GRADUATE PROGRAM

PHYSICS
Welcome to the Boston College Department of Physics. Our department’s primary focus is cutting-edge research concentrated in experimental and theoretical condensed matter physics. Over a relatively short period of time, we have become one of the leading condensed matter departments in the country. Some specific areas of current interest are superconductivity, photovoltaics, metamaterials, thermoelectrics, nanostructures and nanomaterials for biosensing, plasmonics, plasmas, topological insulators, novel electronic materials and other strongly correlated electron systems.

Graduate students share in this research, gaining the technical and intellectual training needed for future success in the career paths of their choice. The department includes 20 faculty, numerous post-docs and about 50 graduate students, all of whom are fully supported by generous teaching assistantships or research assistantships.

Significant research facilities are available to our graduate students. The Physics Department is continually enhancing and supplementing these facilities and has developed strong ties to many outside facilities, including Los Alamos National Laboratory, Argonne National Laboratory, the Institute for Complex Adaptive Matter (ICAM), Brookhaven National Laboratory, the Naval Research Laboratory and the National High Magnetic Field Laboratory.

In addition to course work and research participation, graduate students become members of the worldwide research community. Each week there are colloquia and seminars presented by leading physicists from around the country and world. The department is a close-knit community of scientists as well as part of the vibrant Boston intellectual and scientific community, allowing for collaboration among local universities.

After years of study and research, we send our young physicists into the world to successful careers in many areas, including academic, industrial and governmental positions. If this community is attractive to you, we invite you to learn more about the vibrant scientific environment by visiting bc.edu/physics.
The Physics Department’s graduate program is selective, offering a comprehensive course of study and research leading to the Ph.D. Courses emphasize a broadly based foundation in the fundamental principles of physics, preparing the student to think independently and to undertake advanced research under the supervision of a faculty advisor.

PH.D. PROGRAM
Upon entering the doctoral program, each student selects a field of specialization and establishes a working relationship with a member of the faculty. With the approval of the chosen faculty member, who normally serves as the principal advisor, the student informs the chairperson of his/her major field selection. The chairperson then appoints a faculty doctoral committee consisting of at least two full-time faculty members to advise and direct the student through the remainder of his/her graduate studies.

REQUIREMENTS
Required courses for the doctorate, beyond core physics graduate courses, are Statistical Physics II, Quantum Mechanics II and Graduate Seminar I and II plus four additional distributional courses in distinct areas outside the student’s research specialty. These are chosen from the graduate electives of the department or from other graduate departments with the approval of the chairperson. Solid State Physics I is strongly recommended as one of these courses. Some teaching or equivalent educational experience is also required. This requirement may be satisfied by at least one year of service as a teaching assistant or by suitable teaching duties. Arrangements are made with each student for a teaching program best suited to his or her overall program of study.

COMPREHENSIVE EXAMINATION
Within one year of entering Boston College, each student must take the comprehensive examination, usually offered each September. Students with an advanced level of preparation (e.g., students with a master’s degree in physics) may choose to take this examination immediately upon entering Boston College. In principle, this examination covers all of physics that a student can be expected to know at the end of one year of formal course work in the doctoral curriculum; however, it also stresses classical mechanics, electromagnetism, quantum mechanics and statistical physics. The examination has both written and oral sections. The examination is prepared and administered by a faculty committee, appointed by the chairperson; the examination is evaluated by this committee with approval of the entire graduate faculty of the department.

RESEARCH AND THESIS
After passing the comprehensive examination, a student’s principal activity is research. Normally, within a year after passing the comprehensive examination, the student takes the research proposal examination. The purpose of this examination is for the student to demonstrate knowledge of his/her area of research specialization and to expose the topic of his/her proposed thesis to scrutiny for its soundness and scientific merit. This is done at a public meeting.
**PH.D. CURRICULUM**

A typical sequence of graduate courses during the first two years:

**Year I**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>Quantum I</td>
<td>Quantum II*</td>
</tr>
<tr>
<td>Math Physics</td>
<td>EM I</td>
</tr>
<tr>
<td>Mechanics</td>
<td>Statistical Physics I</td>
</tr>
<tr>
<td>Grad. Sem. I* (if offered)</td>
<td>Grad Sem. II* (if offered)</td>
</tr>
</tbody>
</table>

**Year II**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical Physics II*</td>
<td>Distributional</td>
</tr>
<tr>
<td>Distribution</td>
<td>Distributional</td>
</tr>
<tr>
<td>Grad. Sem. I* (if offered)</td>
<td>Grad Sem. II* (if offered)</td>
</tr>
</tbody>
</table>

**Notes:** (1) “Distribution” courses are basically electives, e.g., Solid State Physics I and II, Group Theory, Elementary Particle Physics, etc. Four distribution courses are required for the Ph.D. (2) Courses required for the Ph.D. degree are marked by an asterisk.
FACULTY PROFILES

DAVID A. BROIDO  
Professor of Physics  
Ph.D., University of California, San Diego, 1985  
Theoretical condensed matter physics, theory of thermoelectric transport, first principle approaches to phonon thermal transport in crystalline and disordered bulk and nanostructured materials.  
Recent Publications  

KENNETH S. BURCH  
Associate Professor of Physics  
Ph.D., University of California, San Diego, 2006  
Thermoelectrics, topological insulators, high temperature superconductors, novel nanofabrication techniques and devices, superconducting proximity effect, optical spectroscopy (infrared, Raman and ellipsometry) and nanospectroscopy.  
Recent Publications  

Baldassare Di Bartolo  
Professor of Physics  
Ph.D., Massachusetts Institute of Technology, 1964  
Luminescence spectroscopy of laser solids, molecular spectroscopy and flash photolysis, laser theory, theory of atomic and molecular spectra, photoacoustics, femtospectroscopy.  
Recent Publications  

Jan R. Englebrecht  
Associate Professor of Physics  
Ph.D., University of Illinois, Urbana, 1993  
Recent research focuses on systems that order in time, including stable collective ordering in the spiking activity of model and real neural networks, as well as more general coupled oscillator systems such as Kuramoto oscillator networks in addition to continuing research on strongly correlated electron systems.  
Recent Publications  
• Classification of attractors for systems of identical coupled Kuramoto oscillators, Chaos 013114, 2014.  
**Michael J. Graf**  
Professor of Physics and Associate Chairperson  
Ph.D., Brown University, 1987  
Experimental condensed matter physics at low temperatures; electronic, magnetic and thermodynamic properties; NMR and muon spin spectroscopy of novel electronic materials, including magnetically frustrated materials, molecular and single-ion magnets; nanostructured thermoelectrics and superconductors.  

**Recent Publications**  
*“Evolution of Spin Relaxation Processes in LiY1-xHoxF4 with Increasing x Studied Via Ac-susceptibility and Muon Spin Relaxation,” Physical Review B 86, 014427, 2012.*  

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**Ruihua He**  
Assistant Professor of Physics  
Ph.D., Stanford University, 2010  
Experimental studies of strongly correlated electron systems, including cuprates, iridates, nickelates and other complex oxides, transition metal dichalcogenides, etc. in the form of bulk single crystals and thin films, with various techniques based on synchrotron radiation, mainly, angle-resolved photoemission spectroscopy, resonant elastic x-ray scattering, x-ray absorption spectroscopy and circular dichroism; also with in-house facilities, including ozone-assisted molecular beam epitaxy, low-temperature quantum capacitance and resistivity measurement, x-ray diffraction, etc.  

**Recent Publications**  
*“Spectroscopic evidence for negative electronic compressibility in a quasi-three-dimensional spin-orbit correlated metal,” Nature Materials, 2015 (online).*  
*“Direct spectroscopic evidence for phase competition between the pseudogap and superconductivity in Bi2Sr2CaCu2O8+δ,” Nature Materials 14, 37, 2015.*  
*“From a Single-band Metal to a High-temperature Superconductor via Two Thermal Phase Transitions,” Science 331, 1579, 2011.*

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**Andrzej Herczynski**  
Research Associate Professor and Laboratory Director  
Ph.D., Lehigh University, 1987  
Analytical methods in fluid dynamics-perturbation theory for compressible flows, similarity solutions in hydrodynamics, waves; physics and art, scaling properties and fluid dynamical aspects in abstract paintings. Recent projects concern sloshing waves in freely moving containers and “Bragg Resonance” in waves passing over corrugated channel floor.  

**Recent Publications**  

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**Gabor J. Kalman**  
Distinguished Research Professor of Physics  
D.Sc., Israel Institute of Technology, 1961  
Theoretical investigation and molecular dynamics simulation of strongly correlated Coulomb, Yukawa and related systems, complex (dusty) plasmas, plasma crystals, charged particle bilayers, two dimensional bosonic dipole systems and quark-gluon plasmas. Issues of interest are collective modes, response functions, non-linear response, and phase transitions. Intensive collaboration and student exchange with European research groups.  

**Recent Publications**  
*“Molecular Dynamics Simulation of Strongly Coupled QCD Plasmas,” Nuclear Physics A 774, 881, 2006.*  
KRZYSZTOF KEMPA
Professor of Physics
Ph.D., University of Wroclaw, 1980

Plasmonic and metamaterial effects in metallic and semiconducting nanostructures, plasmon scattering, superfluorescence and plasmon instability, photovoltaics beyond the Shockley-Queisser limit, bioapplications of nanostructures.

RECENT PUBLICATIONS

MICHAEL J. NAUGHTON
Evelyn J. and Robert A. Ferris Professor and Department Chairman
Ph.D., Boston University, 1986

Experimental condensed matter and materials physics, and nanoscale integrated science; electrical, magnetic and nanophotonic studies of low dimensional and nanoscale matter; organic superconductors; low temperature physics; nanostructures for photovoltaics, biosensing and high resolution neurointerface development.

RECENT PUBLICATIONS

Cyril P. Opeil, S.J.
Associate Professor of Physics
Ph.D., Boston College, 2004

Experimental condensed matter physics (2 < T < 300 K) including transport, dilatometry, magnetometry, resonant ultrasound, x-ray and UV photoemission on uranium single crystals and Martensite alloys; ferroelectric material response under magnetic and electric fields; the physics of nano-composite thermoelectric materials (2-800 K.)

RECENT PUBLICATIONS
- “Experimental Determination of the Lorenz number in Cu 0.01Bi2Te2.7 Se0.3 and Bi0.88Sb0.12,” Physical Review B, in press.
- “Dramatic Thermal Conductivity Reduction by Nanostructures for Large Increase in Thermoelectric Figure-of-merit of FeSb2,” Applied Physics Letters 99, 163101, 2011.
YING RAN
Assistant Professor of Physics
Ph.D., Massachusetts Institute of Technology, 2007

Quantum condensed matter theory, electronic systems with strong interaction, frustrated magnets, high-Tc superconductors, topological aspects of condensed matter system such as topological defects and topological band insulators.

RECENT PUBLICATIONS

REIN A. URITAM
Associate Professor of Physics
Ph.D., Princeton University, 1968

Particle phenomenology, current algebra, broken symmetries; foundations of quantum mechanics; non-Western and Medieval scientific traditions; role of history and philosophy of science in physics education; role of science in liberal education; connection between science and religion.

RECENT PUBLICATIONS

ZIQIANG WANG
Professor of Physics
Ph.D., Columbia University, 1989

Theory of correlated electronic materials: high temperature superconductors and transition metal oxides, pnictides and chalcogenides; Mott transition and spin liquids in Mott-Hubbard systems; heavy fermion physics; quantum Hall systems; correlated and topological phases of quantum electronic matter.

RECENT PUBLICATIONS

ILIJA ZELJKOVIC
Assistant Professor of Physics
Ph.D., Harvard University 2013

Experimental condensed matter physics; correlated electron systems; high-temperature superconductors; topological materials; novel two dimensional systems; transition metal dichalcogenides; strain induced phase transitions; scanning tunneling microscopy (STM); molecular beam epitaxy (MBE); thin film growth.

RECENT PUBLICATIONS
The combined and varied interests of the faculty, as indicated in the faculty profiles, ensure that the department offers a wide range of graduate course electives. While the number and content of the graduate electives varies from year to year, the following courses are illustrative of the range offered.

### FALL 2015
- Classical Mechanics: Bakshi
- Statistical Physics II: Kalman
- Quantum Mechanics I: Wang
- Solid State Physics: Ran
- Mathematical Physics I: Uritam

### SPRING 2016
- Optics: Di Bartolo
- Statistical Physics I: Ran
- Electromagnetic Theory I: Andronoche
- Quantum Mechanics II: Broido
- Solid State Physics I: Wang
- Techniques/Experiments in Physics: He

### Recent Dissertations
#### 2014-2015
- **Muna Aryal Rizal**, “Transient disruption of vascular barriers using focused ultrasound and microbubbles for targeted drug delivery in the brain”
- **Kristen Loncich**, “A biologically inspired model of bat echolocation in a cluttered environment with inputs designed from field recordings”
- **Mani Pokharel**, “Thermoelectric Transport Properties of Nanostructured FeSb2 and Ce-based Heavy Fermions CeCu6 and CeAl3”
- **Zhensong Ren**, “Combined Neutron, Transport and Material based investigation in Ca3Ir4Sn13”
- **Binod Rizal**, “Nanocoax Arrays for Sensing Devices”
- **Claire Watts**, “Metamaterials and Their Applications Towards Novel Imaging Technologies”
- **Yi Zhang**, “Fermi Liquid Study of Exotic Modes in Magnetically Ordered Systems”
- **Wenwen Zhou**, “STM probe on the surface electronic states of spin-orbit coupled materials”

#### 2013-2014
- **Wen-Chen Chen**, “Metamaterials and Surface Electromagnetic Waves”
- **Yu Dai**, “Observational Study of Dust-Rich Quasars”
- **Fan Ye**, “Surface plasmon polaritons along metal surfaces with novel structures”

#### 2012-2013
- **Justin Butler**, “Quantum Well Structures for Plasma Instability-based Terahertz Radiation Sources”
- **Feng Cai**, “Chern-Simons Effective Theory and the Fractional Quantum Hall Effects in Graphene”
- **Steven Disseler**, “Magnetic Order in the Pyrochlore Iridates”
- **Timothy Kirkpatrick**, “Geometric Photovoltaics Applied to Amorphous Silicon Thin Film Solar Cells”
- **David Shrekenhamer**, “Dynamic Control of Metamaterials at Terahertz Frequencies”

#### 2011-2012
- **Yuan-Ming Lu**, “Exotic Phases of Correlated Electrons in Two Dimensions”
- **Chang-Sheng Mei**, “Accelerated Magnetic Resonance Thermometry for High Intensity Focused Ultrasound Therapy”
- **Yun Peng**, “Simulations of Optical Effects in Nanostructures”
- **Gaohua Zhu**, “Exotic Phases of Correlated Electrons in Two Dimensions”
- **Ryan Johnson**, “A Study of the Onset of Magnetic Correlations in LiY1-xHoF4”
- **Bo Yu**, “Power Factor Improvement and Thermal Conductivity Reduction by Band Engineering and Modulation-doping in Nanocomposites”
The oldest and largest of the University’s eight schools and colleges, the Morrissey College of Arts and Sciences offers graduate programs in the humanities, social sciences and natural sciences, leading to the degrees of Doctor of Philosophy, Master of Arts and Master of Science. In addition, numerous dual-degree options are offered in cooperation with the Carroll School of Management, the Boston College Law School, the Lynch School of Education and the Graduate School of Social Work.

With approximately 1,000 students and 400 full-time faculty, the Graduate School is small enough to know you as a person, but large enough to serve you and prepare you for a rewarding life and satisfying career.

**Research Instrumentation and Facilities**

Departmental resources include TEM, SEM and XRD facilities, a wide array of materials preparation and fabrication equipment, extensive computational facilities, low-temperature STM, several mK refrigerators and high-field magnets (up to 46 tesla), and AFM and NSOM. These facilities are housed in the newly expanded and renovated Higgins Hall. Also new to the University is a professionally staffed, state-of-the-art Integrated Sciences Nanofabrication Clean Room Facility, with complete photolithographic and nanolithographic capabilities, including electron beam and focused ion beam instruments.

The Department of Physics has strong collaborations with many outside facilities, including Los Alamos, Oak Ridge and Brookhaven National Laboratories, as well as the Institute for Complex Adaptive Matter and the ISIS Rutherford-Appleton Laboratory.

**Academic Resources**

**BOSTON AREA CONSORTIUM**

The Boston Area Consortium allows graduate students to cross-register for courses at Boston University, Brandeis University and Tufts University.

**BOSTON COLLEGE LIBRARIES**

The University is home to eight libraries, containing 2.87 million volumes; more than 700 manuscript collections, including music, photos, art and artifacts; 440,000 e-books; and more than 600 electronic databases. O’Neill Library, Boston College’s main library, offers subject-specialist librarians to help with research, to set up alerts to new publications in areas of interest and to answer any research- and library-related questions.

**THE BOSTON LIBRARY CONSORTIUM**

The Boston Library Consortium allows Boston College students access to millions of volumes and other services at 19 area institutions in addition to the world-class resources available through the Boston College Library System.
Boston College is located on the edge of one of the world’s most vibrant cities. Just six miles from downtown Boston—an exciting and dynamic place to live and learn—Boston College is an easy car or “T” ride away from a booming center for trade, finance, research and education.

Home to some of New England’s most prestigious cultural landmarks, including the Museum of Fine Arts, the Isabella Stewart Gardner Museum, Boston Symphony Hall and the Freedom Trail, Boston provides a rich environment for those passionate about art, music and history. For sports fans, Boston hosts a number of the country’s greatest sports teams: the Celtics, Patriots, Bruins and, of course, Fenway Park’s beloved Red Sox. Found within a short drive from Boston are some of New England’s best recreational sites, from the excellent skiing in New Hampshire to the pristine beaches of Cape Cod.

Boston also offers a wide range of family-friendly attractions, including the Children’s Museum, New England Aquarium, Franklin Park Zoo and the Museum of Science. There are roughly 50 universities located in the Boston area, and the large student population adds to the city’s intellectually rich and diverse community. Events, lectures and reading groups hosted by world-renowned scholars abound on area campuses, providing abundant opportunities to meet and network with other graduate students and faculty throughout the Boston area.

The University

Boston College is a Jesuit university with more than 14,000 students, 758 full-time faculty and more than 165,000 active alumni. Since its founding in 1863, the University has known extraordinary growth and change. From its beginnings as a small Jesuit college intended to provide higher education for Boston’s largely immigrant Catholic population, Boston College has grown into a national institution of higher learning that is consistently ranked among the top universities in the nation: Boston College is ranked 31st among national universities by U.S. News & World Report.

Today, Boston College attracts scholars from all 50 states and over 80 countries, and confers more than 4,000 degrees annually in more than 50 fields through its eight schools and colleges. Its faculty members are committed to both teaching and research and have set new marks for research grants in each of the last 10 years. The University is committed to academic excellence. As part of its most recent strategic plan, Boston College is in the process of adding 100 new faculty positions, expanding faculty and graduate research, increasing student financial aid and widening opportunities in key undergraduate and graduate programs.

The University is comprised of the following colleges and schools: Morrissey College of Arts and Sciences, Carroll School of Management, Connell School of Nursing, Lynch School of Education, Woods College of Advancing Studies, Boston College Law School, Graduate School of Social Work and School of Theology and Ministry.

General Resources

HOUSING

While on-campus housing is not available for graduate students, most choose to live in nearby apartments. The Office of Residential Life maintains an extensive database with available rental listings, roommates and helpful local real estate agents. The best time to look for fall semester housing is June through the end of August. For spring semester housing, the best time to look is late November through the beginning of the second semester. Additionally, some graduate students may live on campus as resident assistants. Interested students should contact the Office of Residential Life.
JOHN COURTNEY MURRAY, S.J., GRADUATE STUDENT CENTER

One of only a handful of graduate student centers around the country, the Murray Graduate Student Center is dedicated to the support and enrichment of graduate student life at Boston College. Its primary purpose is to build a sense of community among the entire graduate student population and cultivate a sense of belonging to the University as a whole. Its amenities include study rooms, a computer lab, two smart televisions, kitchen, deck and patio space, complimentary coffee and tea, and more. Throughout the year, the center hosts programs organized by the Office of Graduate Student Life and graduate student groups. The Murray Graduate Student Center also maintains an active job board (available electronically), listing academic and non-academic opportunities for employment both on and off campus.

MCMULLEN MUSEUM OF ART

Serving as a dynamic educational resource for the national and international community, the McMullen Museum of Art showcases interdisciplinary exhibitions that ask innovative questions and break new ground in the display and scholarship of the works on view. The McMullen regularly offers exhibition-related programs, including musical and theatrical performances, films, gallery talks, symposia, lectures, readings and receptions that draw students, faculty, alumni and friends together for stimulating dialogue. Located on the main campus, the McMullen Museum is free to all visitors.

CONNORS FAMILY LEARNING CENTER

Working closely with the Graduate School, the Connors Family Learning Center sponsors seminars, workshops and discussions for graduate teaching assistants and teaching fellows on strategies for improving teaching effectiveness and student learning. Each fall, the Learning Center and the Graduate School hold a one-and-a-half day “Fall Teaching Orientation” workshop designed to help students prepare for teaching. The center also hosts ongoing seminars on college teaching, higher learning and academic life; assists graduate students in developing teaching portfolios; and provides class visits and teaching consultations, upon request. Through these and other activities, the Connors Family Learning Center plays an important role in enhancing the quality of academic life at Boston College.

FLYNN RECREATION COMPLEX

The 144,000-square-foot Flynn Recreation Complex houses a running track; tennis, basketball, volleyball, squash and racquetball courts; an aquatics center with pool and dive well; saunas and more. Its 10,000-square-foot Fitness Center offers over 100 pieces of cardio equipment, a full complement of strength training equipment and free weights, an air-conditioned spin studio and three air-conditioned group fitness studios. During the academic year, BC Rec holds more than 80 group fitness classes per week in a variety of disciplines, including Zumba, spin, yoga, strength training, Pilates and more.

BOSTON COLLEGE CAREER CENTER

The Boston College Career Center works with graduate students at each step of their career development. Services include self-assessment, career counseling, various career development workshops, resume and cover letter critiques, and practice interviews. In addition to extensive workshop offerings, Career Center staff members are available throughout the year for one-on-one advising about any aspect of the career path. The Career Resource Library offers a wealth of resources, including books, periodicals and online databases.
The application deadline for fall admission is January 2. Please visit bc.edu/gsas for detailed information on how to apply.

Application requirements include:

- **Application Form:** Submitted online, via the GSAS website.
- **Application Fee:** $75, non-refundable.
- **Abstract of Courses Form:** A concise overview of background and related courses completed in an intended field or proposed area of study.
- **Official Transcripts:** Demonstrating coursework completed/degree conferred from all post-secondary institutions attended.
- **GRE General Test:** Official score report required for all applicants.
- **GRE Subject Test:** Official score report required for all applicants.
- **Three Letters of Recommendation:** From professors or supervisors. It is highly advisable that at least one letter be from an academic source.
- **Statement of Purpose:** A brief (1-2 page) discussion of an applicant’s preparation, motivation and goals for their proposed course of study.
- **Proof of English Proficiency:** Official TOEFL/IELTS reports accepted. (International only)

Financial Assistance

DEPARTMENT FUNDING

The Physics Department offers five years of funding to all qualified Ph.D. students contingent upon satisfactory academic performance and progress toward degree completion. Support for qualified students is available in the form of teaching assistantships. Research assistantships are also available during the summer and academic year, depending on research area and the extent of current funding.

FEDERAL FINANCIAL AID

Graduate students can apply for federal financial aid using the FAFSA. The loans that may be available to graduate students are the Federal Direct Unsubsidized Stafford Loan and Perkins Loan, based on eligibility. If additional funds are needed, student may apply for a Grad Plus Loan. For more information, see the Graduate Financial Aid website at bc.edu/gradaid or contact the Graduate Financial Aid Office at 617-552-3300 or 800-294-0294.

OFFICE OF SPONSORED PROGRAMS

The Office of Sponsored Programs (OSP) assists both faculty and graduate students in finding sources of external funding for their projects and provides advice in the development of proposals. OSP maintains a reference library of publications from both the public and private sectors listing funding sources for sponsored projects. In the recent past, graduate students have received research support from prominent agencies, corporations and organizations such as the Fulbright Commission, the Guggenheim Foundation, the National Science Foundation, the American Political Science Association, the American Association of University Women and the American Chemical Society.