Department of Physics

The Department of Physics has been a national resource for over a hundred years. It has been at the center of the twentieth-century revolution in understanding the nature of matter and energy and the dynamics of the cosmos. Our faculty—of whom four are Nobel Prize winners and 19 are National Academy of Sciences members—include leaders in nearly every major area of physics. In addition, ten alumni have won Nobel Prizes (four since 1997). Robert Noyce and Jay Last, two of the eight founders of Fairchild Semiconductor, earned PhDs in our department. Fairchild is the company that gave birth to Intel and, arguably, all of Silicon Valley. The number of SB degrees awarded to students majoring in physics was higher in 2007 than we have seen since the 1980s and more than twice the number in 2000. At the graduate level, 42 percent of our offers were accepted. *U.S. News and World Report* rated us the number one physics program, a distinction we have held since 2002. Physics faculty continue to win prizes for research and teaching, and we attract the best physicists in the field at all levels of seniority.

Honors and Awards

Following are a few of the many honors and awards conferred on Physics faculty during the 2007 academic year. Daniel Kleppner, Lester Wolfe professor emeritus, was awarded the 2006 National Medal of Science, America's highest honor for scientific achievement. He was also one of two Department of Physics recipients of the Frederick Ives Medal of the Optical Society of America. Professor Kleppner received the 2007 prize for "sustained innovation, discovery and leadership in the interaction of radiation with atoms and for his service and general educational activities." Erich P. Ippen, Elihu Thomson professor of electrical engineering and professor of physics, won the prize in 2006 for "laying the foundations of ultrafast science and engineering, and providing vision and sustained leadership to the optics community." Nergis Mavalvala, associate professor of physics and Cecil and Ida Green career development professor, received the Harold E. Edgerton Faculty Achievement Award. In addition, she was awarded the John de Laeter Medal of the Australian Institute of Physics.

Thomas J. Greytak, professor of physics and associate department head for education, was named the Lester Wolfe professor of physics. In addition, he was awarded the 2007 Dean's Educational and Student Advising Award of the MIT School of Science. Both Ulrich J. Becker and Peter Fisher were named fellows of the American Physical Society.

Institute Professor and professor of physics and electrical engineering Mildred S. Dresselhaus received honorary doctorates from the Federal University of Ceara (Brazil), the University of Pennsylvania, and the University of Arkansas at Little Rock. Professor Dresselhaus also received the L'Oréal-UNESCO Award for Women in Science. Sara Seager, associate professor of physics and Ellen Swallow Richards associate professor of earth, atmospheric and planetary sciences, was awarded the Helen B. Warner Prize of the American Astronomical Society.

Young physics faculty continue to receive honors. Joseph Formaggio, assistant professor of physics, was named an outstanding junior investigator in nuclear physics by the US Department of Energy. He also received the Reed Junior Faculty Award as well as the Polansky Prize. Those who were noted for their outstanding teaching included Eric W. Hudson, assistant professor and class of 1958 career development chair, who received the Buechner Teaching Award of the MIT Physics Department and Alexander van Oudenaarden, Keck career development professor in biomedical engineering and associate professor of physics, who received the School of Science Prize for Excellence in Graduate Teaching.

Retired Physics faculty were acknowledged for their work. Rainer Weiss, professor of physics emeritus, shared the Gruber Cosmology Prize for his contributions to the success of the Cosmic Background Explorer satellite and was a corecipient of the Einstein Prize of the American Physical Society "for fundamental contributions to the development of gravitational wave detectors based on optical interferometry, leading to the successful operation of LIGO." Anthony French and John King, professors of physics emeriti, were corecipients of the Excellence in Physics Education Award of the American Physical society.

The Department continued to be active with faculty promotions and appointments. Nergis Mavalvala and Iain Stewart were promoted to associate professor, while three faculty members were granted tenure: Gunther Roland, Senthil Todadri, and Vladan Vuletic. The Department appointed two new faculty members, who joined the Condensed Matter Experiment group—Nuh Gedik and Pablo Jarillo-Herrero. Both previously were postdoctoral scholars, Gedik at the California Institute of Technology and Jarillo-Herrero at Columbia University.

Education

The Physics faculty reviewed and endorsed the TEAL (Technology Enabled Active Learning) format as the primary method of instruction for 8.01 Physics I and 8.02 Physics II. This was the second year that 8.01 was taught with TEAL and the sixth year for 8.02. Teaching staff in 8.02 were pleased the overall course evaluation score increased substantially this year, an indication the teaching method is being accepted as standard. 8.01L Physics I was offered to students with weak backgrounds and included some desktop experiments from the TEAL format. 8.012 Physics I and 8.022 Physics II were offered in the lecture/recitation format while also utilizing some of the facets of TEAL.

This year 234 students pursued physics SB degrees, the largest number in 17 years. This translated to 85 SB degrees, an 18-year high. Of the degree recipients, 64 percent chose the flexible option and 45 percent of the recipients earned dual degrees, while 21 percent were nominated into Phi Beta Kappa. Further, 29 percent of all MIT Phi Beta Kappa inductees were physics majors.

The graduate program welcomed a large first-year class of 66 students. Our yield for the 2007 class decreased slightly to 42 percent, a normal correction from an unusually high yield of 50 percent in 2006. Fellowships continue to be vital to our recruiting efforts in an increasingly competitive top-tier program environment. Of our incoming graduate students, 80 percent have fellowships, most awarded by the Department. We are pleased to note that the sense of community among physics graduate students was cited by incoming students as an attractive program feature. Graduate student Jake Hartman was the 2007 recipient of the Edward L. Horton Fellowship Award for fostering fellowship within the graduate student community.

Diversity

The Department of Physics uses multiple strategies to recruit minority graduate students. Professor Eric Hudson serves as the Department's designated faculty member in these efforts. Professor Hudson, along with the graduate admissions coordinator, reviews and tracks all minority applications to ensure that due diligence is applied in the candidate review. The Department subsequently funds all travel expenses for accepted underrepresented North American applicants who choose to visit the MIT campus. Professor Hudson also represents the Department in MIT recruitment programs such as Converge and the MIT Summer Research Program. This year the National Society of Black Physicists held its annual meeting in Boston. Professor Hudson represented the Department at conference recruiting events including the organization of an information session for potential MIT applicants. Despite these efforts, the pool of qualified minority candidates for graduate school is extremely limited, which results in aggressive recruitment among our peer institutions.

The Department also supports women graduate students through the generous financial assistance of an alumna donor. There are Women in Physics groups in both the graduate (http://web.mit.edu/physics/wphys/) and undergraduate (http://web.mit.edu/uwip/) populations. Both groups organize events such as biweekly dinners, a mentor program, professional development forums, and other social events. The Graduate Women in Physics group is vital in recruiting female applicants through personal phone calls, housing open house attendees, and organizing a welcome brunch. The Department recognized the importance of providing a supportive environment this year by including a dedicated space in the Green Center for female students. The Margaret Wong Room was designed based on student input.

Finally, the Department continues to recognize the importance of recruiting and retaining underrepresented minorities and women to its faculty. Search committees are actively working to make sure efforts are being made to seek out underrepresented groups by preparing a pre-search plan to attract underrepresented qualified candidates. Throughout the recruitment process, advertising is targeted to reach these groups through diversity and organizational job boards and publications. Applicant data is closely tracked, and applications from qualified women and minority candidates are given consideration across all the divisions.

Our Pappalardo Fellowship program is a wonderful opportunity for us to meet with and identify women physicists who will soon be prospective faculty members. Since the inception of the program in 2000, after a thorough review of applicants by a committee that includes representatives from all physics subfields, we have been able to make offers to 53 percent of the women applicants interviewed. Of those receiving offers, 62.5 percent joined the program. For the three most recent years of the program, there have been an equal number of offers made to men and women. In any year, the program has a much greater representation of women than is found in other areas of the Department. The program also provides the postdoctoral candidates the opportunity to get to know the Department in a more informal way than they would as postdoctoral associates appointed in labs or centers, or if they were simply visiting MIT as interviewees. We have hired several faculty members who had Pappalardo Fellowships, including Gabriella Sciolla.

Pappalardo Fellowships in Physics

In 2000, Mr. A. Neil Pappalardo (EE, 1964) provided the funds to inaugurate and sustain a competitive postdoctoral fellowship program for physics, named the Pappalardo Fellowships in Physics. He recognized that a distinguishing feature of the sciences in general, and physics in particular, is the invaluable contribution made by the accomplishments of outstanding individuals. With this in mind, the mission of the Pappalardo Fellowships in Physics was creating a preeminent postdoctoral program for the Department that would identify, recruit, and support the most talented and promising young physicists at an early stage in their careers.

The program appoints three new fellows per academic year for a three-year fellowship term each. Fellows are selected by means of an annual competition, global in scope, for which candidates cannot apply directly but must be nominated by a faculty member or senior researcher from the international community of physics, astronomy, and related fields. Two notable program features are the fellows' complete freedom of choice in research direction (within the Department) throughout their fellowship appointment and the active faculty mentoring of fellows, fostered by weekly luncheons and monthly dinners with the Department's faculty.

The department head appoints the 10 members of the program's executive committee, which encompasses a nine-member faculty committee and a staff administrator, who directly manages the program. Each division of the Department is represented on the committee by faculty members in both theory and experiment, whose primary responsibilities are to carefully review and evaluate the fellowship candidates in their respective area of physics as well as to select and interview each year's 18 to 20 finalists during the two-day on-campus marathon of panel-style interviews.

Former fellows are now faculty members at, among others, MIT, the University of Pennsylvania, Cambridge University, the University of Chicago, and the University of California at Berkeley. Three are faculty at MIT: Marin Soljacic, who studies novel ways to control light; Gabriella Sciolla, who uses high-energy physics to explore profound symmetries of nature; and Robert Simcoe, who hunts for the first stars in our universe.

Green Center

On October 5, 2007, the MIT President and Corporation will dedicate the new Cecil H. and Ida F. Green Center for Physics. This new space is a significant accomplishment for MIT that has been decades in the making. Indeed, there were several attempts to design a much needed home for the Department of Physics beginning in the late 1960s. One step in this journey occurred in the 1980s, when Cecil Green (SB, SM, 1924) made a significant gift toward a space renovation. The Green Center for Physics concept was revived soon after Marc Kastner become department head in February 1998. Neil Pappalardo (EE, 1964) offered to give the Department a significant sum for the building of a center if Physics could raise matching funds. One year later, the Department had reached this financial goal.

The goal included not only funding for the center, but the cooperation of the Department of Materials Science and Engineering (DMSE). This resulted in an exchange of spaces between the two Departments that facilitated the unification of Physics administrative and educational space. With these gifts and agreements in hand and support from MIT's upper administration, the Green Center for Physics was finally moving forward as the centerpiece of what ultimately became the larger Physics, DMSE, Spectroscopy, and Infrastructure (PDSI) construction project.

The architectural firm of Imai, Keller, Moore (IKM) successfully created designs that were both innovative in anticipating Departmental needs for the next decades while preserving the historic Bosworth Buildings. For example, the corridor outside the Pappalardo Community Room is a welcoming area to congregate, rest, or just take in the view of the Killian Court, the Charles River, and the Boston skyline. The architectural firm of Payette Associates had just completed the Institute's Main Group Master Plan, which was a study for the upgrade of the main buildings' infrastructure. Payette joined forces with IKM for completion of the design and incorporation of Payette's use of the infill for infrastructure. Payette continued with the construction phase of the project, while retaining the integrity of the original IKM design.

Programmatically, the Green Center not only unified the Department's administrative and educational activities, it simultaneously brought the bulk of Department's renowned theoretical research groups together in a single space designed to encourage the sort of spontaneous collaboration essential to these scientists. The PDSI project also marks the first implementation of the Institute's Main Group Master Plan, and thus serves as a model for all future large renovations of the campus's historic core. Along with extensive renovation, the project also includes the construction of a new 49,000-square foot building, named 6C, which partially fills the Main Group's Atomic Courtyard. This infill building enables or renews infrastructure for the Main Group's 255,000 square feet. In addition, 90,000 square feet of unrenovated space received life safety upgrades, resulting in a PDSI net area of influence of 345,000 square feet: approximately one-third of the Main Group's 1,085,000 square feet. Within the area of renewed infrastructure, 127,000 square feet is space that received major mechanical system upgrades—primarily in the ventilation and life safety systems—without undergoing major renovation. The remaining 128,000 square feet is the fully renovated program space, including new space in Building 6C.

Construction began in the summer of 2005, and most spaces in the project have now been occupied as the tail end of construction came to completion in summer 2007. No MIT group experienced major downtime due to construction. Most impacts to campus activities topped out at only "major inconvenience." The Physics Department is already experiencing the benefits of all these sacrifices, and the Institute as a whole will experience them in the years to come.

The Green Center is a major accomplishment for the Institute, representing cooperation between departments and a synergy of Departmental needs, Institutional planning, philanthropic vision, and strategic execution. This short report cannot begin to touch upon the complexity of this project, or the number of individuals required to bring it to completion. Everyone involved takes pride in this significant body of work.

For more information about the Green Center for Physics and the PDSI project, please see http://web.mit.edu/facilities/construction/pdsi/index.html and http://scripts.mit.edu/~physics/greenctr/slideshow.php

Research Highlights

New Spectroscopic Technique Increases Energy Resolution in Solids by a Factor of 1000

A new spectroscopy technique has been developed that allows measurement of the spectrum of electron energy levels in a 2D system with 1000 times better energy resolution than was previously possible. Professor Ray Ashoori and his postdoctoral associate Oliver Dial use a quantum mechanical effect called tunneling, where electrons are able to pass through barriers that would otherwise be insurmountable. Because electrons can only tunnel into the 2D system if their energy matches one of the system's energy levels, tunneling can provide accurate measurements of the spectrum.

Over a century ago, it was understood that light emitted from atoms comes in certain well-defined colors, which led to a scientific revolution when physicists developed quantum theory to explain the spectrum of emitted colors. They discovered the distinct quantum energy levels of electrons orbiting a nucleus were responsible for the spectrum. Energy levels also exist in solids, and are especially interesting when electrons are trapped closely together. One way to trap electrons uses walls made of thin layers of different materials, creating two-dimensional systems where electrons are only free to move in a plane, as if placed on a sheet of paper. These 2D electron systems, where the electrons are disturbed electronically, have not only hosted amazing discoveries leading to two Nobel prizes, but they are also used in sensitive high-frequency amplifiers. Unfortunately, it has proved difficult to measure their energy levels. Similar to creating small ripples on the surface of the sea, previous techniques show only what is happening at the edge of the energy levels that are filled in the spectrum.

Pictures made using the new spectroscopy technique provide the first glimpse of the entire sea in these systems, both above and below the surface. This opens an entirely new dimension of measurement— energy from the surface to exploration of the entire sea. For more information on Professor Ray Ashoori and this research, see http://electron.mit.edu/.

String Theory Finds Connections between Black Holes and Heavy Ion Collisions

Microseconds after the big bang, the universe was filled with quark-gluon plasma, a state of matter in which quarks and gluons are not confined inside protons or neutrons but can freely roam around. Scientists at Brookhaven National Laboratory on Long Island have recently recreated exploding droplets of quark-gluon plasma by colliding high-energy gold nuclei at the Relativistic Heavy Ion Collider (RHIC). The quark-gluon plasma at RHIC exhibits many surprising properties: it is close to an ideal liquid with almost no viscosity, and it strongly attenuates the high-energy quarks trying to plow through it. These experimental results present exciting but tough challenges for theoretical explanations. Properties of quarks and gluons are described by a theory called Quantum Chromodynamics (QCD). The interactions between quarks and gluons in the plasma, however, appear to be strong, and this is a regime in which QCD calculations are very hard to perform.

Professors Hong Liu and Krishna Rajagopal, along with their collaborators, are making progress on these questions from a different perspective, via string theory. String theory is the leading candidate for a theory of quantum gravity—an ambitious framework to unify all the fundamental forces in nature. Their approach is based on an earlier discovery that a family of QCD-like theories have an equivalent description in terms of quantum gravity in certain five-dimensional curved spacetimes. In particular, strongly interacting quark-gluon plasmas in these theories, which share features with that of real-world QCD, are described by strings propagating outside black holes. The researchers studied the ability of a quark-gluon plasma to stop external high energy quarks, finding how it would increase with temperature and with the number of species of gluons that make up the plasma. Their quantitative results are consistent with data from RHIC and will be further tested in the Large Hadron Collider (LHC) at CERN, Geneva in a couple of years. They also studied how the J/psi meson (which is made of heavy quarks) could dissolve in a plasma due to an effect called screening. They found that the screening effect increases with the velocity of the J/psi—faster ones will dissolve more easily. Based on this observation, they made a qualitative prediction for the survival rate of J/psi in heavy ion collisions, which will also be tested in LHC. For more information on Professor Hong Lu and this research, see http://www.nature.com/nphys/journal/v3/n5/full/nphys604.html.

Laser Cooling a Coin-sized Object to within 1 Degree of Absolute Zero

Laser cooling of a coin-sized object down to temperatures below 1 Kelvin was achieved in the lab of Professor Nergis Mavalvala. Using a variation on the laser-cooling technique used in chilling vapors of gases down to sub-kelvin temperatures, Mavalvala, graduate student Thomas Corbitt, and collaborators used laser beams to cool a coin-sized mirror with a mass of 1 gram down to a temperature of 0.8 K. The goal of chilling such a relatively large object (with more than 10^{22} atoms) is to investigate the quantum properties of large ensembles of matter. Quantum mechanics is frequently thought of as only governing the behavior of microscopic objects (such as atoms and molecules), but large (macroscopic) objects should also obey its laws. Macroscopic objects must be cooled to remove kinetic energy of motion that otherwise blurs out quantum behavior. In this experiment the cooling takes place in one dimension—the temperature of 1 K applies to the motion along the direction of the laser beams, while the mirror is free to move (although not much) in other directions. Consequently, the mirror would not feel cryogenically cold when touched.

In addition to the record low temperature achieved for an object as large as 1 gram, another interesting feature of the experiment pertains to the strength of the force exerted by the laser beams. In the cooled dimension, the beams fix the mirror so rigidly that it is equivalent to being held in place by a spring that is 20 percent stiffer than a diamond rod with the same dimensions as the laser beam (about 1 m long and 1 mm in diameter). The group has subsequently used this technique to cool the mirror to just under 7 mK. For more information on Professor Nergis Mavalvala and this research, see http://sciencenow.sciencemag.org/cgi/content/full/2007/409/1.

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More information on the Department of Physics can be found at http://web.mit.edu/physics/.