eric	faculty, University of Kansas
2010 PhD	Jensen, Kirstan	faculty, San Francisco State University
2010 PhD	Wasem, Joe	staff scientist, LLNL
2010 PhD	Wei, Jiang	faculty, Tulane University
2010 PhD	Wang, Zenghui	faculty, Univ. of Electronic Science and Technology
2009 PhD	Luzum, Matt	faculty, University of Sao Paulo
2009 PhD	Pesin, Dima	faculty, University of Virginia
2009 PhD	Sjue, Sky	staff scientist, LANL
2009 PhD	Smigielski, Brian	staff scientist, Lincoln Laboratories
2008 PhD	Drut, Joaquin	faculty, University of North Carolina
2008 PhD	Miller, Kai	faculty, Mayo Clinic, Minnesota
2008 PhD	O'Bannon, Andy	faculty, University of Southampton
2008 PhD	Kryjevskaia, Mila	faculty, North Dakota State University
2007 PhD	Nishida, Yusuke	faculty, Tokyo Institute of Technology
2007 PhD	Cramer, Claire	staff scientist, DOE ASCR
2007 PhD	Lindsey, Beth	faculty, Penn State Greater Allegheny
2006 PhD	Walker-Loud, Andre	staff scientist, LBNL
2006 PhD	Zurek, Kathryn	staff scientist, LBNL
2006 PhD	Clark, Adam	faculty, Muhlenberg College
2005 PhD	Van de Water, Ruth	staff scientist, FNAL
2005 PhD	Close, Hunter	faculty, Texas State San Marcos
2004 PhD	Kovtun, Pavel	faculty, University of Victoria
2004 PhD	Unsal, Mithat	faculty, North Carolina State University
2004 PhD	Tiburzi, Brian	faculty, CCNY
2004 PhD	Kryjevski, Andre	faculty, North Dakota State University
2003 PhD	Yu, Yongle	faculty, Wuhan Institute of Physics and Mathematics
2003 PhD	Luu, Thomas	faculty, Universitat Bonn
2003 PhD	Ha, Meesoon	faculty, Chosun University
2002 PhD	Fox, Patrick	staff scientist, FNAL
2002 PhD	Boudreaux, Andrew	faculty, Western Washington University
2001 PhD	Liu, Cheng-Pang	faculty, National Dong Hwa University
2001 PhD	Hoyle, C.D.	faculty, Humboldt State University
2001 PhD	Shoresh, Noam	staff scientist, Broad Institute
2000 PhD	Rupak, Gautam	faculty, Mississippi State University

Appendix H: Institute for Nuclear Theory

The Institute for Nuclear Theory is the nation's ``think tank'' for theoretical nuclear physics. Founded in 1990, its mission is to bring new ideas into nuclear physics and transmit new ideas to other fields by engaging with scientists in other areas, such as astrophysics, condensed matter, computational physics, high-energy physics, and emerging areas. The INT Senior Fellows and the Institute's National Advisory Committee have research interests that span across these fields and serve on national committees that define the agenda for the future of nuclear physics. The INT compliments other strong efforts in nuclear physics at the UW including the Center for Experimental Nuclear and Particle Astrophysics (CENPA) and the Department's Nuclear Theory group, which together are consistently ranked as one of the top nuclear physics efforts in the US.

The INT has complementary components. One is to serve the community by hosting proposed workshops and programs that address forefront issues in nuclear physics research and generate new research opportunities and directions. About 400 scientists visit each year and the INT provides an environment conducive to creative thinking and problem solving, facilitates interactions between scientists for periods of intense collaboration, and provides a center for workforce development. Recent workshops and programs include: Nuclear ab initio Theories and Neutrino Physics, Fundamental Physics with Electroweak Probes of Light Nuclei, Neutrino-less Double-Beta Decay, The Phases of Dense Matter, Quantum Computing for Nuclear Physics, Modern Exotic Physics, Binary Neutron Star Coalescence as a Fundamental Physics Laboratory, and Nuclear Physics with Lattice QCD. The INT hosts International Summer Schools, for instance, in Lattice Quantum Chromo-dynamics, and Talent Schools in Low-Energy Nuclear Physics and



A simulations of merging neutron stars forming a black-hole discussed at the INT program on multi-messenger signals from binary neutron stars.

Graduate students from the US and around the world at a summer school on nuclear forces and effective field theories held at the INT in 2015.

Astrophysics, and hosts international conferences, such as the Sign Conference. The INT also administers the UW Physics REU program, and the US's National Nuclear Physics Summer School that is held at institutions within the US.

A second component of the INT is to provide a vibrant local research environment for the INT Senior Fellows and junior scientists, including Research Assistant Professors, Postdoctoral Fellows, Graduate students and undergraduate students, spanning areas of importance to nuclear physics research. Senior and junior Fellows may choose to teach graduate-level courses within the physics department in support of workforce development in nuclear theory covering, for instance, theoretical nuclear physics, group theory, advanced quantum field theory, nuclear astrophysics, and the standard model of particle physics. INT junior scientists typically go on to have highly productive and influential careers at universities, national laboratories and private industry, and receive significant recognition for their contributions to science in the form of prizes and funding awards. Currently, over fifty former INT post-docs and students hold tenured, tenure-track or permanent lab positions around the world.

Recent renovations create additional open spaces for discussion and collaboration..

INT and NTG Junior fellows, postdocs and graduate students hold tenured positions around the world.

Appendix I: Funded Research Projects

Astrophysics

Burnett, Thompson	Gamma Large Area Space Telescope (GLAST) Computing	Stanford University
Lazowska, Edward & Morales, Miguel	Moore/Sloan Grant	Gordon & Betty Moore Foundation
Morales, Miguel & Hazelton, Bryna	From 21 cm observations to precision reionization science	NSF
Morales, Miguel; Hazelton, Bryna; ...	Mitigating ultra-faint RFI to enable radio cosmology	NSF
Morales, Miguel & Hazelton, Bryna	HERA: Illuminating our early universe	University of California, Berkeley
Morales, Miguel	HERA: Unveiling our cosmic dawn	NSF
Morales, Miguel	Precision data analysis software for hydrogen epoch of reionization measurements	
Tuttle, Sarah	Epistemological schemata of astrophysics: A reconstruction of observers	Foundational Questions Institute

Atomic Experiment

Blinov, Boris	Development of 2-D trapped ion crystals for quantum computing and quantum simulations	Royalty Research Fund
Blinov, Boris	Mistletoe unfettered research grant	Mistletoe Foundation
Blinov, Boris	Remote entanglement of trapped ions and loophole-free Bell inequality	NSF
Gupta, Subhadeep	Interacting quantum mixtures of lithium and ytterbium atoms	NSF
Gupta, Subhadeep	Lattice confined mixtures and molecules of Yb and Li atoms for quantum simulation	Air Force Office of Scientific Research
Gupta, Subhadeep	Precision contrast interferometry with ytterbium Bose-Einstein condensates	NSF
Gupta, Subhadeep	Precision laser frequency stabilization to explore novel quantum matter	Royalty Research Fund
Gupta, Subhadeep & Rybka, Gray	REU Site: University of Washington Physics	NSF
Heckel, Blayne	Search for an electric dipole moment of ^{199}Hg	NSF

Biological Physics

Fu, Kai-Mei	Investigation of fT magnetometer for magnetic encephalography	Facebook
Fu, Kai-Mei & Wiggins, Paul	Instrument development: A nanoscale, unbleachable orientation and position sensor for biophysical imaging	NSF
Gundlach, Jens	High accuracy nanopore sequencing	NIH

Kannan, Sreeram & Gundlach, Jens	An information-theoretic approach to nanopore sequencing	NSF
Wiggins, Paul	Bacterial ultra-structure and chromosome segregation	NSF

CENPA

Detwiler, Jason	Surface alpha mitigation and active veto R&D for tonne-scale ^{76}Ge-based neutrinoless double-beta decay searches	University of North Carolina
Detwiler, Jason	Neutrinoless double-beta decay and other physics with ultra-low background enriched-germanium detector arrays	DOE
Fertl, Martin	Muon $g-2$: participate and support reconstruction of the magnetic field	Universities Research Association
Garcia, Alejandro	$g-2$ magnetic field analysis and surface coil shimming	Universities Research Association
Garcia, Alejandro	Searches for new physics in nuclear beta decay	Royalty Research Fund
Gundlach, Jens	Four beam rotation sensors for LLO	Caltech
Gundlach, Jens	Sensors for low-frequency improvements in advanced LIGO	NSF
Gundlach, Jens; Adelberger, Eric; ...	Probing fundamental physics with gravitational experiments	NSF
Hertzog, David	Analysis coordination, workshops, and optimization of calorimeter system for absolute scale energy calibration	Universities Research Association
Hertzog, David	Experimental nuclear physics	DOE
Hertzog, David	Upkeep and improvements to calorimeter hardware opera- tions for the Muon $g-2$ experiment.	Universities Research Association
Rosenberg, Leslie	A proposal to the Heising-Simons foundation	The Heising-Simons Foundation
Rosenberg, Leslie & Rybka, Gray	Experimental particle-astrophysics at the University of Washington	DOE
Rosenberg, Leslie & Rybka, Gray	ADMX-G2: fabrication, commissioning and operations in the 0.6-2 GHz frequency bands	DOE
Rybka, Gray	3rd workshop on microwave cavities and detectors for axion research	The Heising-Simons Foundation
		NSF

Condensed Matter Experiment

Chu, Jiun-Haw	Moore Fellows in materials synthesis	Gordon and Betty Moore Foundation
Chu, Jiun-Haw	New superconductors near broken rotational symmetry instabilities	Air Force Office of Scientific Research
Chu, Jiun-Haw	Sloan Research Fellowship	Sloan Foundation
Cobden, David & Fidkowski, Lukasz	EAGER: Majorana modes in monolayer topological insulator WTe_2	NSF
Cobden, David	EFRI: Spin-valley coupling for photonic and spintronic devices	NSF
Cobden, David, Chu, Jiun-Haw, ...	Development of an instrument combining optics, transport and strain for studying quantum matter	NSF

Cobden, David	Strain and photocurrent microscopy in strongly correlated and layered materials	DOE
Fu, Kai-Mei	An on-chip hybrid gallium phosphide-diamond quantum entanglement device	NSF
Fu, Kai-Mei	CAREER: A "holistic approach toward scalable quantum optical networks in semiconductors	NSF
Fu, Kai-Mei & Majumdar, Arka	EFRI: An integrated quantum communication transmission node	NSF
Fu, Kai-Mei	Hybrid nanophotonic devices for integrated quantum circuits	ORISE
Fu, Kai-Mei	Synthesis of a promising new defect for quantum information processing applications	Royalty Research Fund
Fu, Kai-Mei	Postdoctoral fellowship award	Washington Research Foundation
Gamelin, Daniel; Andreev, Anton; ...	MRSEC: UW Molecular Engineering Materials Center	NSF
Majumdar, Arka; Cobden, David; ...	Integrated 2D nonlinear nanophotonics	Air Force Office of Scientific Research
Majumdar, Arka & Xu, Xiaodong	Electrically controlled solid-state cavity QED with single emitters in monolayer material	NSF
Seidler, Gerald	X-ray characterization of nickel-rich battery materials	Argonne National Laboratory
Seidler, Gerald	New physics in the hot electron furnace	DOE
Seidler, Gerald	Learn X-ray LANL-XES	Los Alamos National Laboratory
Xu, Xiaodong; Cobden, David; ...	A millikelvin optoelectronic quantum material laboratory	Murdock Charitable Trust
Xu, Xiaodong & Fu, Kai-Mei	Ab-initio solid-state quantum materials: design, production, and characterization at the atomic scale	MIT
Xu, Xiaodong	EFRI: Deterministic photonic graph-state repeater networks from solid state emitters in chiral photonic circuits	Virginia Tech
Xu, Xiaodong	Exploitation of magnetism in 2D quantum materials for new spintronic devices	UW Innovation Award
Xu, Xiaodong	Exploring van der Waals ferromagnetic semiconductor chromium triiodide	NSF
Xu, Xiaodong	New quantum phenomena by combining 2D materials with complex oxides	PNNL
Xu, Xiaodong	Quantum engineering exciton dynamics in 2D heterostructures	DOE
Xu, Xiaodong	Ultrafast control of emerging electronic phenomena in 2D quantum materials	DOE

High Energy Experiment

Hsu, Shih-Chieh	Jet substructure and ITk pixel	BNL
Hsu, Shih-Chieh	Quarknet at the University of Washington	U. Notre Dame
Hsu, Shih-Chieh	Search for dark matter using mono-Higgs and the ATLAS pixel detector	DOE

Lubatti, Henry, ... Goussiou, Anna Lubatti, Henry Hsu, Shih-Chieh	Beyond the Standard Model Physics Top quark properties Searches for very long-lived new particles Jet structure, vector meson searchs, ...	NSF
Lubatti, Henry	HL-LHC pixels IST	BNL
Lubatti, Henry	MOU for the maintenance and operation of the WBS 3.6 TDAQ subsystem	BNL
Lubatti, Henry & Hsu, Shih-Chieh	Pixels front-end chip	BNL
Watts, Gordon & Lubatti, Henry	Searching for ultra long lived particles at the LHC	Royalty Research Fund

INT

McLerran, Larry …	National Institute for Nuclear Theory	DOE
McLerran, Larry …	Multifarious Minds	Simons Foundation
Reddy, Sanjay	JINA Center for the Evolution of the Elements	Michigan State University
Reddy, Sanjay	Towards Exascale Astrophysics of Mergers and Supernovae (TEAMS)	University of Tennessee
Reddy, Sanjay	National Nuclear Physics Summer School	NSF
Savage, Martin	Exploratory Research for Extreme -Scale Science: Quantum Algorithm Teams	ORNL
Savage, Martin	Nuclear Physics Pre-Pilot Program in Quantum Computing	DOE

Physics Education Research

Brahmia, Suzanne	Collaborative Research: Physics Inventory of Quantitative Literacy	NSF
Heron, Paula	Examining the development of student reasoning skills through scaffolded physics instruction	NSF
Heron, Paula	University student conceptual resources for understanding physics	NSF
Shaffer, Peter	Next Generation Research-Based and Research-Validated Instructional Materials for Teaching Physics in Different Instructional Environments	NSF

Theory

Andreev, Anton	Electron transport in topologically nontrivial conductors and nanosystems	DOE
Bulgac, Aurel	Center of Excellence in low energy nuclear science	Texas A&M
Fidkowski, Lukasz	Interplay of symmetry and topology in gapped phases of condensed matter systems	NSF

Li, Xiaosong & Rehr, John	Center for scalable, predictive methods for excitation and correlated phenomena	PNNL
Miller, Gerald, ...	Theoretical nuclear theory	DOE
Beane, Silas	Nuclear effective field and lattice gauge theory	
Bulgac, Aurel	Nuclear structure and dynamics	
Miller, Gerald	Meson and nucleon structure	
Miller, Gerald	Standard Research Contract with Argonne National Lab.	DOE
Nelson, Ann, ...	Theory of particles, fields, and strings	DOE
Nelson, Ann	Baryogenesis, hidden sectors, axion cosmology	
Karch, Andreas	3D dualities, bosonization, conformal field theory	
Sharpe, Stephen	Scattering amplitudes from lattice gauge theory	
Yaffe, Laurence	Holography and extreme QCD, large *N* gauge theories	
Rehr, John	Reactivity & structural dynamics of supported metal nanoclusters using electron microscopy, in-situ x-ray ...	University of Illinois
Rehr, John	New dimensions in the theory of excited states and x-ray spectra	DOE
Rehr, John	Theory institute for materials and energy spectroscopies	SLAC
Spivak, Boris	Theory of fluctuations and onset of hot spots in burning media	LANL

Appendix J: Physics Education Research at UW

- *What initial ideas, attitudes, and habits of mind do students bring to the university physics classroom and how do these impact students' experience of instruction?*
- *Which ideas represent raw material for the construction of more sophisticated thinking?*
- *Which conceptual and reasoning difficulties impede progress?*
- *How do learners develop sophisticated mathematical reasoning?*
- *To what extent do students grasp the nature of scientific models?*
- *How can physics programs best prepare students for future studies, or for the workplace?*
- *At a fundamental level, how can university physics instruction help best prepare and support K-12 teachers to teach physics and physical science effectively?*

Over the past several decades the field of **physics education research** (PER) has made significant advances in answering these questions, resulting in broad impacts in the classroom. However, the social and cognitive systems under study are highly complex and progress is seldom rapid. Some areas are well-studied, but even there, new discoveries are being made. As in other subfields of physics, clever experiments, systematic observations, theoretical insights and iterative design cycles are needed to drive further progress. PER faculty at UW (McDermott, Shaffer, Heron and Brahmia), all tenure track, are at the forefront of research that encompasses large parts of the above agenda and are well positioned to increase the scope and impact of their work.

The questions above focus on fundamental learning processes and underpin the design of better teaching methods, environments, and materials. The twin goals of advancing our understanding of how people learn and translating the advances into widely-adopted instructional practices are the pillars of the UW's high-visibility, high-impact program in physics education research. While each of the four PER faculty has specific research interests, the overall program is coherent, with mutually reinforcing agendas that increase productivity and impact as well as enhancing the ability to mentor graduate students. The UW PER faculty will continue to expand their investigations into the ability of students to apply fundamental concepts and principles in analyzing sophisticated qualitative and quantitative problems, and to use the findings to inform the development of teaching methods and materials. They have continued to break new ground by adopting new tools, expanding into new classroom settings, and initiating collaborations with colleagues at other institutions whose skills complement those of our PER faculty.

Maintaining a strong and vibrant PER program has significant benefits for the UW and the Department. PER faculty contribute to the stature of the Department through their research, published curricula [*Tutorials* (Pearson, Inc.) and *Physics by Inquiry* (Wiley) as of 2018] and mentoring of the next generation of researchers. The efforts have had ongoing support by NSF and other agencies (~$5.5M in the past 10 years). Another way in which a vigorous effort in PER benefits the Department is through support of instruction. In the early 1990s, McDermott and Shaffer launched an effort to enhance student learning by introducing *Tutorials* into the calculus-based sequence. Since then, the tutorials have had national and international impact on the teaching of introductory physics. Continual revisions and updates are made to reflect the recent evidence on how best to teach. The success of the tutorials with this population has led to the development of similar materials to support learning in upper division courses (junior-level E&M and Quantum Mechanics). More recently, at the request of faculty teaching algebra-based physics, PER faculty have begun developing approaches that bring the benefits of tutorials to large lecture halls. Innovations in the introductory laboratory sections are also planned for the next few years, supported by PER faculty. Moreover, since the inception of the tutorials, PER faculty have been deeply involved in the preparation of TAs (graduate and undergraduate) for their instructional roles in the introductory courses.

Finally, since the early 1970s, PER faculty at the UW have taken responsibility for the physics education of current and future K-12 teachers. Through participation in courses, workshops, and institutes, thousands of teachers, both nationally and internationally, have been impacted. The teacher preparation program and instructional materials (*Physics by Inquiry)* have been adopted at colleges and universities around the world.

Despite continued growth in the field, the UW PER group continues to have a significant impact. Our Department is the only one in the country with active physics education research and curriculum development that spans K-12 teacher preparation to introductory and advanced physics courses. The research and instructional laboratory that has been created by the group is unique and provides opportunities for investigations that are not possible elsewhere. This resource, however, needs significant faculty involvement if the UW and Department are to remain at the forefront of the field and to ensure that our students are being provided with instruction that is among the best in the country.

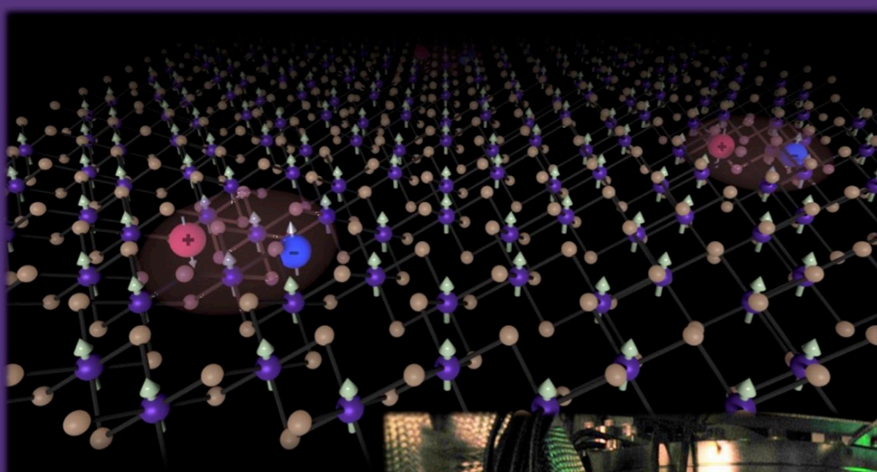
Appendix K: Thouless Institute for Quantum Matter

Thouless Institute for Quantum Matter

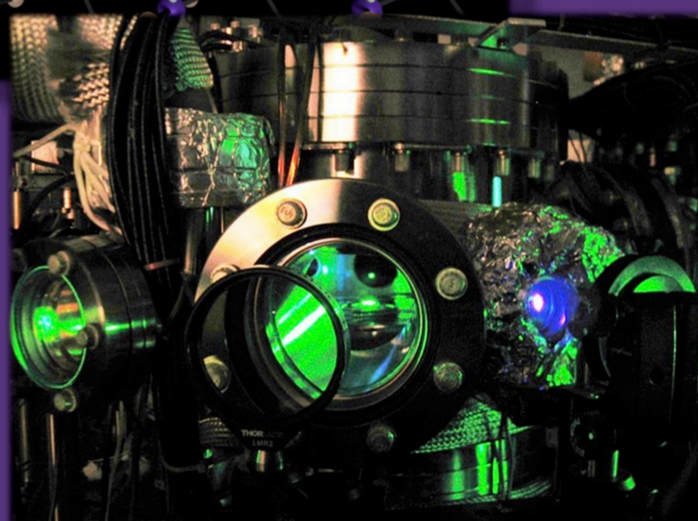
Department of Physics, University of Washington, Seattle

20th century solid state physics made present information technologies possible. Quantum matter research is now poised to enable 21st century technologies, such as quantum information processing.

New theoretical ideas concerning topology, symmetry and many-body interactions play a key role. Progress in quantum matter research rests on tight integration between theory and experiment.

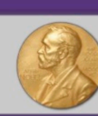


Valley excitons in a two-dimensional semiconductor

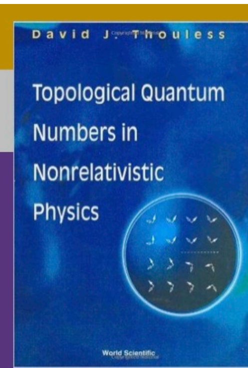


Experiment on double-degenerate quantum fluids

Named in honor of Professor Emeritus David Thouless, recipient of the 2016 Nobel Prize for Physics, the TIQM will assemble world-leading experimental and theoretical scientists dedicated to exploring the fundamental properties of quantum matter. Our shared desire is to spark a quantum technology revolution.



Topology in Quantum Matter



The 2016 Nobel Prize in Physics was awarded with one half to David J. Thouless, and the other half to F. Duncan M. Haldane and J. Michael Kosterlitz.

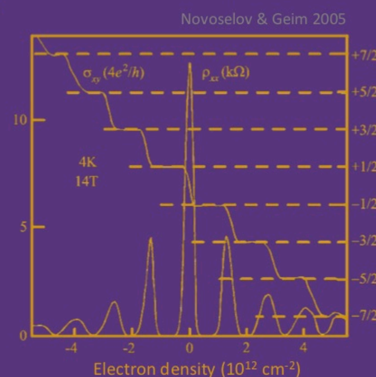
The Nobel laureates' studies of two-dimensional (2D) and one-dimensional (1D) matter revealed the importance of topology in physics, with far-reaching consequences in the present day, for example in quantum computing.

The quantum Hall effect

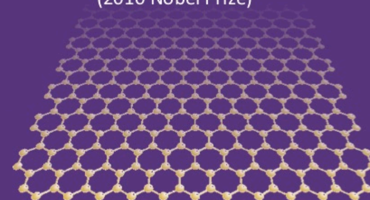
The astonishingly accurate quantization of the Hall conductance σ_{xy} of 2D conductors in magnetic fields was a mystery until Thouless, den Nijs and coworkers (1982) explained it using topology:

$$\sigma_{xy} = \frac{e^2}{h}\sum_n C_1(n)$$

where $C_1(n) = \frac{1}{2\pi}\oint d\boldsymbol{k}.\boldsymbol{B}(\boldsymbol{k},n)$ is the first Chern number and $\boldsymbol{B}(\boldsymbol{k},n)$ the Berry curvature of the n^{th} band.



← Quantum Hall effect in graphene (2010 Nobel Prize)

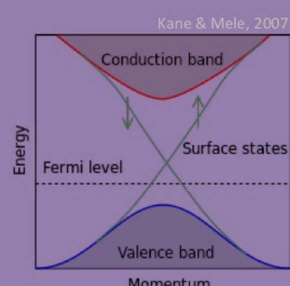


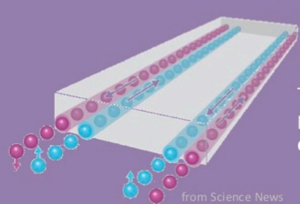
The Chern number is like the number of holes in a solid object – it can only be an integer.

Topological matter

Many other topological states of quantum matter have since been discovered. Topological insulators have topologically protected surface states that could carry current or spin without resistance.

In a **2D topological insulator** there are protected 1D edge modes, rather like in a quantum Hall conductor but with no magnetic field.



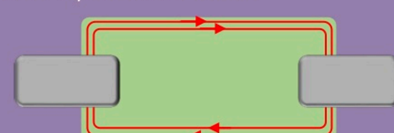


The edge modes are spin-polarized, leading to the **quantum spin Hall effect**.

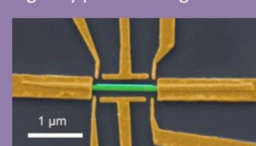
Topological protection

Quantum information processing is plagued by "dephasing" noise. Topological properties can be immune to noise, offering a route to fault-tolerant quantum computation.

In the quantum Hall effect, the conductance is topologically protected: the number of edge channels is dictated by the Chern numbers.



Qubits based on "Majorana states" could be topologically protected against dephasing.



A nanowire Majorana device (Niels Bohr Institute)

What is the TIQM?

The TIQM will be a community of theoretical and experimental physicists engaged in quantum matter research housed in the Department of Physics at UW. It will have extensive connections across local and global scientific communities and be affiliated with visionary technology firms in the Pacific Northwest.

With the success of Bell Labs in mind, the TIQM will be designed to provide a collaborative environment that promotes easy interactions and free-flowing collaborations between theorists and experimentalists, and to encourage the freedom of inquiry needed for breakthrough discoveries. With a focus on profound questions in applied physics and an exceptional concentration of expertise spanning current quantum matter science, it will open new directions and promote innovation.

The TIQM will be a special intellectual resource for the local STEM communities, enhancing UW's role as a global scientific hub in the Pacific Northwest, and inspiring the region's students and its public.

TIQM faculty will work extensively with students, postdoctoral fellows, and collaborators worldwide. Key components will be a named postdoctoral research fellowship program similar to the Pappalardo Fellows at MIT or Miller Fellows at Berkeley; named graduate student fellowships; and a visitors program.

Why here and now?

The University of Washington is presently enlarging its world-leading quantum matter physics effort on the experimental side. With the Nobel Prize just awarded for theoretical work, and the information technology explosion in the Puget Sound area, now is the time to act.

How will it be started?

The main tasks in building the TIQM will be to expand the theoretical quantum matter activity and to launch the above programs.

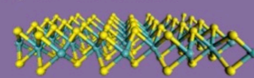
A combination of university, industrial, foundation, and individual support is sought. An endowment of \$1M is sufficient to launch the Institute, and \$2M creates a visitor program and public lecture series. \$1.5M creates a new junior faculty position. \$10M establishes the postdoctoral fellowship program in perpetuity. \$10M supports a prestigious endowed chair with an accompanying research group.

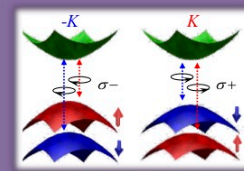
2D Quantum Materials

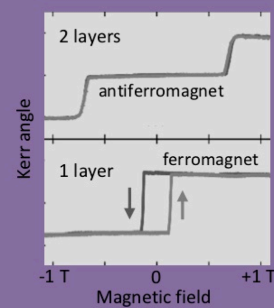
TIQM

UW Physics leads in key areas of 2D quantum materials, which like graphene can exist as stable, atomically thin sheets.

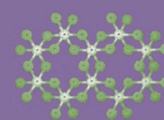
2D valley semiconductors

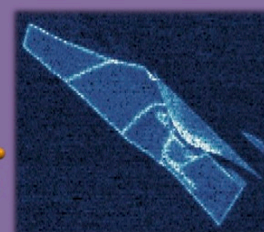




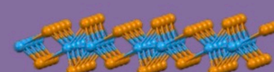


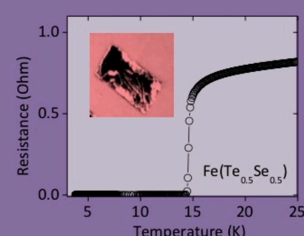
2D magnets



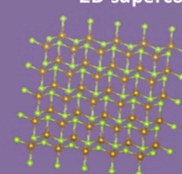


2D topological insulators

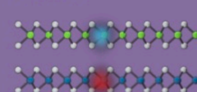


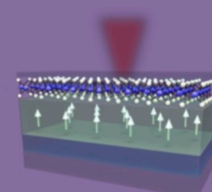


2D superconductors

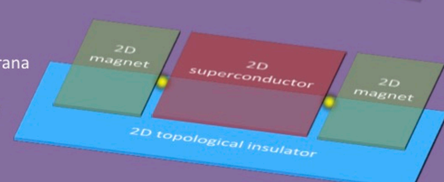


2D heterostructures





Proposed Majorana qubit in a 2D heterostructure



Thouless Institute for Quantum Matter

Department of Physics, University of Washington, Seattle

Current quantum matter researchers

Experiment: Boris Blinov, Jiun-Haw Chu, David Cobden, Kai-Mei Fu, Arka Majumdar, Subhadeep Gupta, Xiaodong Xu

Theory: Anton Andreev, Lukasz Fidkowski (joins in 2017), Marcel den Nijs, Boris Spivak, David Thouless (emeritus)

Affiliates: Matt Hastings, Matthias Troyer (Microsoft Research); Arkady Levanyuk

W UNIVERSITY of WASHINGTON

For more information please contact David Cobden, cobden@uw.edu

Appendix L: Institute for Quantum Information and Computing

Summary:

The famous Einstein-Podolski-Rosen paper of 1935 first identified entanglement as a key and unique feature of quantum mechanics; now over eight decades later, propelled by recent theoretical, experimental, and technological advances, the physics of entanglement has become the focus of a vibrant and growing international research effort with significant technological and security implications. Entanglement science reaches across the boundaries of Condensed Matter, Nuclear, High Energy and Atomic physics, with ties to Computer Science, Quantum Chemistry and Electrical Engineering. With the Physics Department having a number of researchers currently working on aspects of this new field, there is an opportunity now to build this effort into a focused Institute that would nucleate a coherent Quantum Science and Information effort at the University of Washington, with strong ties to local industry.

The envisioned Institute for Quantum Information and Computing (IQIC) would have three main research foci:

- Scientific quantum computing
- Quantum Information science
- Entanglement in the laboratory

Scientific quantum computing:

For decades, scientists have known that devices to store and manipulate information in quantum physical systems such as electrons, atoms, photons or superconductors, could provide radical new capabilities in computing. As existing computing technologies approach fundamental limits to continued scalability, quantum computing (QC), which relies on quantum entanglement as an intrinsic element, has emerged as a profoundly different and potentially vastly more powerful way of computing. By exploiting the novel laws of quantum physics, QC promises to open new scientific and industrial frontiers by transforming important computationally hard classical computing problems into tractable and scalable forms. Examples of such problems exist at the heart of research into nuclear, particle, astro and condensed matter physics, as well as chemistry, material science, encryption, data management and communications. Examples include:

- Computing properties of dense matter and heavy nuclei from Quantum Chromodynamics.
- Computing properties of the quark gluon plasma and the plasmas inside stars.
- Understanding the role of topology in relativistic quantum field theories.
- Computing the properties of asymmetric condensed matter systems, such as models for high T_c superconductivity.
- Computing the electronic structure of catalytic molecules.

Nascent quantum programming models differ from traditional ones and are not nearly as well understood. Some core quantum algorithms show significant promise for computational speedups in physical science applications, such as many-body quantum chemistry, but to date these algorithms have only been developed for a small set of problems of practical interest. Development of new approaches to computational many-body theory and quantum field theory will be a focus of the IQIC, and build on the existing expertise in computational many-body physics and quantum field theory in the Physics Department.

Quantum information science:

Quantum information is the subject of intense study in particle theory, condensed matter physics and atomic physics. In particle theory, key questions have been articulated by the Simons Foundation *It from Qubit* project such as:

- Does spacetime emerge from entanglement?
- Do black holes have interiors?
- What is the information-theoretic structure of quantum field theories?
- Can quantum computers simulate all physical phenomena?
- How does quantum information flow in time?

Entanglement in the lab:

Individual atoms aided by precision manipulation techniques in the lab form pristine systems for testing and applying quantum entanglement towards quantum information processing. Physicists at the UW played a pioneering role in developing precision methods for trapping and manipulating atomic ions (Hans Dehmelt, Nobel Prize 1989). Further advances and refinement of such methods with atomic ions and neutral atoms, and their applications towards quantum information processing led to the 2012 Physics Nobel Prize awarded to Wineland and Haroche, one of whom (Wineland) was a researcher for several years in our department. These precision manipulation techniques are also being extended to harness the greater variety of quantum properties in multi-atom molecules. Recently, metrology and quantum techniques pioneered in atomic systems have also been successfully applied to single atomic-like defects in crystals.

Current and future areas of interest to condensed matter and atomic researchers in our department include:

- Quantum simulation and large-scale entanglement in trapped ion crystals. Laser-cooled, trapped atomic ions form Coulomb crystals. Quantized vibrations of this crystalline lattice can be used to create a large-scale entangled state, as well as to efficiently simulate other physical systems.
- Quantum simulation in neutral atoms and molecules trapped in optical lattices. Optical lattices provide a model crystalline structure to confine cold neutral atoms or molecules. Initialization and subsequent observation of these model systems can inform problems in more complex quantum systems such as superconductors. Pinned at individual lattice sites, atoms and molecules can form registers/transducers for quantum information.
- Quantum entanglement between vastly different physical systems and quantum networks based on photonic measurements in trapped ions and defects in crystals. By matching spectral properties of photons emitted by optically active defects in crystals and trapped ions, entangled states of these vastly different physical systems can be generated. This allows the unique properties of ions (long coherence times, high fidelity control and measurement, and strong coupling to co-trapped ions for local quantum gates) and defects (robustness and scalability) to be combined to form quantum networks.
- Generation of (entangled) many-body states to improve the performance of atom interferometers for metrology and sensing.
- Quantum information processing with single atomic-like defects in crystals.

Funding opportunities:

Many funding sources have identified Quantum Information Science, Quantum Computing, and Entanglement in the Laboratory as clear areas of strong support. For example, one of the 10 “big ideas” at NSF is *The Quantum Leap: Leading the Next Quantum Revolution*:

> *Exploiting quantum mechanics to observe, manipulate, and control the behavior of particles and energy at atomic and subatomic scales, resulting in next-generation technologies for sensing, computing, modeling, and communicating*.

Recent calls from the DOE include ones in Materials and Chemical Sciences Research for Quantum Information Science, there are QIS research programs in ASCR, BES, HE and NP, and Secretary Perry recently announced $30M of new funding for Quantum Information Science at National Laboratories. Both DoD/IARPA and NSF also have new funding initiatives for QIS. In 2017, at the request of the U.S. House Science Committee, the National Photonics Initiative created a white paper entitled “A Call for a National Quantum Initiative”. See also The National Quantum Initiative (NQI) Action Plan.

A campus-wide and regional opportunity:

We envisage creation of a university-wide consortium with a broad focus on quantum information science and quantum computing that brings together expertise from physics, chemistry, engineering and computer science to address larger scale problems than those in physics alone. We see the Institute for Quantum Information and Computing as a way to catalyze a broader research effort across departments and schools at the UW.

Interested faculty members are also establishing ties with technology companies in the Seattle area and beyond. The INT and condensed matter group have fruitful relationships with scientists at Microsoft, and look forward to strengthening these connections. We currently have faculty members collaborating with teams of QIS researchers at national laboratories, and we have national laboratory staff scientists residing within the Physics Department. The envisioned IQIC will host workshops and would raise the UW’s profile in this broad area.