A message to engineers, scientists, and others interested in continuing their professional development:

Welcome to the Engineering and Applied Science Programs for Professionals at The Johns Hopkins University. The Whiting School of Engineering has earned a reputation for excellence among top schools in the nation for providing advanced engineering education for working professionals. I invite you to explore our catalog and discover the many programs, certificates, and courses that we offer, both online and throughout the Baltimore-Washington region.

Our mission is to cultivate and impart knowledge in a range of engineering disciplines—fully supported by the outstanding faculty, students, and industry leaders who comprise the Johns Hopkins engineering community. Since 1916, The Johns Hopkins University has been at the vanguard of professional development in engineering. From the start, our focus has been to make engineering education accessible to our community’s workforce. Today, Engineering Programs for Professionals has grown in size and selection, now with 14 master’s degree programs to choose from as well as a number of advanced certificates.

Our programs have continued to grow and succeed as a result of our commitment to provide an education that balances the most advanced theory with current industry practices. Among our faculty are outstanding practitioners and researchers in the region’s leading private and government organizations. As industry leaders, they enrich our courses by incorporating their unique experiences as a teaching tool. Faculty ensure that our students excel in their careers by giving them the practical knowledge they need to keep abreast of current technologies and lead the way in innovation. In addition, our faculty stresses the mastery of theory, empowering students to apply what they’ve learned with a sound understanding of their fields.

This year we continue to increase our online course offerings, with more than 30 courses now online in a number of program areas. Also, beginning this fall, a master’s degree in Environmental Planning and Management will be available fully online in addition to the Bioinformatics degree introduced last year. Be sure to visit our website to check for these and other program updates at: www.epp.jhu.edu.

At Hopkins, we believe that engineering and innovation are inseparable. In line with our vision statement, “Leadership Through Innovation,” we believe that an advanced degree through Hopkins will give our students the tools to be innovators as well as leaders in their fields.

I invite you to join the Hopkins engineering community—and challenge you to become both an innovator and a leader in your field.

Nicholas P. Jones
Dean, Whiting School of Engineering
Whiting School of Engineering

Engineering and Applied Science
Programs for Professionals

Graduate Programs

Academic Year 2007–2008
# Academic and Registration Calendar

**Academic Year 2007–2008**

<table>
<thead>
<tr>
<th>Important Semester Dates:</th>
<th>Summer 2007</th>
<th>Fall 2007</th>
<th>Spring 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Day of Classes</td>
<td>June 4</td>
<td>September 5</td>
<td>January 28</td>
</tr>
<tr>
<td>Last Day of Classes</td>
<td>August 25</td>
<td>December 15</td>
<td>May 10</td>
</tr>
<tr>
<td>Graduation Application Deadlines</td>
<td>June 15</td>
<td>September 15</td>
<td>January 15</td>
</tr>
<tr>
<td>Holidays</td>
<td>July 4</td>
<td>November 21–25</td>
<td>March 17–23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Registration Deadlines:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration Opens</td>
<td>March 22</td>
<td>June 21</td>
<td>October 25, 2007</td>
</tr>
<tr>
<td>Registration Closes</td>
<td>May 25</td>
<td>August 24</td>
<td>January 18, 2008</td>
</tr>
<tr>
<td>Final Day to Add</td>
<td>2nd class meeting</td>
<td>September 18</td>
<td>February 9</td>
</tr>
<tr>
<td>Drop/Audit Deadline</td>
<td>9th class meeting</td>
<td>November 30</td>
<td>April 14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Online Course Deadlines:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deadline to Register</td>
<td>May 23</td>
<td>August 24</td>
<td>January 18</td>
</tr>
<tr>
<td>Orientation for First-Time Students</td>
<td>May 29–June 3</td>
<td>August 29–September 4</td>
<td>January 21–27</td>
</tr>
<tr>
<td>Final Day to Add</td>
<td>June 11</td>
<td>September 12</td>
<td>February 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New Student Advising Session:</th>
<th>Dorsey</th>
<th>APL</th>
<th>APL</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 29</td>
<td>April 27</td>
<td>January 22, 2008</td>
<td></td>
</tr>
<tr>
<td>4:30-6:00 pm</td>
<td>4:30-6:00 pm</td>
<td>4:30-6:00 pm</td>
<td></td>
</tr>
<tr>
<td>MCC</td>
<td>MCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 28</td>
<td>January 23, 2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5:00-6:30 pm</td>
<td>5:00-6:30 pm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tuition Payment Deadlines</th>
<th>June 18</th>
<th>September 19</th>
<th>February 11, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>There will be a $125 late fee if tuition is not paid by due date.</td>
</tr>
</tbody>
</table>

Whiting School Graduate Ceremony is Wednesday, May 21, 2008.
University Commencement Day is Thursday, May 22, 2008.
Engineering Administration

Whiting School of Engineering
Nicholas P. Jones, Dean
Andrew S. Douglas, Associate Dean for Academic Affairs
Robert Spiller, Associate Dean for Development and Alumni Relations
Marc D. Donohue, Associate Dean for Research

Engineering and Applied Science Programs for Professionals
Allan W. Bjerkaas, Associate Dean
James L. Teesdale, Director, APL Education Center

Graduate Program Administration
James C. Spall
Program Chair, Applied and Computational Mathematics
Russell L. McCally
Program Chair, Applied Biomedical Engineering
Harry K. Charles Jr.
Program Chair, Applied Physics
Denis Wirtz
Program Chair, Chemical and Biomolecular Engineering
Annalingam Anandarajah
Program Chair, Civil Engineering
Ralph D. Semmel
Program Chair, Computer Science
Dexter G. Smith
Program Chair, Electrical and Computer Engineering
Hedy V. Alavi
Program Chair, Environmental Engineering, Science and Management
Ralph D. Semmel
Program Chair, Information Systems and Technology
Robert C. Cammarata
Program Chair, Materials Science and Engineering
Kevin J. Hemker
Program Chair, Mechanical Engineering
Kenneth A. Potocki
Program Chair, Systems Engineering
Kenneth A. Potocki
Program Chair, Technical Management
Table of Contents

Academic and Registration Calendar ................................................................. ii
Contact Information ........................................................................................... iii
Engineering Administration .............................................................................. iv

The Johns Hopkins Community of Excellence ................................................. 1
Whiting School of Engineering ................................................................. 1

Graduate Programs .................................................................................. 2
  Chart: Graduate Degree Offerings by Location ........................................... 2

Degrees and Certificates .......................................................................... 3
  Master of Science ....................................................................................... 3
  Master of Engineering ............................................................................... 3
  Advanced Certificate for Post-Master’s Study .............................................. 3
  Graduate Certificate ................................................................................ 3
  Non-Degree-Seeking Students ................................................................... 3

Admission Requirements ........................................................................... 3
  Master’s Degree Candidate ....................................................................... 3
  Advanced Certificate for Post-Master’s Study Candidate ......................... 3
  Graduate Certificate Candidate ............................................................. 4
  Special Student ......................................................................................... 4
  Application Procedures .......................................................................... 4
  Readmission ............................................................................................ 4
  Admission to Other Divisions of the University .......................................... 4
  International Credential Evaluation ......................................................... 4
  Visa Status .............................................................................................. 5
  Requests to Change Program of Study .................................................... 5

Registration ............................................................................................... 5
  Course Schedule ...................................................................................... 5
  Course Numbering .................................................................................. 5
  Course Credit ............................................................................................ 5
  Web Registration ...................................................................................... 5
  Registering for Online Courses .............................................................. 5
  Late Registration ....................................................................................... 5
  New Applicants ........................................................................................ 6
  Interdivisional Registration ..................................................................... 6
  Course Enrollment Limits ........................................................................... 6
  Course Load ................................................................................................ 6
  Auditors ...................................................................................................... 6
  Adding and Dropping Courses ............................................................... 6
  Textbooks .................................................................................................. 6

Academic Regulations .............................................................................. 6
  Advisers and Program Planning .............................................................. 6
  Probation and Dismissal .......................................................................... 7
  Second Master’s Degree .......................................................................... 7
  Time Limitation ....................................................................................... 7
  Leave of Absence ..................................................................................... 7
  Transfer Courses ...................................................................................... 7
  Graduation ................................................................................................ 7
  Honors ....................................................................................................... 8
  Grading System ....................................................................................... 8
  Incompletes ............................................................................................. 8
  Grade Reports ........................................................................................... 8
# Table of Contents

- Grade Appeals ................................................................. 9
- Student Attendance ............................................................ 9
- Academic Standing ............................................................ 9
- Academic Misconduct ........................................................ 9
- Violation of Academic Integrity ............................................ 9
- Copyright Violations ........................................................... 9
- Computer Usage ............................................................... 9

## Tuition and Fees

- Tuition .................................................................................. 10
- Application Fee ................................................................. 10
- Graduation Fee ................................................................. 10
- Late Registration Fee ........................................................... 10
- Late Tuition Payment Fee ....................................................... 10
- Transfer Credit Fee ............................................................. 10
- Fee for Removal of an Incomplete Grade ................................ 10
- Refund Policy ................................................................. 10
- Chart: Refund Schedule ......................................................... 10

## Financial Aid and Veterans Benefits

- Types of Financial Aid .......................................................... 11
- Title IV Refunds ............................................................... 11
- Veterans Benefits ............................................................. 11

## Facilities and Student Services

- Student ID Cards .............................................................. 12
- Transcripts ........................................................................... 12
- International Student Services ........................................... 12
- Services for Students with Disabilities ................................... 12
- Career Services ................................................................. 12
- Inclement Weather ............................................................. 13
- Web-based Student Directory .............................................. 13
- Computers ........................................................................... 13
- The Homewood Campus ....................................................... 13
  - Libraries ........................................................................... 13
  - Book Store ....................................................................... 13
  - Hopkins Student Union ................................................... 13
  - Security Services .............................................................. 13
  - Parking ............................................................................. 14
- Applied Physics Laboratory Education Center ..................... 14
  - Library ............................................................................. 14
  - Computers ....................................................................... 14
  - Bookstore ....................................................................... 14
  - Parking ............................................................................. 14
- Montgomery County Campus .............................................. 14
  - Library ............................................................................. 14
  - Computers ....................................................................... 14
  - Bookstore ....................................................................... 15
  - Cafe ................................................................................ 15
  - Parking ............................................................................. 15
- Dorsey Student Services Center ........................................... 15
- Southern Maryland Higher Education Center ....................... 15
- Washington DC Center ....................................................... 15
- Higher Education and Applied Technology (HEAT) Center ...... 15
- Online Courses .................................................................. 15
  - Registration Deadlines ....................................................... 15
  - Online Orientation ........................................................... 16
  - Books for Online Courses ................................................. 16
- Inter-Site Links .................................................................... 16
Applied and Computational Mathematics .................................................. 17
Applied Biomedical Engineering ............................................................ 25
Applied Physics ...................................................................................... 31
Bioinformatics ....................................................................................... 40
Chemical and Biomolecular Engineering .................................................. 51
Civil Engineering ................................................................................... 58
Computer Science .................................................................................. 63
Electrical and Computer Engineering ....................................................... 83
Environmental Engineering, Science and Management .................................. 99
Information Systems and Technology ....................................................... 111
Materials Science and Engineering ........................................................ 116
Materials and Condensed Matter Option .................................................. 121
Mechanical Engineering ........................................................................ 122
Nanotechnology Option ......................................................................... 128
Photonics Option .................................................................................... 130
Systems Engineering .............................................................................. 131
Technical Innovation and New Ventures .................................................. 136
Technical Management .......................................................................... 138
Telecommunications and Networking Option ......................................... 142

Policy Statements .................................................................................... 143
 Equal Opportunity/Nondiscriminatory Policy as to Students ......................... 143
 Policy on the Reserve Officer Training Corps (ROTC) ................................. 143
 Admissions Policy ................................................................................ 143
 Statement Regarding the Privacy Rights of Students .................................. 143
 Americans with Disabilities Act Policy ......................................................... 143
 Sexual Harassment Prevention and Resolution Policy ............................... 144
 University Alcohol and Drug Policy for Students ................................... 144
 Policy on Possession of Firearms on University Premises .......................... 145
 Campus Security Act Notice .................................................................... 145
 Photograph and Film Rights Policy .......................................................... 145
 Return of Title IV Funds Policy ............................................................... 145

Trustees and Administration ..................................................................... 146

EPP Advisory Council ............................................................................. 148

Advisory Board for Environmental Engineering ........................................ 149

Faculty .................................................................................................... 150

Directions and Maps ................................................................................ 164
 Directions ................................................................................................ 164
 Location Map of all Facilities ................................................................ 166
 Applied Physics Laboratory .................................................................... 164, 167
 Montgomery County Campus .................................................................. 164, 168
 Dorsey Student Services Center ............................................................... 164, 169
 Homewood Campus ................................................................................ 164, 170, 171
 Southern Maryland Higher Education Center .......................................... 165, 172
 Higher Education Applied Technology Center ....................................... 165, 173
 Washington Center .................................................................................. 165, 174

Index ....................................................................................................... 175

The University of necessity reserves the freedom to change without notice any programs, requirements, or regulations published in this catalog. This catalog is not to be regarded as a contract. Multiple means of communication may be used by the University for announcing changes of this nature, including, but not exclusive to, e-mail and/or paper notice. Students are responsible for providing current e-mail and mailing address information to the University administrative offices.
Dr. John Sheppard (left), an instructor in the Computer Science program, works with independent study student Stephyn Butcher.

Dr. David Zaret, 2006 recipient of an Excellence in Teaching Award, helps students in a computer lab at the Applied Physics Laboratory.
The Johns Hopkins Community of Excellence

Since the beginning of the 20th century, The Johns Hopkins University has been a leader in providing working adults with opportunities to continue their engineering education on a part-time basis. The Whiting School of Engineering’s Engineering and Applied Science Programs for Professionals maintains as its core mission a dedication to provide a community of excellence to professionals whose personal and career goals include continuing education.

"Where Excellence Surrounds You" is how Engineering Programs for Professionals defines its commitment to students. The Johns Hopkins community of excellence means that students attend classes taught by faculty who are at the top of their fields, receive inspiration from the high caliber of classroom interaction, and have access to exemplary administrative services. Consequently, the Programs are among the largest such programs in the nation, attesting to the students’ enthusiasm for the programs as well as the Whiting School’s concern for engineers and scientists who pursue study after working hours.

As they have grown, Engineering Programs for Professionals have extended their reach into the surrounding community, providing students a variety of classroom locations, as well as selected online courses, suited to their academic needs and busy schedules. Graduate students take courses at the Homewood campus in Baltimore, the Applied Physics Laboratory in Laurel, the Montgomery County Campus in Rockville, the Dorsey Center near Baltimore/Washington International Thurgood Marshall Airport, the Southern Maryland Higher Education Center in St. Mary’s County, the Washington Center in Washington, D.C., and the Higher Education and Applied Technology Center in Harford County. Students take courses during the late afternoon and evening, on Saturday, or online.

Accredited by the Middle States Commission on Higher Education, Johns Hopkins University is privately endowed. Founded in 1876 as the first American educational institution dedicated to research, it established the model for advanced study in this country.

Nine divisions of the University grant degrees. They are the Whiting School of Engineering; the Krieger School of Arts and Sciences; and the School of Education on the Homewood campus; the schools of Medicine and Nursing and the Bloomberg School of Public Health adjacent to The Johns Hopkins Hospital; the Peabody Institute and the Carey Business School in downtown Baltimore; and The Paul H. Nitze School of Advanced International Studies based in Washington, D.C. (with foreign study centers in Bologna, Italy, and Nanjing, China). The 10th division of the University is the Applied Physics Laboratory (APL), a research institute located in Laurel, Maryland.

Whiting School of Engineering

Engineering began at Johns Hopkins in 1913 when University leaders decided to establish a curriculum that focused on professional education but included significant exposure to the liberal arts and scientific inquiry. Fostering interdisciplinary creativity, this unique approach to engineering education was emulated by many engineering schools around the country.

Some seven decades later, Johns Hopkins underscored its commitment to engineering distinction by establishing the Whiting School of Engineering as a separate division on the Homewood campus.

The School consists of the following departments: Applied Mathematics and Statistics, Chemical and Molecular Engineering, Civil Engineering, Computer Science, Electrical and Computer Engineering, Geography and Environmental Engineering, Materials Science and Engineering, Mechanical Engineering, and, in collaboration with the School of Medicine, Biomedical Engineering. Information about full-time education may be found in the Johns Hopkins University Arts and Sciences/Engineering Undergraduate and Graduate Catalog or on the Web at www.jhu.edu. Admission information for full-time undergraduate education is available from the Office of Admissions, 140 Garland Hall, Homewood campus, 410-516-8171. For full-time graduate education, the student should contact the department in which they are interested.

The University has offered part-time engineering education since before World War I. Over the intervening decades, thousands of working engineers and scientists have received graduate and undergraduate degrees through part-time study, achieving personal and professional goals without interrupting their careers.

Today, the Engineering and Applied Science Programs for Professionals (EPP) fosters a community of excellence for students and faculty alike. This community extends into the surrounding region, in which the programs have created partnerships with a number of companies for unique learning experiences.

Students take courses that are continually updated for relevance, addressing industry trends and the latest advances in engineering and applied science fields. Classes are scheduled at convenient times in late afternoon, evening, and on Saturday. Each year, EPP offers an increasing number of courses online to meet the needs of busy students.
Graduate Programs

Graduate students in the Engineering and Applied Science Programs for Professionals (EPP) constitute one of the nation’s largest student bodies in continuing engineering education at the master’s degree level. Graduate courses are offered at seven locations and online. Students receive individual attention from their advisers and instructors and benefit from small classes and well-equipped laboratory, computing, and classroom facilities.

Graduate programs leading to master’s degrees are offered at the locations shown in the table below. Almost all courses are scheduled either in the late afternoon or evening Monday through Friday and on Saturdays or online, so that students can further their education without interrupting their careers. Graduate students may take courses at any Hopkins location listed in the table at the end of this section. Please note that all courses are not offered at all locations.

The University is accredited by the Middle States Commission on Higher Education, 3624 Market St., Philadelphia, Pa. 19104-2680; 215-662-5606. The Accreditation Board for Engineering and Technology (ABET) is the accrediting authority for engineering and technology programs in the United States. Universities and colleges may choose to have their basic (undergraduate) or advanced (graduate) programs accredited, but not both. Nearly every engineering school, including the Whiting School, chooses to have its basic programs accredited by ABET.

<table>
<thead>
<tr>
<th>Location</th>
<th>Graduate Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homewood</td>
<td>Chemical and biomolecular engineering; civil engineering; environmental engineering, science and management; and materials science and engineering. Selected courses in mechanical engineering.</td>
</tr>
<tr>
<td>Applied Physics Laboratory</td>
<td>Applied and computational mathematics, applied biomedical engineering, applied physics, computer science, electrical and computer engineering, information systems and technology, photonics, systems engineering, technical management, and telecommunications and networking. Selected courses in bioinformatics; environmental engineering, science and management; materials science, and mechanical engineering.</td>
</tr>
<tr>
<td>Montgomery County Campus</td>
<td>Bioinformatics; computer science; electrical and computer engineering; environmental engineering, science and management; information systems and technology; systems engineering; technical innovation and new ventures; technical management; and telecommunications and networking. Selected courses in applied and computational mathematics, and applied biomedical engineering.</td>
</tr>
<tr>
<td>Dorsey Center</td>
<td>Mechanical engineering; selected courses in applied and computational mathematics; applied biomedical engineering; applied physics; civil engineering; computer science; electrical and computer engineering; environmental engineering, science and management; information systems and technology; photonics; systems engineering; technical management; and telecommunications and networking.</td>
</tr>
<tr>
<td>Southern Maryland Higher Education Center</td>
<td>Systems engineering and technical management.</td>
</tr>
<tr>
<td>Washington DC Center</td>
<td>Selected courses in environmental engineering, science and management.</td>
</tr>
<tr>
<td>Higher Education and Applied Technology Center</td>
<td>Selected courses in environmental engineering, science and management, and systems engineering.</td>
</tr>
<tr>
<td>Online</td>
<td>Bioinformatics; environmental planning and management; selected courses in computer science, electrical and computer engineering, information systems and technology, and environmental engineering, science and management.</td>
</tr>
</tbody>
</table>
Degrees and Certificates

The Johns Hopkins University confers a variety of degrees and certificates upon students in the Whiting School of Engineering. Requirements for each discipline are detailed in the individual program listings in this catalog.

Master of Science
Programs are offered in applied and computational mathematics, applied biomedical engineering, applied physics, computer science, electrical and computer engineering, environmental engineering and science, environmental planning and management, information systems and technology, systems engineering, and technical management.

A joint degree in bioinformatics is now being offered by the Engineering and Applied Science Programs for Professionals and the Krieger School of Arts and Sciences Advanced Academic Programs. The description of this degree can be found under Graduate Programs under the Bioinformatics program.

Master of Engineering
Graduate degree programs are offered in chemical and biomolecular engineering, civil engineering, environmental engineering, materials science and engineering, and mechanical engineering.

Advanced Certificate for Post-Master’s Study
This certificate is awarded upon completion of six courses beyond the master’s degree in the same or a closely related discipline area.

Graduate Certificate
This certificate is awarded upon completion of a select number of courses of graduate study within one of the master’s degree discipline areas. This certificate is available in several areas, including environmental engineering, science and management, technical innovation and new ventures, technical management, and systems engineering.

Non-Degree-Seeking Students
Students who wish to enroll in courses, but are not interested in pursuing a degree or certificate, may enroll as Special Students.

Admission Requirements

The Whiting School of Engineering encourages all students who have serious academic interests to apply. Qualified students may structure their course work to pursue a specific degree or certificate program, or they may take courses under the Special Student (i.e., non-degree-seeking) designation if they have met program and course prerequisites. An applicant may be admitted in one of four categories:

1. Master's Degree candidate
2. Advanced Certificate for Post-Master's Study candidate
3. Graduate Certificate candidate
4. Special Student

An applicant must meet the general admission requirements appropriate for all graduate study and the specific admission requirements for the desired program. Note that these requirements represent minimum standards for admission; the final decision on an applicant's suitability for a given program is made by the admissions committee for that program. The general application procedures and admission requirements are stated below. Please refer to the individual program sections for additional specific requirements.

Master’s Degree Candidate
The program consists of 10 courses planned in consultation with an adviser. General admission requirements for master’s degree candidates and others seeking graduate status are as follows: applicants must be in the last semester of undergraduate study or hold a bachelor’s degree from a regionally accredited college or university. Applicants must have earned grade point averages of at least 3.0 on a 4.0 scale (B or above) in the latter half of their studies or hold graduate degrees in technical disciplines.

Students must complete the master's degree within five years from the start of the first course in the student's program.

Advanced Certificate for Post-Master’s Study Candidate
To accommodate students who wish to pursue studies beyond the master’s degree, many of the disciplines in the programs offer a certificate of post-master's study. This program is intended to add depth and/or breadth in the discipline of the student’s master’s degree, or a closely related one.

The program consists of six courses planned in consultation with an adviser. In some cases students may substitute independent projects for up to two of the courses.

The general admission requirement for the Advanced Certificate program is that candidates must have completed a master’s degree in an engineering or science discipline. Academic credentials must be submitted for admission committee review. After acceptance, each student is assigned an adviser.
Admission Requirements

with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the Advanced Certificate for Post-Master’s Study within three years of the first enrollment in the program.

Courses taken for the Advanced Certificate for Post-Master’s Study may be counted toward a master’s degree.

Graduate Certificate Candidate
The Graduate Certificate is offered in a select number of degree disciplines and is directed toward students who may not need a master’s degree, may not have the opportunity to pursue the entire master’s degree, or may wish to focus their studies on a set of courses in a specific subject area.

The certificate generally consists of five to six courses. The program area of study specifies the selection and number of applicable courses. Deviations may be permitted if approved by the program chair. If, in the future, the student decides to pursue the full master’s degree, all courses will apply provided they meet the program requirements and fall within the five-year limit.

Students must meet the general master’s degree admission requirements, as well as the specific requirements of the desired program. Academic credentials must be submitted for admission committee review. After acceptance, each student is assigned an adviser with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the Graduate Certificate within three years of first enrolling in the program.

Special Student
The general requirement for admission as a Special Student is that the applicant must hold a bachelor’s degree from a regionally accredited college or university or be in the last semester of undergraduate study. Applicants must have earned a grade point average of at least 3.0 on a 4.0 (B or above) scale in the latter half of their studies or hold graduate degrees in relevant technical disciplines and meet admission prerequisites for the program in which they have applied to be a special student.

Visiting Graduate Students include students who are enrolled in a graduate program at another university, and are registering for EPP courses.

All Special Students must satisfy program prerequisites as well as specific course prerequisites in order to enroll.

Courses taken while a Special Student do not necessarily count toward fulfillment of degree requirements if the student is subsequently accepted as a degree candidate. Determinations on course applicability toward a degree are made on an individual basis.

Application Procedures
To be considered for admission to a degree or certificate program or to take courses as Special Students, applicants must submit a formal application, a nonrefundable $75 application fee, made payable to Johns Hopkins University, official transcripts of all college studies, and any other documents specified by particular programs. If a Special Student applicant later decides to apply for a degree, a letter of intent is required. The application fee is waived for graduates of the Whiting School of Engineering.

In addition to being included in this catalog, the application is also available online at www.epp.jhu.edu. Those completing this form must forward the application fee and official transcripts to the EPP offices. Complete instructions are available on the web site.

An application for admission is not reviewed by an admissions committee until official transcripts from all colleges attended and required supporting documents are received. Failure to provide all official transcripts and required documents will delay review of the application.

Readmission
An application is held on file for one year from the date of its receipt. Applicants who fail to submit required materials within this period must reapply and submit another application and fee.

Applicants must satisfy admission requirements in force at the time of reapplication. Admitted students may defer the start of their studies for up to one year following admission. Thereafter, they must begin the process anew.

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

Admission to Other Divisions of the University
Any student who wishes to transfer to another school in the University or to a full-time engineering program must apply to the appropriate department or to the Office of Admissions. Admission to an EPP program establishes no claim or priority for admission to other divisions of the University.

International Credential Evaluation
Applicants who hold degrees or have earned credits from non-U.S. institutions must have their academic records evaluated by the World Education Services, Inc. before they can be considered for graduate or special student status or admission to a degree/certificate program. In addition to submitting official records to EPP, applicants should make arrangements with the credential evaluation agency listed below, for an evaluation of the degree, an assessment of the overall grade point average, and a course-by-course evaluation.

World Education Services, Inc.
P.O. Box 745
Old Chelsea Station
New York, New York, 10113-0745
Telephone: 212-966-6311
Fax: 212-739-6120
E-mail: info@wes.org
Visa Status
The EPP office is not authorized to certify the I-20 form required for a student visa. Those holding student visas granted by other universities are not allowed to register for classes and cannot be accepted as degree candidates or Special Students. For visa questions please contact the International Student and Scholar Services office at 410-516-1013 or theworld@jhu.edu.

Requests to Change Program of Study
A student who wishes to change his/her status (e.g., from special student to master's degree candidate) or field of study (e.g., from technical management to systems engineering, or from the general computer science program to the telecommunications and networking option) must submit a written request to the EPP Office. The student must meet all the admission requirements of the new program.

Registration
Before registering for any engineering classes, each student must apply as a degree or certificate candidate, or as a special student, and must submit appropriate application materials for review. Application procedures are found on the Admission Requirements page. Applications are accepted on a continuing basis.

Payment of tuition is due at the specified deadline listed in the academic calendar. Payment may be made by check, VISA, MasterCard, Discover, tuition remission, or company contract accompanied by purchase order. We will not defer payment when companies provide tuition reimbursement at the end of the term. In this instance, students must pay tuition themselves and be reimbursed by their employer. If payment is not made by the deadline date, a late payment fee of $125 will be incurred.

If you have registered and have not paid your balance, an email statement will be sent to you on the 16th of each month with the balance due the University. This is not a bill. This is a reminder of the debt owed to the University and is a reflection of your account status at the time of the email. Changes in circumstances may have an effect on the amount that you are responsible to pay, for instance, adding or dropping courses, if only registration, or late payment fees.

Students are not permitted to register if there are unpaid bills from a previous term.

Course Numbering System
All Whiting School of Engineering courses are numbered in the form 605.402, where
- 605 indicates the program—in this example, Computer Science,
- 402 indicates the course number—in this example, Software Analysis and Design

Courses with a zero before the first decimal point—e.g. 600.439—are daytime offerings of the Whiting School departments.

Course Credit
Credit hours are not assigned for graduate level courses (400-level and above).

Web Registration
Advance registration takes place three times a year: prior to the fall semester, the spring semester, and the summer term.

All students are encouraged to use web registration. Web registration is available by logging onto the EPP website (www.epp.jhu.edu) and following the web registration link. Students must establish a JHED account in order to use web registration; instructions are available on the opening page.

Registering for Online Courses
Initial contact and instructions for online courses will be delivered via email prior to the first day of classes each term. It is the responsibility of students registering for online courses to supply a current and active email address and an alternate contact method, such as work and/or home phone numbers, on the registration form for each term.

Late Registration
Students may register after the beginning of a term if necessary. However, students enrolling in their first JHU EPP online course must be registered no later than a week and a half prior to the first day of classes in order to attend a mandatory online orientation prior to the start of the term. The deadline for adding online courses is a week after the first day of classes each term, which is earlier than the deadline for conventional classes. See the Registration Deadlines section of the Facilities and Student Services page for a detailed description of the orientation and student participation requirements. Without exception, late registration requires payment of a $65 fee. Students who delay registering until these times may find course selection severely restricted. Late registrations may be faxed (410-579-8049) or delivered to the following locations:

APL Education Center, Rm. L-2,
R. E. Gibson Library Bldg.
Mon-Thurs: 8:30 a.m. to 7:30 p.m.
Fri: 8:30 a.m. to 5:00 p.m.

Montgomery County Campus,
Central Building, Rm.103
Mon-Thurs: 9 a.m. to 8 p.m.
Fri: 9 a.m. to 6 p.m.
Sat: 8:30 a.m. to 12:30 p.m.
Academic Regulations

Dorsey Center
Mon-Thurs: 8:30 a.m. to 10 p.m.
Fri: 8:30 a.m. to 5 p.m.

New Applicants
An applicant who has not received an admission decision prior to registration must attend an advising session. Dates of advising sessions are listed on the academic calendar. Contact EPP Student Services office, 410-540-2960, for advising information. If the student is subsequently accepted to a degree or certificate program, the program committee will determine whether courses taken prior to admission may be counted in fulfillment of degree requirements.

Interdivisional Registration
With approval of their advisers, students are encouraged to take courses in the full-time programs of the Whiting School or in other divisions of the University. Registration for these classes should be submitted on the EPP registration form. Please note that tuition rates vary by division.

Students in other divisions of Johns Hopkins may register for courses in Engineering Programs for Professionals, subject to the regulations of their home divisions and availability of space. The form requesting registration is available at the Homewood Registrar’s Office, 75 Garland Hall.

Course Enrollment Limits
In order to foster high-quality faculty-student interaction, all courses have enrollment limits. Although every effort is made to offer additional sections of over-subscribed courses, this is not always possible.

Students may ask to be placed on waiting lists if their desired courses are filled or they may indicate alternate course selections.

The University reserves the right to change instructors or to cancel any course with insufficient enrollment or for reasons beyond the control of the university.

Course Load
Students who are employed full-time are strongly urged to limit their course load to no more than two per term.

Auditors
Students may register as auditors with the approval of the appropriate program adviser. Although regular attendance is expected of auditors, they are exempt from quizzes, examinations, and other assigned work, and they receive no credit for the course. Students who are enrolled for credit but wish to become auditors must file the “add/drop” form before the deadline listed for each term in the Academic and Registration Calendar. There is no reduction in fees when auditing a course.

Adding and Dropping Courses
Courses may be added or dropped by submitting the “add/drop” form available at www.epp.jhu.edu and at the instructional sites. Deadlines for completing this procedure are given in the Academic and Registration Calendar. Notification to the instructor does not constitute dropping a course. Students who stop attending a course without completing and submitting the drop form will receive an F grade. The refund policy pertaining to dropped courses is described on the Tuition and Fees page.

Textbooks
Texts are available during advising sessions and during the first two weeks of classes at the site where the student is registered. Textbooks can also be purchased online:

For Montgomery County and the DC Center
Books can be found online at Reiter’s www.jhutextbooks.com

For All Other Locations and Online Courses
Books can be found online at Barnes & Noble http://johns-hopkins.bncollege.com

Academic Regulations

Following are the general requirements governing study in Engineering and Applied Science Programs for Professionals at Johns Hopkins. Students are expected to be familiar with these requirements and with the specific regulations set forth in the sections relevant to particular programs of study.

Requirements for degree programs and certificate programs described in this catalog may change from time to time. When this occurs, students may fulfill either the requirements in force at the time of admission or those in force at the time of graduation.

Advisers and Program Planning
Students are assigned an adviser when accepted. In addition, students in most master’s degree and certificate programs are required to submit a Program Planning form for their adviser’s approval. The Program Planning form provides students an opportunity to structure their course work according to their educational objectives and to meet degree requirements. Submission of the form confirms the student’s acceptance of admission and his or her intention to begin study. After this form has been approved by an adviser, all changes in the course of study must also be approved. Courses that deviate from the program plan and have not been approved by an adviser may not count toward degree requirements. The Program Planning form may be accessed on the EPP website under “student forms.”

Students in programs that do not require Program Planning forms are urged to consult their adviser prior to registration for courses.

If a newly admitted student fails to return the Program Planning form when requested, it is assumed that the student does not wish to enter the program at that time. Even if the form is returned but the student fails to enroll within one year, it is necessary to reapply.
Academic Standing

**Master's Degree Candidates**

Only one grade of C may be counted toward the master's degree.

**Academic Probation** – Any student receiving either one grade of F or two grades of C during their program of study will be placed on academic probation. Students placed on probation are permitted to retake any graduate course in which they have earned a grade of C or below. If a grade of B or above is earned in the repeated course, the probationary status will be removed. There are circumstances described below where students will not be placed on probation but will be immediately dismissed from the program.

**Academic Dismissal** – The following are causes for dismissal from the program:

- Students already on probation who receive an additional grade of C or below
- Students receiving a grade of C and a subsequent F
- Students receiving three grades of C
- Students receiving two grades of F

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins University, within the past four years are not eligible for admission.

**Certificate or Advanced Certificate for Post-Master's Study**

No grade of C can be counted toward a certificate or advanced certificate for post-master's study. The above policy for probation and dismissal will apply.

**Special Students**

The above policy for probation and dismissal will apply.

**Second Master's Degree**

After receiving a master's degree from the programs, students may continue their graduate education in a second field if the appropriate prerequisites of the new program are fulfilled.

To receive a second master's degree, all requirements for the second program must be satisfied. However, if the following conditions are met, up to two courses taken as part of the first degree may be applied toward requirements of the second:

- The course(s) must satisfy the requirements of the second degree;
- The student's adviser must approve the course(s) as appropriate to the plan of study; and
- The course(s) must fall within the five-year limit for the second degree; i.e., completion of the second degree must fall within five years from the date of the first class counted toward that degree.

Time Limitation

To be counted toward the degree or certificate, all course work in the program must be completed within a specified period which begins with the start of the first course in the student's program:

- Master's degree – 5 years
- Advanced Certificate – 3 years
- Graduate Certificate – 3 years

If necessary, a request for an extension should be submitted in writing to the relevant program committee at Engineering and Applied Science Programs for Professionals, Dorsey Student Services Center at least one term before the student otherwise would be expected to graduate.

**Leave of Absence**

Students who do not plan to enroll in classes for a period of one year or more must notify the Engineering Programs for Professionals office in writing and request a leave of absence for a specified period of time. The appropriate program chair will consider the request and inform the student of the decision. Students who are granted a leave of absence must resume their studies at the end of the allotted leave time. If warranted, the time permitted to complete degree requirements will be extended by the length of time granted for the leave of absence.

Students who do not resume their studies after a leave of absence has expired, or who have not enrolled for more than one year without having requested a leave of absence, will assume the status of a student who has withdrawn from the program. Such students must reapply, pay the $75 application fee and are subject to the admission requirements in force at the date of the new application. Acceptance is not guaranteed even for students previously admitted, and any courses taken prior to the interruption of studies may not count toward requirements if they are not completed within the time allowed for degree completion.

**Transfer Courses**

Requests to transfer courses toward the master's degree will be considered on an individual basis. Courses must be graduate level, not previously applied toward an awarded degree, and directly applicable to the student's program of study in the Engineering and Applied Science Programs for Professionals. Requests should be submitted, in writing, to the appropriate program chair at the Dorsey Student Services Center. Please include a course description. The fee for transfer is $250 per course.

**Graduation**

Students who expect to receive a degree or certificate must submit an Application for Graduation, available at www.epp.jhu.edu. Applications should be mailed back with your registration form for your final term of course work.
Academic Regulations

Students who are planning to graduate should complete all coursework on time and should not request to receive the grade of I (Incomplete) during their final term.

Approximately two months after the semester begins, students who have submitted the Application for Graduation receive a preliminary letter stating their names have been placed on the tentative graduation list for the semester in which they anticipate completing their degree requirements.

The WSE Graduate Committee meets three times each year to review candidates for graduation and to make recommendations to the University president for commencement. Students completing all requirements at the end of the summer term are reviewed by the committee in late October; those finishing at the end of the fall semester are reviewed in late February; and those finishing at the end of the spring semester are reviewed in May. After the WSE Graduate Committee meets, students on the graduation list receive a letter confirming the committee’s action.

All students receive their diplomas/certificates at the May commencement exercises, regardless of when they complete their degree requirements and regardless of the date of recommendation by the Graduate Committee. Commencement information is sent the first week in March. To receive their diploma, students must pay all student accounts in full and resolve all outstanding charges of misconduct and violations of academic integrity. Students receive bills for graduation in early spring. For graduation fees, see the Tuition and Fees page.

Johns Hopkins diplomas indicate the degree and major (e.g., Master of Science–Computer Science) without identifying the student's concentration or option.

Honors
A student will graduate with honors if they have earned an A in all courses taken between admission to the degree program and graduation from the degree program. Any other grade except a withdrawal or audit will disqualify a student from receiving honors. The designation “Honors” will appear on the student’s transcripts.

Grading System
The following grades are used for the courses: A—excellent, B—good, C—unsatisfactory, F—failure, I—incomplete, WD—official withdrawal, and AU—audit (the last two are not assigned by instructor).

A grade of F indicates the student’s failure to complete or comprehend the course work. A course for which an unsatisfactory grade (C or F) has been received may be retaken. The original grade is replaced with an R. If the failed course includes a laboratory, both the lecture and laboratory work must be retaken unless the instructor indicates otherwise.

The transcript is part of the student’s permanent record at the University. No grade may be changed except to correct an error, to replace an incomplete with a grade, or to replace a grade with an R.

The Whiting School assumes that students possess acceptable written command of the English language. It is proper for faculty to consider writing quality when assigning grades.

Incompletes
A grade of Incomplete (I) is assigned when a student fails to complete a course on time for valid reasons, usually under circumstances beyond his/her control. In consultation with the instructor, the student completes a Resolution of Incomplete form in which he or she states the reasons for requesting the incomplete and plans for resolving it. The form must be signed by the instructor. The student and instructor each retain a copy; the remaining copies are attached to the grade roster and are sent by the instructor to the Registrar. An incomplete submitted without this form is recorded as an F on the student’s academic record. Resolution of Incomplete forms are included with the final grade roster. They may also be obtained at any of the instructional site offices.

The Resolution of Incomplete form requires that the instructor specify the grade that the student would receive in the course if the incomplete work were not completed. (This grade may be, but need not be, an F.) Thus, if the course work is not completed, the student receives the “reversion” grade; that is, the grade that reflects work completed to that point. A $60 change of grade fee must be mailed to the EPP Dorsey Student Services Center office before the final grade will be posted on the student’s transcript (except for grades of F).

Conditions for resolving an incomplete are established by the instructor. A final grade must be submitted to the Registrar within four weeks after the start of the following term. For academic year 2007–2008, the dates by which final grades for incomplete work must be resolved are:

<table>
<thead>
<tr>
<th>Term</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer term</td>
<td>October 3</td>
</tr>
<tr>
<td>Fall semester</td>
<td>February 25</td>
</tr>
<tr>
<td>Spring semester</td>
<td>July 2</td>
</tr>
</tbody>
</table>

Students who expect to complete degree requirements, but have an incomplete, are not certified for graduation until the end of the following term.

Grade Reports
At the midpoint of each term, instructors are requested to provide a list of students whose work at that time is unsatisfactory. Students are notified by the EPP Student Services Center staff if their names are reported so they can take corrective action. These early reports are for the benefit of students and their advisers and are not part of the permanent record.

Following the end of each term, the Office of the Registrar mails a grade report to each enrolled student. Grades are also available online at www.registration.jhu.edu. These reports CANNOT be requested by telephone or personal inquiry. Students who desire additional copies of their grade reports or who want their transcripts sent to other institutions should make arrangements with the Office of the Registrar, 75 Garland Hall, 410-516-7088.
Grade Appeals
Student concerns regarding grades must be first discussed thoroughly with the instructor. If the student and the instructor are unable to reach agreement, the student may appeal in writing the instructor’s decision to the appropriate program chair, and, finally, to the associate dean. At each review level, evaluation criteria will be limited to: (1) verification that there was not an error in recording the grade and (2) verification that the grade was determined on the basis of considered academic judgment. Grade appeals must be initiated within one semester after completing the course in question.

Student Attendance
Students are expected to attend regularly all courses in which they are enrolled. Although EPP and the University have no specific rules governing absences, the course instructor may announce certain attendance requirements. It is the student’s responsibility to be aware of those requirements. Students who know they will be absent from class, especially for an extended period of time, should notify the instructor as far in advance as possible. It is the student’s responsibility to discuss missed assignments and exams with the instructor. If an instructor is unavoidably late for class, the site office will attempt to notify students and tell them to wait, if it is practical. If an instructor is unable to meet a class, every attempt will be made by EPP staff to inform students of the cancellation, a make-up time for the class (if available), and information regarding assignments. If an instructor informs the EPP office of a class cancellation, with enough lead time, phone calls will be made to students.

Academic Standing
The University reserves the right to exclude at any time a student whose academic standing or general conduct is deemed unsatisfactory.

Academic Misconduct
This section summarizes the policy on academic misconduct.

The Roles of Students and Faculty
Johns Hopkins faculty and students have a joint responsibility to maintain the academic integrity of the University in all respects. Students must conduct themselves in a manner appropriate to the University’s mission as an institution of higher education. Students are obligated to refrain from acts that they know, or under the circumstances have reason to know, impair the academic integrity of the University. Violations of academic integrity include, but are not limited to: cheating; plagiarism; unapproved multiple submissions; knowingly furnishing false information to any agent of the University for inclusion in academic records; and falsification, forgery, alteration, destruction, or misuse of official University documents. Members of the faculty are responsible for announcing the academic requirements of each course, for the conduct of examinations, and for the security of examination papers and teaching laboratories. It is the duty of faculty to report suspected violations of academic integrity to the appropriate program chair. It is the responsibility of each student to report to the instructor any suspected violations of academic integrity.

Violations of Academic Integrity
After reviewing the circumstances of any suspected violation of academic integrity to determine if a violation may have occurred, a program chair will promptly report (in writing) the suspected violation to the associate dean of the Engineering Programs for Professionals. Supporting evidence (e.g., copies of examination papers) should accompany the report. The associate dean will resolve the issues following the procedures set forth on the web site noted above.

Copyright Violations
Copying, downloading or distributing music, videos, software, games or other copyrighted materials without permission of the owner is a violation of University policy, which will be submitted for disciplinary action, and is a serious violation of federal law.

Original works fixed in any tangible medium of expression, which includes storage within computers, are copyrighted to the author from the moment of creation. No notice of copyright is required. Except under limited circumstances for limited purposes, you may not make or distribute copies of material belonging to others without their permission. Unless a site specifically grants you permission to download and copy material from the site, you should assume that you cannot do so. You should also assume that all person to person sharing of music, programs, videos and software is a violation of copyright. Copyright violations will be submitted for disciplinary action.

Computer Usage
Because JHU's Office of Information Technology updates its policies frequently, please visit the JHU IT website for the latest information on usage, security, as well as the “Jumpstart” guide for student policies: http://www.it.jhu.edu/policies/index.html.

The following includes key elements of the policy, which is posted in all EPP computer labs:

Acceptable use of IT Resources is use that is consistent with Johns Hopkins’ missions of education, research, service, and patient care, and is legal, ethical, and honest; it must respect intellectual property, ownership of data, system security mechanisms, and individuals’ rights to privacy and freedom from intimidation, harassment, and annoyance; it must show consideration in the consumption and utilization of IT Resources; and it must not jeopardize Johns Hopkins’ not-for-profit status. Incidental personal use of IT Resources is permitted if consistent with applicable JH and divisional policy, and if such use is reasonable, not excessive, and does not impair work performance or productivity.

Please visit the JHU IT link above for additional information on unacceptable use of IT Resources.
Tuition and Fees

Students whose tuition is paid by contract should begin processing requests with their employers well before registration deadlines to ensure that payment is made as required. Students are ultimately responsible for all costs associated with their registration.

Tuition
The graduate tuition fee is $2,475 per course, unless otherwise noted. The tuition for 200-level courses is $1,360. Tuition for courses in the daytime programs of the Whiting School is a percentage of full-time tuition. If students need a receipt for the classes they are attending they may contact Student Accounts at 410-540-2960.

Application Fee
The fee for degree and certificate programs and special students is $75. This fee must be submitted with the application and is not refundable under any circumstances. Whiting School of Engineering degree and certificate recipients who wish to enter into another degree or certificate program may apply without paying an application fee.

Graduation Fee
The graduation fee is $100 and is payable upon receipt of a bill from the office of Student Accounts.

Late Registration Fee
Students registering after the first day of classes indicated on the academic calendar are required to pay a late fee of $65.

Late Tuition Payment Fee
Tuition payment due dates are indicated on the academic calendar. If payment is received after the due date, a late payment fee of $125 will be incurred.

Transfer Credit Fee
Graduate courses completed at another school and approved for transfer are assessed a fee of $250 per course.

Fee for Removal of an Incomplete Grade
Students who receive an incomplete grade for a course are required to pay a $60 fee to have the I grade changed to the final grade. This fee must be paid to the EPP office, Dorsey Student Services Center before the grade change can be released by the Registrar. No payment is required if the final grade is an F.

Refund Policy
Refunds apply only to the tuition portion of a student’s charges and are calculated from the date the student’s “add/drop” form is received in one of the EPP offices. Telephone withdrawals are not accepted. Refunds are not applicable to any fees. Refunds are not granted to students suspended or dismissed for disciplinary reasons.

Tuition refunds are made in accordance to the schedule below.

<table>
<thead>
<tr>
<th>Withdrawal Date</th>
<th>Refund</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to first class meeting</td>
<td>100%</td>
</tr>
<tr>
<td>Prior to second class meeting</td>
<td>90%</td>
</tr>
<tr>
<td>Prior to third class meeting</td>
<td>75%</td>
</tr>
<tr>
<td>Prior to fourth class meeting</td>
<td>50%</td>
</tr>
<tr>
<td>Prior to sixth class meeting</td>
<td>25%</td>
</tr>
</tbody>
</table>

Students who are enrolled at the Johns Hopkins University for the first time and who are receiving federal student financial aid are subject to a separate refund policy during their first period of enrollment. Refer to Title IV Refunds on the Financial Aid page for further information.

Financial Aid and Veterans Benefits

Federal financial aid in the form of grants and student loans is available to part-time undergraduate and graduate degree candidates who are enrolled in two or more courses per term (or the equivalent of at least six credits). Before receiving federal or other financial aid, students must establish financial need by completing the Free Application for Federal Student Aid (FAFSA) and a Hopkins application. These forms are available from the Office of Student Financial Services, 146 Garland Hall, call 410-516-8028 or e-mail fin_aid@jhu.edu or download from www.jhu.edu/finaid/elecserv. Students can also file the FAFSA electronically with FAFSA on the Web at www.fafsa.ed.gov. A copy of your and your spouse’s (if applicable) most current federal income tax return is also required.

The FAFSA should be submitted no later than March 1 for the upcoming academic year. Students should indicate on the aid form that they will be attending the Johns Hopkins University Whiting School of Engineering, code #E00473, and should identify themselves as students in the Engineering and Applied Science Programs for Professionals when they call or write the Office of Student Financial Services.

Annual application and submission of the FAFSA is required for all federal programs. In accordance with federal regulations, only U.S. citizens and permanent residents who have been accepted into a degree program or who enroll as special students for one academic year will be considered for financial aid. Students on academic probation are not eligible to receive financial aid.
Types of Financial Aid

Federal Pell Grants—Undergraduate students working toward their first baccalaureate degree and taking a minimum of six credits per semester are eligible for consideration. Those students who are less than half-time may also be eligible for the Federal Pell Grant. Applicants must be U.S. citizens or permanent residents, and should submit the Free Application for Federal Student Aid to be considered for the upcoming academic year.

Federal Direct Student Loans—Undergraduate and graduate students enrolled in a degree program for a minimum of six credits or two classes per semester may apply for a Federal Direct Student Loan which carries a fixed interest rate of 6.8 percent. All subsidized Federal Direct Student Loan applicants must show eligibility based on a need analysis and must complete the FAFSA, a Hopkins application, and submit tax returns and W-2s. If you wish to apply for an unsubsidized loan (interest accrues while you are in school), follow the same directions. Applicants must be U.S. citizens or permanent residents. Maximum annual loan limits for the subsidized and unsubsidized Federal Direct Student Loan programs:

<table>
<thead>
<tr>
<th>Loan Type</th>
<th>Independent Undergraduate</th>
<th>Special Student</th>
<th>Graduate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidized Program</td>
<td>$5,500</td>
<td>$5,500</td>
<td>$8,500</td>
</tr>
<tr>
<td>Unsubsidized Program</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

Loans are processed by Hopkins and students are mailed a promissory note. Funds are credited to the student’s account.

Federal Perkins Loan—Undergraduate and graduate students who demonstrate financial need may apply for the Federal Perkins Loan. Special students are allowed financial aid for two semesters. The Federal Perkins Loan program is administered by Hopkins. The current rate of interest is 5 percent.

Scholarships—A select number of scholarships are available for part-time graduate students. Awards are generally made on the basis of merit and financial need. To be eligible for need-based scholarship funds, students must establish financial need by completing the FAFSA and a Hopkins application.

Outside Scholarships—Outside scholarships from private organizations can be an additional source of aid. Information about these scholarships is available through the financial aid web page, www.jhu.edu/finaid (click on FastWeb), publications in local libraries and bookstores, and community organizations.

More Information—Students interested in financial aid may find more detailed information in the graduate brochures on financial assistance available from the Office of Student Financial Services in Garland Hall or on our web page www.jhu.edu/finaid.

Title IV Refunds

The Higher Education Act stipulates that first-time enrolled students receiving federal student aid who withdraw from school shall obtain a pro-rated refund, which must first be applied to all federal student loans and grants. The refund extends to all university charges if the student withdraws at any point up to 60 percent of the first enrollment period. Students who meet these criteria should identify themselves when they contact the part-time programs office about their intention to withdraw. A copy of the federal refund policy applicable to such students will be provided along with the student’s refund. The pro-rated refund policy does not apply to students who are employees of the federal government and are attending EPP classes with federal tuition remission funding.

Veterans Benefits

Johns Hopkins is approved by the Maryland Higher Education Commission for the training of veterans and the widows and children of deceased veterans under provisions of the various federal laws pertaining to veterans’ educational benefits. Information about veterans’ benefits and enrollment procedures may be obtained at the Registrar’s Office, Garland Hall, 410-516-7071. Students eligible for veterans educational benefits register and pay their university bills in the same manner as other students. Reimbursement is made by the Department of Veterans’ Affairs on a monthly basis. The amount of reimbursement is determined by the veteran’s number of dependents and course load based on the table below.

<table>
<thead>
<tr>
<th>Credits per term:</th>
<th>12</th>
<th>Full-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-11</td>
<td>Three-quarter time</td>
<td></td>
</tr>
<tr>
<td>6-8</td>
<td>One-half time</td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>Payments cover only a portion of assigned fees</td>
<td></td>
</tr>
</tbody>
</table>

Note that credits are not assigned to graduate courses. A statement of “equivalent” credits for each graduate course taken may be obtained from the Registrar’s Office. To obtain reimbursement, a veteran must comply with the following procedures:

Initial Enrollment—The veteran must first apply and be admitted to one of the schools of the University. He or she then obtains an Application for Program of Education or Training (DVA Form 22-1990) from either the Department of Veterans Affairs or the University.

After completing the application, the veteran sends it, with a certified copy of appropriate discharge papers, to the following address:

Veterans Affairs
Office of the Registrar
Johns Hopkins University
3400 N. Charles Street
Baltimore, Maryland 21218-2681
Facilities and Student Services

Transfers—When transferring from another college or university, the veteran must obtain a Request for Change of Program or Place of Training Form (DVA Form 22-1995) from either the Department of Veterans Affairs or the University, and must submit the completed form to the Registrar’s Office in Garland Hall at the University.

Re-enrollment—A student who received veterans benefits while attending the University during the preceding semester or summer session, and who plans to re-enroll with no change of objective, must advise the Registrar when submitting registration materials that he or she wishes to be re-certified under the provisions of the original DVA Form 22-1990.

Students receiving veterans benefits must pursue a program of courses which leads toward the exact objective (normally a degree or certificate) indicated on the original DVA application. Any change in program or objective requires submission of a Request for Change of Program (DVA Form 22-1995). Veteran students are required to advise the Registrar immediately of any change in their program or status which might affect the amount of their monthly payment from the DVA. Failure to do so will cause the Department of Veterans Affairs to seek restitution from the veteran for the overpayment of benefits.

Standards of Progress—Continuation of DVA payments is dependent upon the veteran meeting the academic standards established by the University for all students—veterans and non-veterans alike. The veteran must also meet any standards of progress that are or may be established by DVA regulations. If the student fails to meet these standards, benefits will be suspended until the DVA completes a review of the student’s progress and determines that the benefits may be resumed.

Transcripts

Official transcripts will be mailed upon written request of the student at no charge. Requests for transcripts should be addressed to the Office of the Registrar, 75 Garland Hall or faxed to 410-516-6477. If faxed, please provide a photocopy of two forms of identification. Transcripts may also be ordered online from http://www.studentclearinghouse.org for a fee. For more information about each of these options, see http://www.jhu.edu/~registr/transcript.html.

International Student Services

Students may contact the International Student & Scholar Services at 410-516-1013. For more details please refer to the Admission Requirements section.

Services for Students with Disabilities

Johns Hopkins University is committed to making all academic programs, support services and facilities accessible to qualified individuals. Students with disabilities who require reasonable accommodations should contact the disability services coordinator, at 410-540-2962 or at epp@jhu.edu.

In order to receive accommodations, it is important to provide to the university a comprehensive evaluation of a specific disability from a qualified diagnostician that identifies the type of disability, describes the current level of functioning in an academic setting and lists recommended accommodations. All documentation will be reviewed and reasonable accommodations will be provided based on the student’s needs. Students are required to contact the Engineering Programs for Professionals office at least four weeks prior to the beginning of each semester to ensure that services will be available.

For questions or concerns regarding University-wide disability issues, contact Peggy Hayeslip, associate director of Disability Services, 410-516-8949, or phayeslip@jhu.edu.

Career Services

Career Services is dedicated to assisting current students and alumni understand their career choice and help them in their professional advancement in their chosen career. Partnering with employers and past alumni, the Office of Career Services seeks to provide cutting-edge programming and services on topics such as resume building, career and life balance, networking, marketing yourself, portfolio development, and more. Career Services is not just for those who are currently job searching, but also for those seeking to advance with their current employer. To make an appointment, please call 410-290-1934 or email careerervices@jhu.edu. To learn more about our services, please visit us at www.careerservices.jhu.edu.

Facilities and Student Services

The Engineering and Applied Science Programs for Professionals of the Whiting School are offered at the Homewood campus in Baltimore, the Applied Physics Laboratory (APL) in Laurel, Montgomery County Campus in Rockville, the Dorsey Student Services Center near Baltimore/Washington International Thurgood Marshall Airport, the Southern Maryland Higher Education Center in St. Mary’s County, the Washington Center in Washington, D.C., the Higher Education and Applied Technology Center (HEAT) in Harford County, and fully online. The educational and student facilities and services provided at each location are described below.

Student ID JCards

University identification cards are mailed to the home address of every registered student. The JCard acts as the University library card, which enables students to check out books from the Homewood Eisenhower Library or at any of the campus center libraries, and provides access to many computer laboratories. To replace a lost or stolen JCard, contact the JCard Office at 410-516-5121.

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Inclement Weather
The JHU Weather Emergency Line can be reached at 410-516-7781 or 800-548-9004. The JHU Weather Emergency Line provides information on class and campus closing, due to inclement weather. The University may also use the same phone lines occasionally to distribute other urgent information. Announcements and closings will also be posted on the website: webapps.jhu.edu/emergencynotices.

Web-based Student Directory
JHED (Johns Hopkins Enterprise Directory) is the primary source for contact information of Johns Hopkins students. Your JHED login ID will be used for many web-based services, such as online registration, remote library access, and some course web sites. You may find your login ID and initiate your account by going to http://jhed.jhu.edu from a computer at any of the campuses or by calling 410-516-HELP. Once you have set a password, you may use JHED from anywhere by logging in. If you have any questions, contact Hopkins Information Technology Services at 410-516-HELP.

Computers
Hopkins Information Technology Services (HITS) provides a number of resources that are useful to students. Brief descriptions are provided below. For more information, refer to http://jumpstart.jhu.edu/compguide/index.html.

JHEM – JHEM (Johns Hopkins Enterprise Messaging) is an e-mail system provided by the university. All students may request a JHEM email account through JHED. If you have another email account and prefer to use it, you can forward JHEM mail to that account. You may access your JHEM e-mail account via a web interface at http://jhem.jhu.edu or by using pop or imap protocols through an e-mail client such as Netscape Messenger, Outlook Express, or Eudora. Visit http://nts.jhu.edu/es/jhem for more information.

Jshare – Jshare is a web-based utility that provides students an interface to upload, download, and share files with users inside and outside of the university. Jshare is accessible from JHED and includes such things as:

- 100 megabytes of space for file storage
- Secure file access from anywhere at any time
- Advanced collaboration and document management
- File sharing ability both inside and outside the university
- Ability to email files as links to reduce the load on email systems
- Ability to create and maintain personal web sites

Visit http://www.it.jhu.edu/jshare/ for more information.

Virtual Private Network – JHSecure VPN (Virtual Private Network) is a combination of software and hardware that allows EPP students off-campus access to Hopkins restricted resources, including most of the Library’s online materials. More information and instructions on using the VPN are available from JHED or go to http://nts.jhu.edu/networking/remoteaccess.cfm.

Anti-Virus Software – HITS recommends the use of anti-virus software to all students. Software is available for both Windows and Macintosh operating systems, and can be downloaded from http://www.it.jhu.edu/antivirus. (You must be using VPN to download if you are off campus.)

The Homewood Campus
The Homewood campus, located at 3400 North Charles Street in Baltimore, is grouped around two adjoining quadrangles. The Georgian architecture and wooded walkways and lawns make Homewood a pleasant retreat in a residential area of Baltimore.

- Libraries
The entire library collection of the Johns Hopkins University contains close to three million volumes; more than two million of these and one million microforms are available on the Homewood campus. Most of the Homewood collections are shelved in the Milton S. Eisenhower Library, which is open until 10 p.m. on Friday and Saturday, and until midnight on the other days of the week.

Students are issued a JCard by the JCard Office upon registering. This card entitles them to use the Eisenhower Library and the Hutzler Reading Room (a 24-hour undergraduate library located in Gilman Hall).

- Bookstore
Barnes & Noble Johns Hopkins is located at 3300 St. Paul Street (corner of St. Paul and 33rd). Store hours are Monday through Saturday, 9 a.m. to 10:00 p.m.; and Sunday 10 a.m. to 9 p.m. Textbooks can be ordered online at http://johns Hopkins.bkstore.com. Barnes & Noble Johns Hopkins sells new and used textbooks, study aids, school supplies, Johns Hopkins sportswear, and a variety of discount books. Special book order services also are available. For more information, call 410-662-5850.

- Hopkins Student Union
Located in Levering Hall and the Glass Pavilion, the Hopkins Union offers various programs and activities for students, faculty, staff, and friends of the University. Levering Hall contains the Levering Food Court, a complete dining facility with various retail venues offering a combination of American and ethnic fare, and the Jazzman’s Café located in the Levering Lobby, offering gourmet coffee, sandwiches, and pastries. The hours of operation at the food court vary by restaurant and are as follows: Sky Ranch Grill, Pete’s Arena, and Sub Connections are open Monday through Friday, 10:30 a.m.–2:30 p.m.; the Salsa Rico is open Monday through Friday, 10:30 a.m.–8 p.m. The Jazzman’s Café is open Monday through Friday, 7:30 a.m.–4 p.m.

- Security Services
A daily escort van service is available during the evening hours (5 p.m. to 3 a.m.) to pick up and deliver students to any campus parking lot or other location within a one-mile radius of campus. Vans leave every half hour from the Eisenhower Library.
Walking escorts are available by calling extension 8700 from any campus phone or 410-516-8700 from an outside or public telephone. Push button security/escort phones, located in several campus buildings, can be used to alert security officers of an emergency, to request information, or to summon the escort van.

Emergency telephone stands with blue lights, which connect directly with the security office, are located strategically at 14 locations around campus. These telephones open a direct line to the security office as soon as the receiver is lifted or the button pushed. To ward off a possible attacker, an alarm sounds at the phone. Pay telephones also are available in most campus buildings. Security officers also patrol parking lots Garland, Clark, and Stony Run from 3 to 11 p.m., Monday through Friday. Student monitors, wearing bright orange vests and carrying radios, patrol the upper and lower quads during fall and spring semesters.

To reach the security office, call 410-516-4600. In case of an emergency, call 410-516-7777.

- **Parking**
  Parking arrangements are made in Room 7 of Shriver Hall. Parking office hours are Monday through Thursday, 8 a.m. to 7:30 p.m.; Fridays, 8 a.m. to 5 p.m. 410-516-7275.

**Applied Physics Laboratory Education Center**

The mission of the Applied Physics Laboratory (APL), a division of the Johns Hopkins University, includes the application of advanced science and technology to the solution of problems of national and global significance. Although APL is primarily a research and development organization, the Laboratory maintains strong academic relationships with the other divisions of the University.

The APL Education Center is a major site for part-time Hopkins graduate students pursuing technical degrees. Most courses are offered in the Kossiakoff Center, a modern auditorium and class room building on the APL campus. One wing of the building contains classrooms, well-equipped laboratories and computer facilities, and a vending area.

- **Library**
  The R.E. Gibson Library maintains a 56,000 volume collection for research by the APL professional staff and scholarly community. In addition, over 800 journal subscriptions and a current collection of reserved books are available for student use. Subject holdings include physics, aeronautics, electrical engineering, computer science, mathematics, and mechanical and biomedical engineering. During the fall and spring terms when classes are in session, the hours are 8:30 a.m. to 9 p.m. Monday through Thursday, and 8:30 a.m. to 5:30 p.m. on Friday, during the summer session the hours are 8:30 a.m. to 5:30 p.m. Monday through Friday.

  Students must present their JCard at the circulation desk to use library resources.

  Additional classrooms, laboratories, and the center office are located in the library building.

- **Computers**
  Computer facilities at the Kossiakoff Center include SUN UNIX servers, xterminals, workstations, and personal computers. Remote access to the servers at APL is also available.

- **Bookstore**
  Textbooks for courses at APL may be purchased or exchanged during late afternoon and early evening hours during the start of each term. Textbooks can also be ordered online at [http://johns-hopkins.blkstore.com](http://johns-hopkins.blkstore.com). Specific hours of the bookstore’s operation at APL are posted at [www.epp.jhu.edu](http://www.epp.jhu.edu).

- **Parking**
  Parking tags are not required. The lower level parking lot near the Kossiakoff Center is recommended.

**Montgomery County Campus**

The mission of the Montgomery County Campus in the Shady Grove Life Sciences Center in Rockville is to create a community of education, business and government organizations where collaborative thinking and scientific discovery advance academic and economic development. The campus, which houses 46 smart classrooms and 11 computer labs, a full-service library, café, bookstore and extensive conference space, welcomes 5,000 students per year. Five of the University’s nine schools offer more than 60 degree and certificate programs at this location. In recent years, three technology research centers have co-located with Johns Hopkins University on this campus.

- **Library**
  The Montgomery County Campus Library maintains a reference and circulating collection of materials for use by faculty and students. Subject areas in the collection include computer science, electrical engineering, environmental engineering and science, management, and physics. Interlibrary loan service is provided to assist in obtaining journals and books not available at the MCC library. An online catalog of the collection and a variety of full-text INSPEC and IEEE databases, including Compendex, are accessible through personal computer workstations in the library.

  To use materials, present your JCard at the circulation desk. The library is open from noon to 9 p.m., Monday through Thursday; noon to 6 p.m., Friday; and 10:00 a.m. to 5 p.m., Saturday.

- **Computers**
  Computer facilities at the Montgomery County Campus include Sun Ray thin clients, Unix servers and workstations, as well as personal computers available for student use. In addition, students have access via high-speed data links to Unix servers at Homewood and APL. Dial-in PPP access to the servers is also available.
• Bookstore
Textbooks are available before and during in-person registration and during the first two weeks of classes. Throughout the semester, books, supplies, and other course-related materials can be purchased at the bookstore and can also be purchased online at www.jhutextbooks.com. The bookstore has daytime and evening hours to accommodate student and faculty needs.

• Café
Located in the Academic and Research building, the café serves snacks and sandwiches during the daytime and early evening hours.

• Parking
Free parking permits are issued upon completion of the application form. Parking permits may be obtained at the Gilchrist Hall front desk during the first two weeks of classes. There is no charge for this service.

Dorsey Student Service Center
In addition to classrooms and computer labs, the Dorsey Center now houses the admissions and registration staff, and will serve as a central point of access for academic advising and financial services. The Dorsey Center is located near the Baltimore/Washington International Thurgood Marshall Airport at 6810 Deerpath Road, Elkridge, MD.

The center has an instructional laboratory equipped with x-terminals, workstations, personal computers, and a high-speed data link to the UNIX servers at APL.

The center is also the site of the School’s Microwave Engineering Laboratory, a state-of-the-art facility for designing, developing, and testing microwave chips. In addition to workstations with CAD capability (ACADEMY, LIBRA, OMNISYS, and other software), the laboratory houses microwave test equipment such as network analyzers, spectrum analyzers, noise measuring equipment, fabrication and assembly equipment, and microwave sweepers and synthesizers.

Southern Maryland Higher Education Center
This facility was created by the Maryland General Assembly to serve as the regional upper-level undergraduate and graduate education and research institution for Southern Maryland. Currently, nine colleges and universities are participating and offering programs in education, management, and engineering and applied science. Facilities include two buildings with classrooms, a large multipurpose room, computer labs, a learning conference room, a student lounge, a vending area, and interactive videoconferencing capability.

Washington DC Center
The Washington Center is a convenient location in the heart of Washington, D.C., Dupont Circle Metro stop. Selected courses in the environmental engineering and science program are currently being offered on site.

Higher Education and Applied Technology (HEAT) Center
The HEAT Center is located in Harford County. Selected courses in chemical engineering, environmental engineering, science and management, materials science and engineering, and mechanical engineering are currently being offered.

Online Courses
EPP offers some courses and degrees completely online. Available courses are listed in a separate location category under each program in the course schedule for each term. The number of online courses will increase each term, so students are encouraged to check each term for new online offerings.

EPP also offers two fully online degrees. The Master of Science in Bioinformatics degree is offered jointly with the Krieger School of Arts and Sciences (KSAS) Advanced Academic Programs (AAP). All courses may be taken online and there is no residency requirement. See the Bioinformatics program for more information. The Master of Science in Environmental Planning and Management is also offered fully online. See the Environmental Engineering, Science and Management program for more information.

Initial contact and instructions for online courses will be delivered via e-mail prior to the first day of classes for each term. Students are responsible for entering a current e-mail address and phone numbers on their registration form for each term.

The online courses follow the normal academic schedule for each term. They are not self-paced. All registered students proceed through the course as a group, communicating online with their instructor and each other and, where appropriate, working in groups on team projects. This method fosters active and collaborative learning and an interactive style of problem solving that improves student comprehension. The workload in online courses is comparable to those that meet face to face, but is often distributed more evenly throughout the week than is typical for courses taught in the classroom. The courses are taught completely over the internet and primarily through a website. Students must have a working e-mail address and readily and easily accessible internet access in order to complete course work successfully. There may be additional technical requirements for some courses, such as specific software or access to a fax machine. Further information about the requirements for a specific course can be obtained by e-mailing epponline@jhu.edu or calling 410-516-8758.

• Registration Deadlines
Students enrolling in their first EPP online course must be registered a week and a half prior to the first day of classes in order to attend the mandatory online orientation during that week. Returning online students are strongly encouraged to register early. Registration later than a week before the first day of the term may result in delayed access to the course website. Note that these deadlines may preclude registration at some of the advisory session dates. The deadline for adding
Facilities and Student Services

online courses is a week after the first day of classes each term, which is earlier than the deadline for conventional courses. See the Academic and Registration Calendar for exact dates for each term.

• **Online Orientation**
Students enrolling in their first EPP online course must attend a mandatory online orientation. See the Academic and Registration Calendar for the exact dates each term. The orientation takes place online during the week prior to the start of the term. Students will be given access to the orientation via email. The time commitment overall is minor, but students are required to log in at least twice, separated by 24 hours, so early participation is recommended. The orientation will identify and address technical access issues, introduce the student to the interface and online tools used to deliver the course, and prepare the student to be a successful online learner. Students are only required to take this orientation the first time they enroll in an online course offered by EPP.

**Books for Online Courses**
Students will receive a list of required and recommended textbooks via e-mail prior to the first day of classes each term. Textbooks and other course-related materials may be purchased online at [http://johns-hopkins.bncollege.com](http://johns-hopkins.bncollege.com).

**Inter-site Links**
To increase the variety of course selection at the centers, select courses are offered using video-teleconferencing equipment. This technology allows for two-way audio and video connectivity, creating real-time interaction between the sending and receiving sites. The system provides links between APL and Southern Maryland, and the Montgomery County Campus and permits students at any of the sites to enroll at courses originating at the other.

To further facilitate communication, high-speed data links connect Homewood, APL, the Montgomery County Campus, and the Dorsey Center, enabling students to access systems internally and via the Internet.
Applied Biomedical Engineering

Biomedical engineering is the application of knowledge from engineering and physics to enhance the understanding of and provide solutions to problems in biology and medicine. The goal of the Master of Science Program in Applied Biomedical Engineering is to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences. This program began in 1993.

The strength of the applied biomedical engineering program lies in the active involvement of the faculty in research and development. The majority of the courses are offered at the APL campus; however, some electives are offered only at the Homewood campus or at the Medical School.

Program Committee

Russell L. McCallly, Program Chair
Principal Professional Staff, Applied Physics Laboratory
Associate Professor of Ophthalmology, School of Medicine

Isaac N. Bankman
Principal Professional Staff, Applied Physics Laboratory
Assistant Professor of Biomedical Engineering, School of Medicine

Eileen Haase
Instructor, Biomedical Engineering, School of Medicine

Vincent L. Pisacane
Robert A. Heinlein, Professor of Aerospace Engineering
U.S. Naval Academy

Murray B. Sachs
Massey Professor and Director, Biomedical Engineering, School of Medicine
Principal Professional Staff, Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog in the Admission Requirements section. In addition, the applicant must have compiled an average of B (3.0 on a 4.0 scale) or above for all courses in mathematics, physics, engineering, and the other physical and biological sciences. The applicant's preparation must have included: (1) mathematics, through ordinary differential equations; (2) calculus-based physics, including mechanics, heat and energy, electricity and magnetism, and elementary quantum concepts; and (3) chemistry, inorganic and organic. Noncredit courses in organic chemistry and mathematics are offered for those who may need them to satisfy the eligibility requirements or to refresh their knowledge. The noncredit mathematics course is offered in the applied and computational mathematics program.

Course Requirements

A total of 10 one-semester courses must be completed within five years. The curriculum consists of five required courses listed in section II in this program, three to four courses elected from the Applied Biomedical Engineering curriculum listed in section III, and one to two courses elected from other offerings of the School of Engineering with the approval of the student's adviser. Also, with adviser approval, an elective course may be substituted for a required course if the student has previously completed an equivalent graduate level course or can demonstrate competency. Students may also select electives from the graduate courses in the Biomedical Engineering Department that are listed under section IV in this program with the approval of their adviser and the instructor. These courses are offered either at the Medical School or Homewood campus at their regularly scheduled hours during the day. With approval of their adviser, students may also partially fulfill the elective requirement with related courses offered through the part-time programs of the Krieger School of Arts and Sciences. At least four electives must be for advanced graduate credit, i.e., at the 600-, 700-, or 800-level. Students are required to file a program plan listing the courses they plan to take. The program plan must be approved by the student's adviser.

I. Non-Credit Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>585.209</td>
<td>Organic Chemistry</td>
</tr>
<tr>
<td>625.201</td>
<td>General Applied Mathematics</td>
</tr>
</tbody>
</table>

II. Required Courses

Five one-semester courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>585.405-406</td>
<td>Physiology for Applied Biomedical Engineering</td>
</tr>
<tr>
<td>585.407</td>
<td>Molecular Biology</td>
</tr>
<tr>
<td>585.408</td>
<td>Medical Sensors and Devices</td>
</tr>
<tr>
<td>585.409</td>
<td>Mathematical Methods for Applied Biomedical Engineering (625.701-702 Mathematical Methods may be substituted for this course and one elective with permission of the adviser.)</td>
</tr>
</tbody>
</table>

III. Elective Courses

Offered at the Applied Physics Laboratory or the Dorsey Center. The intent is to offer additional electives as the program matures.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>585.605</td>
<td>Medical Imaging</td>
</tr>
<tr>
<td>585.606</td>
<td>Medical Image Processing</td>
</tr>
<tr>
<td>585.607</td>
<td>Medical Imaging II: MRI</td>
</tr>
<tr>
<td>585.608</td>
<td>Biomaterials</td>
</tr>
<tr>
<td>585.609</td>
<td>Cell Mechanics</td>
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<tr>
<td>585.610</td>
<td>Biochemical Sensors</td>
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<tr>
<td>585.611</td>
<td>Practices of Biomedical Engineering</td>
</tr>
<tr>
<td>585.614</td>
<td>Applications of Physics and Technology to Biomedicine</td>
</tr>
</tbody>
</table>
Course Descriptions

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

**585.209 Organic Chemistry**

This course offers an in-depth review and study of organic chemistry. Topics include the fundamental chemistry of carbon compounds, chemical bonding, synthesis, reaction mechanisms, and stereochemistry. The role of organic chemistry in biology and medicine, environmental science, and industry is discussed. (Not for credit for Master of Science in Applied Biomedical Engineering degree.)

*Prerequisite:* 585.209 Organic Chemistry.

**585.405-406 Physiology for Applied Biomedical Engineering**

This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

*Prerequisite:* 585.209 Organic Chemistry.

**585.407 Molecular Biology**

The course is intended to serve as a fundamental introduction to cell and molecular biology. Topics generally included are basic chemistry and biochemistry of the cell; structure, function, and dynamics of macromolecules; cell organization; enzyme kinetics; membranes and membrane transport; biochemistry of cellular energy cycles, including oxidative phosphorylation; replication, transcription, and translation; regulation of gene expression; and recombinant DNA technology. Where appropriate, biomedical application and devices based on principles from cell and molecular biology are emphasized.

*Prerequisite:* 585.209 Organic Chemistry.

**585.408 Medical Sensors and Devices**

This course covers the basic and advanced principles, concepts, and operations of medical sensors and devices. The origin and nature of measurable physiological signals are studied, including chemical, electrochemical, optical, and electromagnetic signals. The principles and devices to make the measurements are also covered.

**585.409 Mathematical Methods for Applied Biomedical Engineering**

The course covers mathematical techniques needed to solve advanced problems encountered in applied biomedical engineering. Fundamental mathematical concepts are presented, but emphasis is placed on application of these techniques to biomedical engineering problems. Topics include probability and statistics, complex variables, difference and differential equations, and nonlinear equations. The first topic is given more emphasis than is found in traditional mathematical methods of engineering courses.

**585.605 Medical Imaging**

This course examines fundamental physical concepts, instrumentation, and signal processing techniques used to produce images in radiography, ultrasonography, tomography, magnetic resonance imaging, and nuclear medicine.
**Prerequisite:** 585.409 Mathematical Methods for Applied Biomedical Engineering.

**Kostenmacher, Staff**

**585.606 Medical Image Processing**
This course covers digital image processing techniques used for the analysis of medical images such as x-ray, ultrasound, CT, MRI, PET, microscopy, etc. The presented image enhancement algorithms are used for improving the visibility of significant structures as well as for facilitating subsequent automated processing. The localization and identification of target structures in medical images are addressed with several segmentation and pattern recognition algorithms of moderate complexity. Image reconstruction algorithms used for three-dimensional image formation are presented. The course covers image registration algorithms used to determine the correspondence of multiple images of the same anatomical structure. Image compression algorithms applied to medical images are also addressed.

**Prerequisite:** Familiarity with linear algebra and Fourier transforms.

**Bankman, Pham, Spiez**

**585.607 Medical Imaging II: MRI**
Following the increasing use and development of new MRI methods, a course on advanced MRI concepts and applications was designed as part of the imaging area of emphasis. The new course, Medical Imaging II, provides more information on the physics, imaging procedures, and advanced techniques of MRI. The new course also includes two lectures on nuclear medicine.

**Prerequisite:** 585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

**Spencer**

**585.608 Biomaterials**
This course covers the fundamentals of the synthesis, properties, and biocompatibility of metallic, ceramic, polymeric, and biological materials that come in contact with tissue and biological fluids. Emphasis is placed on using biomaterials for both hard and soft tissue replacement, organ replacement, coatings and adhesives, dental implants, and drug delivery systems. New trends in biomaterials, such as electrically conductive polymers, piezoelectric biomaterials, and solgel processing are discussed, and the recent merging of cell biology and biochemistry with materials is examined. Case studies and in-class scenarios are frequently used to highlight the current opportunities and challenges of using biomaterials in medicine.

**Prerequisite:** 585.209 Organic Chemistry.

**Potember**

**585.609 Cell Mechanics**
The class starts with introductory lectures on the place of cell mechanics in the broader areas of cell biology, physiology, and biophysics, where the general topics of cell structure, motility, force generation, and interaction with the extracellular matrix are considered. Three important case studies are discussed: blood cells, vascular endothelial cells, and cochlear hair cells. The analysis of each of these cases includes constitutive relations, experiments to estimate cellular parameters, and biological and physiological implications. The constitutive relations are based on nonlinear viscoelasticity in the cases of blood and endothelial cells and linear piezoelectricity in the case of hair cells. The necessary components of engineering mechanics of solids and fluids are introduced. The effective mechanical characteristics of the cell are related to the structure and properties of the cellular membrane, cytoskeleton, and nucleus. Micropipette aspiration, atomic force microscopy, and magnetic cytometry techniques are discussed in detail. The classes also include student presentations of original journal papers, covering additional topics and stimulating the student’s preparation and involvement in the class.

**Spector**

**585.610 Biochemical Sensors**
This course covers the fundamental principles and practical aspects of chemical sensing of physiological signals. The focus of the course is on the electrochemistry and biophysical chemistry of biological sensing elements and their integration with signal transducers. Other topics covered include design and construction of practical sensors, processing and interpretation of signal outputs, and emerging technologies for biosensing.

**Potember, Sample, Bryden**

**585.611 Practices of Biomedical Engineering**
The goal of this course is to present a methodical approach to practical biomedical engineering. The topics include innovation in research and engineering; contracting with the federal government; writing business plans and technical proposals; legal issues such as liability, patents, and the FDA approval process; the practice of biomedical engineering in industry; approaches to biomedical problems, including systems engineering and prototyping; and other issues involved in managing a research program such as marketing, sales, service, and other economic factors. A team of leading biomedical engineers and technical program managers teaches the course.

**Potember, Staff**

**585.612 Biomedical Aspects of Human Space Flight**
This course presents a variety of biomedical issues and technological developments that must be solved before man can journey to Mars. The topics of this course include overview of human space flight; characteristics of space environment; neurophysiological aspects of space travel; results from MIR and space shuttle missions; spacecraft life support systems; environmental hazards; microbiology; radiation and radiobiology; cardiopulmonary factors in space flight; bone and mineral metabolism; muscle structure and atrophy; endocrine functions and biochemical markers; biomedical implications in astronaut training; and countermeasures to space deconditioning.

**Potember, Staff**
Graduate Programs

585.614  **Applications of Physics and Technology to Biomedicine**

The goal of this course is to expose students to several concrete examples of how physical and technological methods are used in biomedicine. Examples will be chosen from ophthalmology (e.g., how the optical properties of the eye's cornea are related to its ultrastructure, applications of lasers, methods of measuring ocular blood flow); topics in biomedical optics (e.g., microscopy, optical coherence tomography); neurophysiology (mechanisms of pain perception); neural signal processing; medical image processing; and MRI. Topics will be presented by instructors who are actively engaged in research in the various areas.

McCally, Staff

585.618  **Biological Fluid and Solid Mechanics**

The goal of this class is to learn the relation between the mechanics and physiology (biology) of tissues and cells. This relation is demonstrated by introducing general models of solid and fluid mechanics and applying them to the cardiovascular system and bones. In particular, the arterial wall and endothelial cell mechanics as well as bone anisotropic properties and remodeling are discussed. The course also shows how theoretical models are used to interpret experiments, and how experimental data are used to estimate important parameters (constants) of the models. Experiments with biaxial stretching, micropipette aspiration, and atomic force microscopy commonly used to probe the mechanical properties of tissues and cells are discussed in detail. The models include anisotropic linear elasticity, nonlinear elasticity, viscoelasticity, and Newtonian (non-Newtonian) fluid dynamics.

Spector

585.620  **Orthopedic Biomechanics**

This course is an introduction to the field of orthopedic biomechanics for the engineer. The course will cover the structure and function of the musculoskeletal system, including detailed discussions on the material properties of bone, ligament, tendon, cartilage, and muscle. Other topics of discussion will include viscoelasticity, bone remodeling, and injury mechanisms. Journal articles from the biomechanics literature will be used to explore current areas of active research.

**Prerequisites:** Statics required and dynamics recommended.

Kleinberger

585.624  **Neural Prosthetics: Science, Technology, and Applications**

This course will address the scientific bases, technologies and chronic viability of emerging neuromodulatory devices. Examples include cochlear and retinal implants for sensory restoration, cortical and peripheral nervous system and brain computer interface devices for deriving motor control and enabling afferent feedback, rehabilitative and therapeutic devices such as deep brain stimulators for Parkinson's disease, functional electrical stimulation systems for spinal cord injuries, and cognitive prosthetic systems for addressing brain trauma. Regulatory (FDA) challenges with emerging technologies and ethical considerations will also be addressed.

Harshbarger, Staff

585.626  **Biomimetics in Biomedical Engineering**

Biomimetic refers to human-made processes, substances, devices or systems that imitate nature. This course focuses on substances prepared and engineered to meet biomedical uses. The course is designed to provide students with: (a) an understanding of the biomimetic process of self assembly; (b) an introduction to bioengineering biological materials and novel biomimetic materials that include forms and structures useful to bioprocesses; (c) an understanding of how different instruments may be used for imaging, identification and characterization of biological and biomimetic materials. Detailed knowledge of biological structure hierarchy is essential for most areas of biomedical engineering and biological materials are becoming an increasingly important resource in creating new biomimetic materials that possess targeted biological structural and functional properties.

Murray, Van Houten

585.800  **Special Project in Applied Biomedical Engineering**

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to the student's specialty of interest. The research problem can be addressed experimentally or analytically. A written report is produced on which the grade is based. This course is open only to graduate candidates in the Master of Science in Applied Biomedical Engineering program. The applied biomedical engineering project proposal form must be completed prior to registration.

**Prerequisite:** Permission of the instructor.

Staff

585.801  **Directed Studies in Applied Biomedical Engineering**

The course permits the student to investigate possible research fields or pursue topics of interest through reading or non-laboratory study under the direction of a faculty member. This course is open only to graduate candidates in the Master of Science in Applied Biomedical Engineering program. The applied biomedical engineering directed studies program proposal form must be completed prior to registration.

**Prerequisite:** Permission of the instructor.

Staff

580.625-626  **Structure and Function of the Auditory and Vestibular Systems**

(Formerly Structure and Function of the Auditory System)

Physiological mechanisms of hearing and balance. Topics include transmission of sound in the ear, transduction of sound and head orientation by hair cells, biophysics and biochemistry of hair cells, representation of sound and balance in
eighth-nerve discharge patterns, anatomy of the central auditory and vestibular systems, and synaptic transmission and signal processing in central neurons. Aspects of hearing and balance such as speech perception, sound localization, vestibular reflexes, and vestibular compensation are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data.

**Prerequisite:** 580.421–422 Physiological Foundations for Biomedical Engineering or equivalent. Recommended: 110.302 Differential Equations, 520.214 Signals and Systems.

Fall (even years), Spring (odd years)

Hearing Science Center Staff

**580.628 Modeling the Auditory System**
The physiology of hearing from a model-oriented viewpoint; intended as a complement to 580.625/626. Topics include basilar membrane mechanics, models of cochlear transduction, stochastic process models of neural discharge, detection-theoretic approaches to relating physiological and psychological data, models of signal processing in central auditory nuclei, and nonlinear methods of characterizing neurons.

**Prerequisite:** 580.421–422 Physiological Foundations for Biomedical Engineering, or equivalent, 110.302 Differential Equations or 500.303 Applied Mathematics I or equivalent. Recommended: 520.214 Signals and Systems.

Spring (even years) Sachs, Young

**580.630 Theoretical Neuroscience**
Theoretical methods for analyzing information encoding and representing function in neural systems. Models of single and multiple neural spike trains based on stochastic processes and information theory; detection and estimation of behaviorally relevant parameters from spike trains; system theoretic methods for analyzing sensory receptive fields; network models of neural systems. Both theoretical methods and the properties of specific well-studied neural systems will be discussed.

**Prerequisite:** Introduction to Neuroscience (580.422 or equivalent), Probability (550.420 or equivalent), and Signals and Systems (520.214).

Spring Wang, Young

**580.632 Ionic Channels in Excitable Membranes**
Ionic channels are key signaling molecules that support electrical communication throughout the body. As such, these channels are a central focus of biomedical engineering as it relates to neuroscience, computational biology, biophysics, and drug discovery. This course introduces the engineering (stochastic and mathematical models) and molecular strategies (cloning and expression) used to understand the function of ionic channels. The course also surveys key papers that paint the current picture of how channels open (gating) and conduct ions (permeation). Biological implications of these properties are emphasized throughout. Finally, the course introduces how optical (fluorescence methods) and electrophysiological methods (patch clamp) now promise to revolutionize understanding of ionic channels. This course can be viewed as a valuable partner of Models of Physiological Processes in the Neuron (580.439). Advanced homework problems, paper presentations, and exam questions are added to the core curriculum.

**Prerequisite:** 580.421–422 Physiological Foundations for Biomedical Engineering or equivalent introductory biology. Recommended: differential equations, linear algebra, signals, and elementary probability.

Fall (even years) Yue

**580.634 Molecular and Cellular Systems Physiology Laboratory**
Laboratory experience in cell imaging, motility, and excitation; stochastic simulation of ionic channel gating; expression and biophysical characterization of cloned and native ionic channels. Students work on one or two projects from this set, under faculty supervision.

Spring (odd years) Tung, Yue

**580.637 Cellular and Tissue Engineering**
This is an advanced course on the latest research accomplishments on cellular and tissue engineering from three different interdisciplinary perspectives: (a) It summarizes the theoretical/experimental tools to investigate adhesion mechanisms and differentiated functions of cells attached on surfaces. (b) It examines the signal transduction and regulation of metabolic activity in mammalian cells due to physical (mechanical) forces. (c) It highlights the mechanisms of cell motility and morphogenesis of anchored cells, and the mechanical properties of circulating cells.

Fall (even years) Alevriadou, Leong, Kuo, Popel

**580.638 Cell Mechanics and Motility**
Fundamental to their function, cells generate and respond to mechanical forces. For example, whole muscle cells contract, but all cells must move chromosomes during cell division. This class will cover macroscopic mechanics of cells and their cytoskeleton, physical models of force generation, and molecular models derived from recent atomic structures of force-generating proteins. Clinical effects, such as cardiomopathies where these processes are defective, and new molecular measurement technologies will also be discussed. An interdisciplinary approach spanning molecular biology, biochemistry, physics, and engineering will be emphasized.

**Prerequisite:** 580.421 Physiological Foundations for Biomedical Engineering or 020.305-306 Biochemistry and Cell Biology

Spring (odd years) Kuo, Hunter

**580.644 Neural Control of Movement and Vocalization**
Generating a sound with our vocal system or moving our arm are both examples of a goal directed movement. This is a course that compares the neural mechanisms responsible for acquisition of sensory information and generation of motion in these two motor behaviors. We will explore the brain systems that integrate 1) visual and somatosensory information in
order to produce limb movements, and 2) auditory information in order to vocalize a sound. Emphasis is on experimental and theoretical results on the primate brain.

Prerequisite: A previous course in neuroscience.

Fall  Shadmehr, Wang

580.651 Introduction to Nonlinear Dynamics in Physiology

This course is designed for students who may be interested in applying the techniques of nonlinear dynamics and chaos to the analysis of physiological data. Topics covered will include fractals, strange attractors, bifurcations, state-space attractor reconstruction, Poincaré sections, dimension calculations, Lyapunov exponents, entropy, tests for determinism, nonlinear forecasting. Examples will be drawn from studies in cardiology, brainfunction, and the oculomotor system.

Prerequisite: basic knowledge of signals and systems or permission of instructor. Limited enrollment.

Fall (even years) Shelhamer

580.673 Advanced Seminar in Magnetic Resonance Imaging

In this course, students present an idea from the current literature to the class in two two-hour seminars and write a 1,020-page review article on the same topic. At the end of the course the class produces a book comprised of these articles. Recent topics: rf and gradient coil design, flow measurements with MRI and contrast injection, sub-second MRI, methods for designing rf pulse shapes, diffusion measurements with MRI, absolute quantification of metabolites with MRS, cardiac MRI. Future topics: adiabatic pulses in MRI and spectroscopy, motion artifact reduction, reconstruction strategies in reduced k-space MRI, thermal and mechanical requirements for MRI hardware, patient safety, induced currents from rapidly switching gradients, rf heating.

Prerequisites: 580.472-473 Medical Imaging Systems and Magnetic Resonance in Medicine.

Spring (odd years) Sachs, Staff

580.683 High Performance Computing in Biology

This course trains students in the use of high performance computing systems to solve problems in biological modeling. Lecture topics include (a) review of high performance computing in molecular modeling, biological fluid dynamics and transport, and cell network modeling; (b) efficient numerical methods for use on high performance computing systems; and (c) architecture and programming of the symmetric vector processor and the symmetric multiprocessor Silicon Graphics Power Challenge XL systems. Material is presented both in lectures and supervised laboratory sessions, during which students do interactive programming.

Prerequisites: introductory programming, UNIX, differential equations, and linear algebra.

Spring  Winslow, Jafri

580.684 Experimental Foundations for Neural Models

This course familiarizes students with the experimental tools that are used to provide the biological data base for neural models. Projects are designed to teach single unit recording in sensory nerve; characterization of complex receptive fields; cellular or synaptic potential measurement; evoked potential techniques; and psychophysical measurement of sensory or motor function.

Prerequisites: An introductory course on the nervous system and permission of instructor.

Spring  Sachs, Staff

580.702 Neuroengineering

Neuroengineering represents the application of engineering principles to develop systems for neurological research and clinical applications. This involves design of instrumentation for brain monitoring, development of signal processing methods to analyze brain rhythms, contemporary imaging methods ranging from optical/CT/MRI, use of micro and nanotechnologies to probe from neurons and brain, and development and application of neural stimulators, prosthesis, and deep brain stimulations and robotic/image guided therapeutic devices. The course will review and research the state of the art in selected fields and support research and development projects by students in these topics.
Applied Physics

The applied physicist bridges the gap between pure physics and engineering by conducting research on technical applications of natural phenomena. The hallmark of the applied physicist is the ability to conceive solutions by applying fundamental physical principles to complex problems.

The graduate program in applied physics leads to the Master of Science degree and is designed to develop professionals with broad capabilities appropriate for careers in technical research or advanced graduate study. Because of today’s changing technology, the program encompasses a wide range of topics, enabling the graduate to contribute solutions to the variety of physics problems. The faculty of the applied physics program is drawn predominantly from the staff of the Applied Physics Laboratory. Faculty interests and expertise include the following areas of specialization: ocean sciences, optics, solid state physics, and space sciences. In their areas of research, the faculty members collaborate with colleagues from various divisions of the University as well as with scientists and engineers at other national and international laboratories.

Program Committee

Harry K. Charles Jr., Program Chair
Principal Professional Staff
Applied Physics Laboratory

Robert C. Cammarata
Professor, Materials Science and Engineering
Whiting School of Engineering

Richard F. Gasparovic
Principal Professional Staff
Applied Physics Laboratory

David L. Porter
Principal Professional Staff
Applied Physics Laboratory

John C. Sommerer
Principal Professional Staff
Applied Physics Laboratory

Joseph J. Suter
Principal Professional Staff
Applied Physics Laboratory

Michael E. Thomas
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog in the Admissions Requirements section. The applicant’s education also must have included mathematics through vector analysis and ordinary differential equations, general physics, modern physics, intermediate mechanics, and intermediate electricity and magnetism. The intermediate mechanics and intermediate electricity and magnetism requirements may be waived if the applicant has an exceptionally good grade point average and a strong background in mathematics.

Course Requirements

A total of 10 one-term courses must be completed within five years. The core curriculum requires four courses with at least three courses selected from a group of six courses designed to provide a mastery of physical principles (mathematical physics, electromagnetics, quantum mechanics, classical mechanics, statistical mechanics and thermodynamics, and modern physics). The fourth core course can be selected from either the basic physical principal offerings above or from a group of three courses (Principles of Optics, Materials Science, and Physical System Modeling) that provide an introduction to the three primary curriculum concentration areas (Geophysical and Space Sciences, Photonics, and Materials and Condensed Matter. Four of the remaining six courses must be selected from among the applied physics courses listed below, and may follow a particular concentration or contain a variety of applied physics courses. The two remaining courses may be selected from any of the offerings of the Whiting School of Engineering with the approval of the student’s adviser.

Four of the 10 courses required for the degree must be at the 700- or 800-level. With the adviser’s approval, an elective course may be substituted for a required course if the student has previously completed an equivalent graduate level course. Academic standards governing graduate study must be maintained.

Neither a thesis nor knowledge of a foreign language is required in this program.

I. Required Courses

Four one-term courses, with at least three selected from the first six courses below:

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.451 Statistical Mechanics and Thermodynamics
- 615.453 Classical Mechanics
- 615.454 Quantum Mechanics
- 615.465 Modern Physics
- 615.471 Principles of Optics
- 615.480 Materials Science
- 615.491 Physical System Modeling

II. Elective Courses

Six one-term courses, with at least four from Applied Physics:

A. Applied Physics Electives

- Geophysics and Space Science

- 615.444 Space Systems I
- 615.445 Space Systems II
- 615.462 Introduction to Astrophysics
### Applied Physics

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>615.748</td>
<td>Introduction to Relativity</td>
</tr>
<tr>
<td>615.753</td>
<td>Plasma Physics</td>
</tr>
<tr>
<td>615.755</td>
<td>Space Physics</td>
</tr>
<tr>
<td>615.761</td>
<td>Introduction to Oceanography</td>
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<tr>
<td>615.769</td>
<td>Physics of Remote Sensing</td>
</tr>
<tr>
<td>615.772</td>
<td>Cosmology</td>
</tr>
<tr>
<td>615.775</td>
<td>Physics of Climate</td>
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### Photonics

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<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>615.472</td>
<td>Optical Remote Sensing</td>
</tr>
<tr>
<td>615.751</td>
<td>Modern Optics</td>
</tr>
<tr>
<td>615.752</td>
<td>Statistical Optics</td>
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<tr>
<td>615.778</td>
<td>Computer Optical Design</td>
</tr>
<tr>
<td>615.780</td>
<td>Optical Detectors and Applications</td>
</tr>
<tr>
<td>615.781</td>
<td>Quantum Information Processing</td>
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<tr>
<td>615.782</td>
<td>Optics and Matlab</td>
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### Materials and Condensed Matter

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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>615.460</td>
<td>Sensors and Sensor Systems for Homeland Security</td>
</tr>
<tr>
<td>615.746</td>
<td>Nanoelectronics: Physics and Devices</td>
</tr>
<tr>
<td>615.747</td>
<td>Sensors and Sensor Systems</td>
</tr>
<tr>
<td>615.757</td>
<td>Solid State Physics</td>
</tr>
<tr>
<td>615.760</td>
<td>Physics of Semiconductor Devices</td>
</tr>
<tr>
<td>615.768</td>
<td>Superlattices and Heterostructure Devices</td>
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</tbody>
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### Additional

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<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>615.448</td>
<td>Alternate Energy Technology</td>
</tr>
<tr>
<td>615.762</td>
<td>Applied Computational Electromagnetics</td>
</tr>
<tr>
<td>615.765</td>
<td>Chaos and Its Applications</td>
</tr>
<tr>
<td>615.779</td>
<td>Computational Physics</td>
</tr>
<tr>
<td>615.800</td>
<td>Applied Physics Project</td>
</tr>
<tr>
<td>615.802</td>
<td>Directed Studies in Applied Physics</td>
</tr>
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#### B. General Electives

The remaining elective one-term courses may be selected from those listed above and/or from other Master of Science programs described in this catalog, subject to approval by the student’s adviser.

### Photonics Option

Students can elect to concentrate their studies in photonics by completing a combination of courses from the applied physics and electrical and computer engineering curricula. Applied physics students specializing in photonics must complete three required courses:

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.454 Quantum Mechanics

Of the remaining seven courses five or more must be photonics courses selected from both the applied physics and electrical engineering curricula.

### Materials and Condensed Matter Option

Students can elect to concentrate their studies in Materials and Condensed Matter by completing a combination of courses from the Applied Physics, Electrical and Computer Engineering, and the Materials Science and Engineering curricula. Applied Physics students specializing in Materials and Condensed Matter must complete three of the first six required courses listed above, plus 615.480, Materials Science.

Of the remaining six courses, four or more must be Materials and Condensed Matter courses selected from the Applied Physics, Electrical and Computer Engineering, Materials Science and Engineering, and Chemical and Biomolecular Engineering curricula.

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Applied Physics offers eight additional optics courses.

- 615.471 Principles of Optics
- 615.472 Optical Remote Sensing
- 615.751 Modern Optics
- 615.752 Statistical Optics
- 615.778 Computer Optical Design
- 615.780 Optical Detectors and Applications
- 615.781 Quantum Information Processing
- 615.782 Optics and Matlab

**Note:** 615.800 Applied Physics Project and 615.802 Directed Studies in Applied Physics can also be used to allow the student to pursue specialized interests in optics.

### Electrical and Computer Engineering offers the following photonics courses:

- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
- 525.753 Laser Systems and Applications
- 525.756 Optical Propagation, Sensing, and Backgrounds
- 525.772 Fiber-Optic Communication Systems
- 525.792 Electro-Optical Systems
- 525.796 Introduction to High-Speed Electronics and Optoelectronics
- 525.797 Advanced Optics and Photonics Laboratory

**Note:** 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.
Course Descriptions

Courses numbered 600-level and above are open only to those students who have been admitted for graduate study. Some courses may not be offered every year. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

615.441 Mathematical Methods for Physics and Engineering

This course covers a broad spectrum of mathematical techniques essential to the solution of advanced problems in physics and engineering. Topics include ordinary and partial differential equations, contour integration, tabulated integrals, saddle-point methods, linear vector spaces, boundary-value problems, eigenvalue problems, Green's functions, integral transforms, and special functions. Application of these topics to the solution of problems in physics and engineering is stressed.

Prerequisite: Vector analysis and ordinary differential equations (linear algebra and complex variables recommended).

Adelmann

615.442 Electromagnetics

Maxwell's equations are derived and applied to the study of topics including electrostatics, magnetostatics, propagation of electromagnetic waves in vacuum and matter, antennas, wave guides and cavities, microwave networks, electromagnetic waves in plasmas, and electric and magnetic properties of materials.

Prerequisite: Knowledge of vector analysis, partial differential equations, Fourier analysis, and intermediate electromagnetics.

Thompson, Najmi

615.444 Space Systems I

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the fundamental technical background, current state of the art, and example applications. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. (This course may be taken for 700-level credit with additional requirement of a research paper.)

Prerequisite: An undergraduate degree in physics or engineering or the equivalent.

Staff

615.445 Space Systems II

This course examines the fundamentals necessary to design and develop space experiments and space systems. The course presents the technical background, current state of the art, and example applications. Topics include spacecraft thermal control, spacecraft configuration and structural design, space communications, command and telemetry systems, data processing and storage, reliability and quality assurance, and systems integration and testing. (This course may be taken for 700-level credit with the additional requirement of a research paper.)

Prerequisite: An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 or 615.744 Space Systems I.

Staff

615.448 Alternate Energy Technology

Energy availability and its cost are major concerns to every person. Fossil fuels in general and oil in particular, are limited and the world reserves are depleting. The question asked by many is, Are there alternatives to the fossil fuel spiral (dwin-
Graduate Programs

Applied Physics

Prerequisites: An undergraduate degree in engineering, physics, or a related technical discipline.

Fall  

Staff

615.451 Statistical Mechanics and Thermodynamics
After a brief historical review of thermodynamics and statistical mechanics, the basic principles of statistical mechanics are presented. The classical and quantum mechanical partition functions are discussed and are subsequently used to carry out derivations of the basic thermodynamic properties of several different systems. Topics discussed include Planck’s black body radiation derivation and the Einstein-Debye theories of the specific heats of solids. The importance of these topics in the development and confirmation of quantum mechanics is also examined. Other topics discussed include Fermi Dirac and the Bose-Einstein statistics and the cosmic background radiation. The importance of comparisons between theory and data is stressed throughout.

Kundu

615.453 Classical Mechanics
This is an advanced course in classical mechanics that introduces techniques that are applicable to contemporary pure and applied research. The material covered provides a basis for a fundamental understanding of not only quantum and statistical mechanics but also nonlinear mechanical systems. Topics include the Lagrangian and Hamiltonian formulation of classical mechanics, Euler’s rigid body equations of motion, Hamilton-Jacobi theory, and canonical perturbation theory. These methods are applied to force-free motion of a rigid body, oscillations of systems of coupled particles, and central force motion including the Kepler problem and scattering in a Coulomb potential. Applications are emphasized through in-class examples and homework.

Prerequisites: Intermediate mechanics and 615.441 Mathematical Methods for Physics and Engineering.

Pisacane

615.454 Quantum Mechanics
This is a course in advanced modern physics that presents the basic concepts and mathematical formalism of quantum mechanics and introduces applications in atomic, molecular, and solid state physics. Topics include the mathematics of quantum mechanics, one-dimensional problems, central field problems, the interaction of electromagnetic radiation with atomic systems, the harmonic oscillator, angular momentum, and perturbation theory.

Prerequisite: 615.441 Mathematical Methods for Physics and Engineering or the equivalent.

Najmi

615.460 Sensors and Sensor Systems for Homeland Security
This course will present an overview of sensors and methods to protect populations against weapons of mass destruction. Using threat scenarios, the course will review common threat agents, methods of dissemination, and assess their effects on infrastructure. Next, the physics of detectors including fundamental technologies and sampling interfaces will be discussed. Sensor technologies for chemical, biological, nuclear, and radiological detection will be studied in detail. Evaluation methods will be presented for sensor selection based on application specific information including sensor performance, environmental conditions, and operational impact. Additional studies will include methods for combining results from various sensors to increase detection confidence. As part of the course, students will be given a threat scenario, and be required to select a sensor suite, and networking information to design a hypothetical system considering the threat, sensor deployment cost and logistics.

Lesho, Carlson

615.462 Introduction to Astrophysics
The techniques and fundamental theories of modern astrophysics are covered with special emphasis on the sun and stars. Topics include stellar structure, opacity of gases, radiative and convective transfer of energy, spectroscopic technique, and interpretation of stellar spectra. Stellar and solar magnetism and the role of magnetic fields in stellar atmospheres are also discussed.

Prerequisite: 615.442 Electromagnetics or the equivalent and 615.454 Quantum Mechanics.

Najmi

615.465 Modern Physics
This course covers a broad spectrum of topics related to the development of quantum and relativity theories. The understanding of modern physics and its applications is essential to the pursuit of advanced work in materials, optics, and other applied sciences. Topics include the special theory of relativity, particle-like properties of light, wavelike properties of particles, wave mechanics, atomic and nuclear phenomena, elementary particles, statistical physics, solid state, astrophysics and general relativity.

Prerequisite: Undergraduate degree in physics or engineering.

Hawkins

615.471 Principles of Optics
This course teaches the student the fundamental principles of geometrical optics, optical instruments, radiometry, vision, and the measurement of color. It begins with a review of basic Gaussian optics to prepare the student for the more advanced concepts. From Gaussian optics the course leads the students
through the principles of ray-trace analysis to develop a detailed understanding of the properties of an optical system. The causes and techniques for the correction of aberrations are studied. It covers the design principles of optical instruments, telescopes, microscopes, etc. The techniques of light measurement are covered in sessions on radiometry and photometry. The elevation of optical sensors and their performance limits are covered. The limitations imposed by the human eye are discussed, and the description and measurement of color are reviewed.

Prerequisite: Undergraduate degree in physics or engineering.

Charles

615.472 Optical Remote Sensing
Remote sensing can be described as the collection of information about an object without direct physical contact with the object. Optical systems are playing an increasingly more important role in remote sensing. The first part of this course will describe the nature of light, its propagation through media, and the optical systems that are designed to collect or image the light. Consideration will be given to optical system radiometry in both the visible and infrared bands. The second part of the course considers specific systems designed for particular applications, both image-based and signal-based, including FTIR and LIDAR systems. Access to Matlab, Mathematica or MathCAD is required to complete some of the assignments.

Prerequisite: An undergraduate degree in engineering or physics or equivalent with a basic understanding of optics and electromagnetics at the undergraduate level.

Rogala

615.480 Materials Science
This course covers a broad spectrum of materials-related topics designed to prepare the student for advanced study in the materials arena. Topics include atomic structure, atom and ionic behavior, defects, crystal mechanics, strength of materials, material properties, fracture mechanics and fatigue, phase diagrams and phase transformations, alloys, ceramics, polymers and composites.

Prerequisite: Undergraduate degree in physics or engineering.

Charles

615.491 Physical System Modeling
This course provides an introduction to the modeling of physical systems. Each field will be introduced in the context of general principle illustrated by the solution of representative problems. Topics to include fluids (viscous, inviscid, compressible and incompressible), linear and nonlinear elasticity, heat conduction, deformable media, strain, plasticity, electromagnetism, etc.

Prerequisite: 615.441, Mathematical Methods for Physics and Engineering and a basic understanding of physics and mechanics.

Staff

615.744 Space Systems I
This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the fundamental technical background, current state of the art, and example applications. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course requires the completion of a research paper. (This course may be taken for 400-level credit without the requirement of a research paper.)

Prerequisite: An undergraduate degree in physics or engineering or the equivalent.

Staff

615.745 Space Systems II
This course examines the fundamentals necessary to design and develop space experiments and space systems. The course presents the theoretical background, current state of the art, and examples of the disciplines essential to developing space instrumentation and systems. Experts in the field will cover the following topics: spacecraft attitude determination and control, space communications, satellite command and telemetry systems, satellite data processing and storage, and space systems integration and testing. This course requires the completion of a research paper. (This course is also offered for 400-level credit and does not require completion of a research paper.)

Prerequisite: An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 or 615.744 Space Systems I.

Staff

615.746 Nanoelectronics: Physics and Devices
This course provides an introduction to state-of-the-art and potential future electronics technologies. The first part of the course focuses on the physics of advanced silicon technology and on its scaling limits. The treatment includes a discussion of future electronics as projected to the year 2012 by the Semiconductor Industry Association’s National Technology Roadmap for Semiconductors (see http://www.sematech.org). This understanding of conventional technology then motivates the second part of the course which covers some of the “new” physics currently being explored for going “beyond the roadmap.” Topics range from the reasonably practical to the highly speculative and include tunneling transistors, single-flux quantum logic, single-electronics, spin-based electronics, quantum computing and perhaps even DNA-based computing. An overview is also given of the prospects for advances in fabrication technology that will largely determine the economic viability for any of these possible electronic futures.

Prerequisites: 625.454 Quantum Mechanics or equivalent; 615.760 Physics of Semiconductor Devices or equivalent.

Ancona
615.747 Sensors and Sensor Systems
The primary objective of this course is to present recent advances made in the field of sensors. A broad overview includes radiation, biological, magnetic, fiber optic, and acoustic sensors. The course will examine basic sensor operation and the implementation of sensors in measurement systems. Other topics to be covered are physical principles of sensing, interface electronic circuits, and sensor characteristics. The focus will be on practical application and state-of-the-art developments.
Bannerjee

615.748 Introduction to Relativity
(formerly 615.772 Introduction to General Relativity and Cosmology) After a brief review of the Special Theory of Relativity, the mathematical tools of tensor calculus that are necessary for understanding the General Theory of Relativity will be developed. Relativistic perfect fluids and their stress-energy-momentum tensor will be defined and the Einstein's field equations will be studied. Gravitational collapse will be introduced and the Schwarzschild Black Hole solution will be discussed.
Najmi

615.751 Modern Optics
This course covers the fundamental principles of modern optical and contemporary optical systems. Topics include propagation of light, polarization, coherence, interference, diffraction, Fourier optics, absorption, scattering, dispersion, and image quality analysis. Special emphasis is placed on the instrumentation and experimental techniques used in optical studies.
Prerequisite: 615.442 Electromagnetics or the equivalent completed or taken concurrently.
Spring Boone

615.752 Statistical Optics
This is an advanced course in which we explore the field of Statistical Optics. Topics covered include such subjects as the statistical properties of natural (thermal) and laser light, spatial and temporal coherence, effects of partial coherence on optical imaging instruments, effects on imaging due to randomly inhomogeneous media, and a statistical treatment of the detection of light. Development of this more comprehensive model of the behavior of light draws upon the use of tools traditionally available to the applied scientist, such as linear system theory and the theory of stochastic processes.
Prerequisite: 525.414 Probability and Stochastic Processes or equivalent.
Staff

615.753 Plasma Physics
This course serves as an introduction to plasma phenomena relevant to energy generation by controlled thermonuclear fusion and space physics. Topics include motion of charged particles in electric and magnetic fields, dynamics of fully ionized plasma from both microscopic and macroscopic points of view, magnetohydrodynamics, equilibria, waves, instabilities, applications to fusion devices, ionospheric, and space physics.
Prerequisite: 615.442 Electromagnetics or the equivalent. Greenwald

615.755 Space Physics
This course studies the solar-terrestrial space environment and its importance for utilization of space. Topics include the solar cycle and magnetic dynamo, the electrodynamics of the solar upper atmosphere responsible for the solar wind; and the solar wind interaction with unmagnetized and magnetized bodies which leads to the treatment of ionospheres, planetary bow shocks, comets, and magnetospheres. Practical issues include penetrating radiation and its effects on spacecraft and man in space; catastrophic discharge phenomena; dust and hypervelocity impacts; material degradation by sputtering and reactive ionospheric constituents; atmospheric heating and orbital drag effects on satellites; and magnetospheric storm disruptions of ground power distribution.
Prerequisite: 615.442 Electromagnetics or the equivalent. Anderson

615.757 Solid State Physics
Students examine concepts and methods employed in condensed matter physics with applications in materials science, surface physics, and electronic devices. Topics include atomic and electronic structure of crystalline solids and their role in determining the elastic, transport, and magnetic properties of metals, semiconductors, and insulators. The effects of structural and chemical disorder on these properties are also discussed.
Prerequisite: 615.454 Quantum Mechanics or the equivalent. Ancona

615.760 Physics of Semiconductor Devices
This course examines the physical principles underlying semiconductor device operation and the application of these principles to specific devices. Emphasis is placed on understanding device operation, rather than on circuit properties. Topics include elementary excitations in semiconductors such as phonons, photons, conduction electrons and holes; charge and heat transport; carrier trapping and recombination; effects of high doping; contacts; the pn junction; the junction transistor; surface effects; the MIS diode; and the MOSFET.
Prerequisite: 615.454 Quantum Mechanics or the equivalent. Ancona

615.761 Introduction to Oceanography
This course covers the physical concepts and mathematics of the exciting field of oceanography and can be taken as an elective. It is designed for the student who wants to learn more about oceanography. Topics range from fundamental small waves to planetary scale ocean currents. There will be a strong emphasis on understanding the basic ocean processes. Initial development gives a description of how the ocean system works and the basic governing equations. Additional subjects...
include boundary layers, flow around objects (seamounts), waves, tides, Ekman flow, and the Gulf Stream. Also studied will be the ocean processes that impact our climate such as El Nino and the Thermohaline Conveyor Belt.

**Prerequisite:** Mathematics through Calculus.

### 615.762 Applied Computational Electromagnetics

This course introduces the numerical methods and computer tools required for the practical applications of the electromagnetic concepts covered in 615.442 to the daily life engineering problems. It covers the methods of calculating electromagnetic scattering from complex air and sea targets (aircraft, missiles, ships, etc.), taking into account the effects of the intervening atmosphere and natural surfaces such as the sea-surface and terrain. These methods have direct applications in the areas of radar imaging, communications and remote sensing. Methods for modeling and calculating long-distance propagation over terrain and in urban areas, which find application in the areas of radar imaging, radio and TV broadcasting and cellular communications, are also discussed. The numerical toolkit built in this course includes the method of moments, the finite difference frequency and time domain methods, the finite element method, marching numerical methods, iterative methods, and the shooting and bouncing ray method.

**Prerequisite:** Knowledge of vector analysis, partial differential equations, Fourier analysis, basic electromagnetics, and a scientific computer language.

### 615.765 Chaos and Its Applications

This course provides a topical introduction to the basic concepts and active areas of modern nonlinear dynamics, including sensitive dependence on initial conditions, fractals, routes to chaos, experimental techniques, symbolic dynamics, and control of chaos in real systems. The course emphasizes applications to and examples from physics and engineering, including geophysical systems, electronic oscillators, mechanical engineering, and information science. Although some mathematical theory is necessary to develop the material, extensive use of concrete examples helps to develop necessary intuition. Students conduct numerical experiments using provided software, which allows for interactive learning. Access to Whiting School computers is provided for those without appropriate personal computers.

**Prerequisite:** Mathematics through ordinary differential equations. Familiarity with classical mechanics helpful. Consult instructor for more information.

### 615.768 Superlattices and Heterostructure Devices

In this course, students are introduced to the physics and technology of superlattices and heterostructure devices (i.e., semiconductor devices whose chemical composition is varied in order to optimize electronic and/or optical performance—“band-gap engineering”). Among the devices covered in the course are modulation-doped FETs, hetero junction bipolar transistors and various quantum well devices, such as heterostructure light sources and detectors. Topics include energy band diagrams, electronic properties of heterojunctions, intervalley and real-space transfer, electron states in quantum wells, excitons, tunneling and transport theory. Student projects involving the use of commercial device simulation software will allow direct exploration of various devices as well as provide experience with a widely used design tool.

**Prerequisites:** 615.454 Quantum Mechanics or the equivalent. Exposure to material covered in 615.760 Physics of Semiconductor Devices and 615.757 Solid State Physics or their equivalent is desirable but not required. No computer experience is necessary.

### 615.769 Physics of Remote Sensing

This course exposes the student to the physical principles underlying satellite observations of the Earth by optical, infrared, and microwave sensors, and techniques for extracting geophysical information from remote sensor observations. Topics will include spacecraft orbit considerations, fundamental concepts of radiometry, electromagnetic wave interactions with land and ocean surfaces and the Earth’s atmosphere, radiative transfer and atmospheric effects, and overviews of some important satellite sensors and observations. Examples from selected sensors will be used to illustrate the information extraction process, and applications of the data for environmental monitoring, oceanography, meteorology, and climate studies.

### 615.772 Cosmology

This course begins with a brief review of tensor calculus and General Relativity principles, cosmological models, and theoretical and observational parameters that determine the fate of the universe. Basics of quantum fields necessary for an understanding of the Standard model and the early universe will be presented. Hubble expansion, the Cosmic Microwave Background Radiation (CMBR), and recent theories of the presence of anisotropy in the CMBR, and their implications will be studied. The horizon problem and the role of the inflationary scenario in the early universe will be thoroughly explored.

**Prerequisite:** 615.748 Introduction to Relativity.

### 615.773 Coastal Oceanography I

Most of the population of earth lives within 100km of the coasts. The effects of man on that environment are immense. In this course we will study the dynamics, modeling, and predictions of the processes in littoral waters. The coastal water dynamics pose new challenges to the oceanographer than those in the deepwater. In the coastal waters the currents can change on time scales of minutes and over spatial scales of meters. There are huge episodic event such as storm surge, water run off, fresh water plumes, and phytoplankton blooms. In this...
course we will develop the controlling equations and delineate
the multiscale, multidisciplinary nature of coastal processes.
**Prerequisites:** Differential Calculus and Physics.

Porter, Gasparovic, Staff

**615.774 Coastal Oceanography II**
This course is a continuation of Coastal Oceanography I. We will
use the delineated processes from Coastal Oceanography I and investigate how those processes are being monitored.
We will discuss the observation systems ranging from coastal
tide gages to the space observing hyperspectral color sensors
and synthetic aperture radar systems. We will study the use
of models in coastal waters ranging from tracking of airplane
debris, to crab larvae, to sewage effluents. The course will
conclude with a discussion of commerce, fisheries, naval appli-
cations, and management.
**Prerequisites:** Differential Calculus and Physics.
Gasparovic, Porter, Staff

615.775 Physics of Climate
To understand the forces that cause global climate variability we
must understand the natural forces that drive our weather and
our oceans. This course covers the fundamental science under-
lying the nature of the Earth’s atmosphere and its ocean. This
includes development of the basic equations for the atmosphere
and ocean, the global radiation balance, description of oceanic
and atmospheric processes and their interactions and variability.
Also included will be a description of observational systems
used for climate studies and monitoring, and fundamentals
underlying global circulation and climate prediction models.
**Prerequisites:** Undergraduate degree in physics or engineer-
ing or equivalent with strong background in mathematics
through the calculus level.
Winstead and Porter

615.778 Computer Optical Design
In this course students learn to use optical ray-trace analysis
to design and analyze optical systems. Students use a full-
function optical ray-trace program on personal computers to
analyze designs beginning with simple lenses for familiariza-
tion with the software, to more complicated wide-angle and
zoom lenses, and finally to three-dimensional systems such as
spectrographs. Emphasis is placed on understanding the
optical concepts involved in the designs while developing the
ability to use the software. Upon completion of the course
students are capable of independently pursuing their own
optical designs. Assignments require the use of a Pentium
PC running Windows with 16Mb of RAM, and 12Mb of free
hard disk space.
**Prerequisite:** 615.471 Principles of Optics.
Rogala

615.779 Computational Physics
Computer modeling and simulation are becoming increas-
ingly important in applied physics and engineering, with
engineers and researchers typically using preexisting, highly
sophisticated, graphically oriented software to solve their real-
world problems. To succeed in this environment one need not
be able to write such state-of-the-art software, but it is vital
that one be a smart consumer. With this in mind, this course
provides the student with a firm grounding in the funda-
amentals of numerical applied physics/engineering. Through
an interesting mix of principles, practical algorithms, and
hands-on computational experience, the student learns the
basic concepts that underlie the practical simulation soft-
ware used in everything from weather prediction to electronic
device design. Both ordinary and partial differential equations
are discussed, and the topics include convergence, stability,
numerical error, ill-conditioning, gridding, finite-differences,
iterative techniques, and stochastic methods. The text for the
course was written by the instructor and is printed and sold by
the bookstore at cost. This text also exists in an experimental
interactive form (Mathcad) which is not required for the course
but which will be provided for free to interested students.
**Prerequisites:** Familiarity with differential equations is
required and prior exposure to computer programming is
recommended.

Ancona

615.780 Optical Detectors and Applications
This course examines the physics of detection of incoherent
electromagnetic radiation from the infrared to the soft x-ray
regions. Brief descriptions of the fundamental mechanisms of
device operation are given. Typical source characteristics are
mentioned to clarify detection requirements. Descriptions of
non-spatially resolving detectors based on photoemission and
photo-excitation follow, including background physics, noise,
and sensitivity. Practical devices and practical operational con-
straints are described. Description of scanning formats leads
into the description of spatially revolving systems (e.g., star-
ing arrays). Main emphasis is on charge-coupled devices and
photo-emissive multiplier tubes such as the image intensifier.
Selection of optimum detectors and integration into complete
system designs are discussed. Applications in space-based and
terrestrial remote sensing are discussed.
**Prerequisites:** 615.471 Principles of Optics desired; under-
graduate-level studies in solid-state physics and mathematics
—preferably statistics—necessary.
Darlington

615.781 Quantum Information Processing
This course provides an introduction to the rapidly develop-
ing field of quantum information processing. In addition to
studying fundamental concepts such as two-state systems,
measurements uncertainty, quantum entanglement, and non-
locality, emphasis will be placed on specific quantum informa-
tion protocols. Several applications of this technology will be
explored, including: cryptography, teleportation, dense cod-
ing, computing, and error correction. The quantum mechan-
ics of polarized light will be used to provide a physical context
to the discussion and will be supplemented with computer
exercises. Current research on implementations of these ideas will also be discussed.

**Prerequisites:** 615.454 Quantum Mechanics; familiarity with Mathematica helpful.

615.782 **Optics and Matlab**

This course provides hands-on experience with Matlab by performing weekly computer “labs” revolving around optics. Each lab will explore a new topic in the optics field, while simultaneously providing experience in Matlab. The goal is to bridge the gap between theoretical concepts and real-world applications or models. Topics include an Introduction to Matlab, Fourier Theory and E&M Propagation, Image Segmentation and Pattern Recognition, Statistical Optics, Geometrical Optics, Interference and Wave Optics, Holography and Computer Generated Holography, Polarization, Speckle Phenomenon and Laser Theory. Students are expected to complete weekly exercises in Matlab and a semester project which will allow the student to investigate a particular topic of interest not specifically covered in the course.

**Prerequisites:** No prior experience with Matlab is required. While a background in optics is helpful, it is not required.

Jacobs

615.800 **Applied Physics Project**

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to his or her field of interest. The research problem can be addressed experimentally or analytically, and a written report is produced.

**Prerequisites:** It is recommended that all required applied physics courses be completed. The Applied Physics Project Proposal Form (available from the student’s adviser) must be approved prior to registration.

**Note:** Only open to candidates in the Master of Science in Applied Physics program.

Rogala

615.802 **Directed Studies in Applied Physics**

In this course qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members.

**Prerequisite:** The Directed Studies Program Proposal Form (available from the student’s adviser) must be completed and approved prior to registration.

**Note:** Open only to candidates in the Master of Science in Applied Physics program.

Charles
Bioinformatics

Joint Offering of The Zanvyl Krieger School of Arts and Sciences and the Whiting School of Engineering

Bioinformatics is playing an increasingly important role in identifying, characterizing, and selecting potential biological targets for development and production. In addition, as the biotechnology industry expands, a growing number of discoveries will move out of research laboratories and into commercial production. The explosion of sequence data from the human genome project and other large scale and small scale sequencing projects calls for skilled professionals who can develop and use sophisticated computer applications to unlock the information within the genetic code, with the ultimate goal of delivering life saving therapies.

To meet the demand for skilled bioinformatics professionals, the Whiting School of Engineering and Applied Science Programs for Professionals and the Zanvyl Krieger School of Arts and Sciences’ Advanced Academic Programs have joined forces to offer a degree in the new and rapidly evolving discipline that combines computer science and molecular biology. The bioinformatics degree draws on the faculty and resources from within each school to provide professionals with in-depth knowledge and technical skills in computational biology, preparing students for careers in bioinformatics and computational biology.

Graduates with the MS in Bioinformatics will have the educational foundation necessary to interpret complex biological information, perform analysis of sequence data using sophisticated bioinformatics software, and program software when needed. The degree covers not only the theoretical aspects of the field, but also the practical side of Bioinformatics, through contact with Hopkins faculty actively developing these technologies.

Program Committee
The program committee oversees the admissions, policy and operations of the joint MS in Bioinformatics. It consists of:

Victor Corces, Co-chair
Department of Biology, Chair, Biotechnology, Zanvyl Krieger School of Arts and Sciences

Ralph Semmel, Co-chair
Computer Science Program, Whiting School of Engineering, Engineering and Applied Science Programs for Professionals

Edwin Addison, EPP Coordinator
Computer Science Program, Whiting School of Engineering, Engineering and Applied Science Programs for Professionals

Kristina Obom, KSAS Coordinator
Associate Program Chair, Biotechnology, Advanced Academic Programs, Zanvyl Krieger School of Arts and Sciences

Patrick Cummings, Senior Associate Program Chair
Biotechnology, Advanced Academic Programs, Zanvyl Krieger School of Arts and Sciences

Admissions Requirement
Students entering this program must have completed a four-year bachelor’s degree in biological sciences or engineering, or a graduate degree in an appropriate field, with the following prerequisites required for admission to the program: two semesters of undergraduate Organic Chemistry or 410.302 Bio-Organic Chemistry, 410.610 Biochemistry, 605.201 Introduction to Programming Using Java, C++, or C, 605.202 Data Structures and an undergraduate or graduate course in Probability and Statistics. All the prerequisites can be taken in the existing Master of Science in Computer Science or in the Master of Science in Biotechnology program. Applicants must have a GPA of 3.0 on a 4.0 scale in the latter half of their undergraduate or graduate studies. Applicants with less than the required GPA may be admitted as provisional students. Applicants with a degree from a country other than the US must provide credential evaluations and a TOEFL.

Note: This program is offered jointly by the Zanvyl Krieger School of Arts and Sciences (KSAS) and the Whiting School of Engineering. However, the administration is handled by KSAS and applications for admission to the Master of Science in Bioinformatics must be submitted directly to KSAS (http://www.bioinformatics.jhu.edu).

Program Structure
The joint MS degree will require certain prerequisites and a total of 11 courses. The course offerings are listed below.

Prerequisites:
- Two semesters of Organic Chemistry (or 410.302 Bio-Organic Chemistry)
- One semester of Advanced Biochemistry (or 410.601 Advanced Biochemistry)
- Introduction to Programming Using Java, C++ or C (or 605.201 Introduction to Programming Using Java)
- Data Structures (or 605.202 Data Structures)
- One course in Probability and Statistics or (410.645 Biostatistics)
- Calculus

Core Courses—Five Required
410.602 Molecular Biology
410.610 Gene Organization and Expression
605.421 Foundations of Algorithms

Select Either:
410.634 Practical Computer Concepts for Bioinformatics or
605.441 Principles of Database Systems

Select Either:
410.633 Computers in Molecular Biology or
605.452 Biological Databases and Database Tools
Concentration Courses – Choose Four
Students may choose any four of these courses. If a student chooses three courses in one concentration area, the student will also be recognized as having completed a “concentration” in that specific area. Concentrating on one area is not required.

Protein Bioinformatics
410.639 Protein Bioinformatics
410.661 Methods in Proteomics
605.751 Computational Aspects of Molecular Structure
605.759 Independent Project in Bioinformatics

Note: Students may take both 410.639 and 605.751 as the content is sufficiently different.

Genomics and Sequencing
410.635 Bioinformatics: Tools for Genome Analysis
410.640 Phylogenetics and Comparative Genomics
410.666 Genomic Sequencing and Analysis
410.671 Microarrays and Analysis
410.754 Comparative Microbial Genomics: From Sequence to Significance
605.753 Computational Genomics
605.754 Analysis of Gene Expression
605.759 Independent Project in Bioinformatics

Computational Biology
410.640 Phylogenetics and Comparative Genomics
410.698 Bioperl
605.451 Principles of Computational Biology
605.743 The Semantic Web
605.759 Independent Project in Bioinformatics

Systems Biology
410.671 Microarrays and Analysis
605.716 Modeling and Simulation of Complex Systems
605.754 Analysis of Gene Expression
605.755 Systems Biology
605.759 Independent Project in Bioinformatics

Note: Students may take either 410.671 or 605.754, but not both.

Electives—Choose Two
Choose one elective from the approved list of computer science courses and one from the approved list of biotechnology courses.

Approved Biotechnology Elective List
410.603 Advanced Cell Biology I
410.604 Advanced Cell Biology II
410.612 Human Molecular Genetics

410.613 Principles of Immunology
410.615 Microbiology
410.616 Virology
410.622 Molecular Basis of Pharmacology
410.629 Genes and Disease
410.630 Gene Therapy
410.632 Emerging Infectious Diseases
410.638 Cancer Biology
410.641 Clinical and Molecular Diagnostics
410.648 Clinical Trial Design & Statistical Analysis

Approved Computer Science Elective List
605.401 Foundations of Software Engineering
605.481 Distributed Development on the World Wide Web
605.482 User Interface Development with the Java Foundation Classes
605.704 Object-Oriented Analysis and Design
605.706 Software Systems Engineering
605.741 Distributed Database Systems on the World Wide Web
605.742 XML: Technology and Applications
605.746 Machine Learning and Data Mining
605.747 Evolutionary Computation
605.781 Distributed Objects
605.782 Web Application Development with Servlets and JavaServer Pages (JSP)
605.783 Reusable Software Components with JavaBeans

Online Options
Effective Fall 2006, the Master of Science in Bioinformatics is available as a fully online degree. Not all courses are available online, but a complete program is offered. All bioinformatics students may take advantage of the online offerings as it suits their needs.

Courses from Other JHU Schools
There are various courses at Homewood (Electrical Engineering and Biomedical Engineering departments) and at the Johns Hopkins Medical School or Bloomberg School of Public Health, related to bioinformatics, that are also relevant. Upon special request, students may take one or two of these courses as part of their program in consultation with their adviser, provided that the students meet the prerequisites, obtain instructor permission and the adviser approves the course as a suitable substitution for one of the requirements above. The course descriptions and offerings are provided on the web sites of the respective schools.

Tuition
Tuition for the courses in the joint degree vary by course and school of origin and are posted in the course schedule each semester.
Facilities
The program uses facilities on the Homewood and Montgomery County campuses. These campuses contain numerous modern classrooms, teaching support equipment, computer laboratories, lounges and food service, and are supported by appropriate staff. Both locations can accommodate additional courses and students. Courses are sometimes offered at APL. An increasing number of courses are being offered online.

Course Descriptions

410.302 Bio-Organic Chemistry
This course provides a foundation in structural organic chemistry, acid base chemistry, chemical thermodynamics, and reaction mechanisms. Subjects include Lewis structures, atomic and hybridized orbitals, stereochemistry, inter- and intramolecular forces of attraction, nucleophilic reaction mechanisms, functional groups, and the organic chemistry of biological molecules.
Prerequisite: Two semesters of college chemistry.
Note: This course does not count toward requirements for the master’s degree in biotechnology.

410.601 Advanced Biochemistry
This course explores the roles of essential biological molecules including proteins, lipids, and carbohydrates, with an introduction to nucleic acids. It provides a systematic and methodical application of general and organic chemistry principles. Students examine the structure of proteins, their function, the methodologies for the purification and characterization of proteins, and the alteration of protein function through protein engineering. Enzymes and their kinetics and mechanisms are covered in detail. This course provides the linkage between the inanimate world of chemistry and the living world of biology.

410.602 Molecular Biology
This course provides a comprehensive overview of the key concepts in molecular biology. Topics include nucleic acid structure and function, DNA replication, transcription, translation, chromosome structure and remodeling and regulation of gene expression in prokaryotes and eukaryotes. Extended topics include methods in recombinant DNA technology, micro-arrays, and microRNA.
Prerequisite: 410.601 Biochemistry.

410.603 Advanced Cell Biology I
This course covers cell organization and subcellular structure. Students examine the evolution of the cell, chromosome and plasma membrane structures and behaviors, mechanics of cell division, sites of macromolecular synthesis and processing, transport across cell membranes, cell dynamics, organelle biogenesis, and cell specialization. Students also are introduced to the experimental techniques used in cell biology to study cell growth, manipulation, and evaluation.

410.604 Advanced Cell Biology II
This course is a continuation of 410.603 Advanced Cell Biology I and further explores cell organization and subcellular structure. Students examine cell-to-cell signaling that involves hormones and receptors, signal transduction pathways, second messenger molecules, cell adhesion, extracellular matrix, cell cycle, programmed cell death, methylation of DNA and modification of chromatic structure, and mechanisms of the cell. The involvement of abnormalities in signal transduction pathways to oncogenesis and other disease states will be stressed. Where appropriate, current drugs and developing techniques will be examined in the context of relevant pathological states.

410.610 Gene Organization and Expression
Students use genetic analysis and molecular biology techniques to investigate chromosome organization, chromatin structure, function genomics, and mechanisms of differential gene expression. Other topics include DNA methylation, silencers, enhancers, genomic imprinting, and micro-array analyses.

410.612 Human Molecular Genetics
In this course students learn to use the tools of modern genomics to elucidate phenotypic variation within populations. The course uses human disease (from simple Mendelian disorders to common complex disorders) to exemplify the types of studies and tools which can be used to characterize cellular pathophysiology as well as to provide genetic diagnostics and therapies. Students become facile with linkage analysis, cancer genetics, microarray analysis (oligo and cDNA arrays), gene therapy, SNP studies, imprinting, disequilibrium mapping and ethical dilemmas associated with the Human Genome Project.

410.613 Principles of Immunology
This course covers molecular and cellular immunology, including antigen and antibody structure and function, effector mechanisms, complement, major histocompatibility complexes, B- and T-cell receptors, antibody formation and immunity, cytotoxic responses, and regulation of the immune response. Students are also introduced to the applied aspects of immunology which include immunoassay design, various formats and detection methods, and flow cytometry. Special
topics include organ transplantation, immunosuppression, immunotherapy, autoimmunity, and DNA vaccination.

410.615 Microbiology
This course is an overview of microorganisms important in clinical diseases and biotechnology. Students are introduced to the general concepts concerning the morphology, genetics, and reproduction of these microbial agents. Lectures focus on individual organisms with emphasis on infectious diseases, biotechnology applications, molecular and biochemical characteristics, and molecular and serological identification methods. Students will also discuss the impact biotechnology, and particularly genomics, will have on the development of antibiotics and vaccines as treatment and preventive measures.

410.616 Virology
This course covers the advanced study of viruses with regard to the basic, biochemical, molecular, epidemiological, clinical, and biotechnological aspects of animal viruses primarily and bacteriophage, plant viruses, viroids, prions, and unconventional agents secondarily. Specific areas of virology including viral structure and assembly, viral replication, viral recombination and evolution, virus-host interactions, viral transformation, gene therapy, antiviral drugs, and vaccines are presented. The major animal virus families are discussed individually with respect to classification, genomic structure, virion structure, virus cycle, pathogenesis, clinical features, epidemiology, immunity, and control. The viral vectors and their applications in biotechnology are discussed.

410.622 Molecular Basis of Pharmacology
This course begins by reviewing receptor binding and enzyme kinetics. Various cellular receptors and their physiology are discussed as well as the pharmacological agents used to define and affect the receptor’s function. Students study the pharmacology of cell surface receptors and intracellular receptors. Also considered are the drugs that affect enzymes.

410.624 Bioanalytical Chemistry
This course covers the analytical methods used to separate and characterize pharmaceutical compounds derived through biotechnology. While emphasis is placed on the general principles of the methodology, current protocols are discussed, and problem sets representing realistic developmental challenges are assigned. Topics include chromatography (HPLC, SEC, IEC), electrophoresis, W/VIS spectroscopic methods, NMR, ELISA, amino acid analysis, sequencing, and methods to measure activity.

Prerequisites: 410.601-602 Advanced Biochemistry I and II.

410.629 Genes and Disease
Because of recent advances, powerful diagnostic tests now detect genetic diseases, and there is promise of gene replacement therapy. In this course students cover general genetic principles, DNA tools for genetic analysis, cytogenetics, gene mapping, the molecular basis of genetic diseases, animal models, immunogenetics, genetics of development, genetics of cancer, and treatment of genetic diseases. Molecular methods of analysis are emphasized.

410.630 Gene Therapy
Students are introduced to gene transfer, its technical evolution, and its testing through clinical studies. Gene therapy holds promise for both genetic diseases and acquired diseases such as cancer and AIDS. The health, safety, and ethical issues surrounding gene therapy are discussed, together with the review and oversight systems established to regulate this therapy. Students also consider how industry is developing these techniques, both in new start up companies as well as in established biotechnology and pharmaceutical companies. An overview of proprietary and patent issues in gene therapy is part of the course.

410.632 Emerging Infectious Diseases
This course focuses on emerging infectious diseases from many different perspectives. The maladies addressed range from diseases that have reappeared in altered genetic forms such as the influenza virus and the West Nile virus to the lethal hemorrhagic fever caused by the Ebola virus. Also discussed is the threat of recombinant and ancient infectious agents such as Bacillus anthracis, causative agent of anthrax, which can be used in biological warfare weapons. Opinions from noted scientists and leaders concerning emerging diseases and the prospects for battling them successfully provide scientific and social perspective.

410.633 Computers in Molecular Biology
Retrieval and analysis of electronic information are essential in today’s research environment. This course explores the theory and practice of biological database searching and analysis. In particular, students are introduced to integrated systems where a variety of data sources are connected through World Wide Web access. Information retrieval as well as interpretation are discussed and many practical examples in a computer laboratory setting enable students to improve their data mining skills. Methods included in the course are searching the biomedical literature, sequence homology searching and multiple alignment, protein sequence motif analysis, and several genome analytical methods. Classes are held in a computer laboratory. Acquaintance with computers is required.
410.634  Practical Computer Concepts for Bioinformatics
This course introduces students with a background in the life sciences to the basic computing concepts of the UNIX operating system, relational databases, structured programming, object-oriented programming, and the Internet. Included is an introduction to SQL and the Perl scripting language. The course emphasizes relevance to molecular biology and bioinformatics. It is intended for students with no computer programming background, but with a solid knowledge of molecular biology.

410.635  Bioinformatics: Tools for Genome Analysis
Several large-scale DNA sequencing efforts have resulted in mega-base amounts of DNA sequences being deposited in public databases. As such, the sequences are of less use than those sequences that are fully annotated. To assign annotations such as exon boundaries, repeat regions, and other biologically relevant information accurately in the feature tables of these sequences requires a significant amount of human intervention. This course instructs students on computer analytical methods for gene identification, promoter analysis, and introductory gene expression analysis using software methods. Additionally, students are introduced to comparative genomics and proteomic analysis methods. Students will become proficient in annotating large genomic DNA sequences. Students complete two large sequence analysis projects during the course.

410.637  Bioethics
Students in this course analyze and discuss traditional philosophical theories regarding the nature of the moral good. They then apply these theories to critical issues and selected cases involving experiments with human subjects, organ transplantation, in vitro fertilization, the use of animals in research, the collection and publication of research data, peer review, conflicts of interest, and other topics of current concern. (This course can be taken concurrently with the core courses.)

410.638  Cancer Biology
This course provides students with knowledge of the fundamental principles of the molecular and cellular biology of cancer cells. Lectures and demonstrations explain the role of growth factors, oncogenes, tumor suppressor genes, angiogenesis, and signal transduction mechanisms in tumor formation. Discussion of aspects of cancer epidemiology, prevention, and principles of drug action in cancer management is part of the course.

410.639  Protein Bioinformatics
Because the gap between the number of protein sequences and the number of protein crystal structures continues to expand, protein structural predictions are increasingly more important. This course provides a working knowledge of various computer-based tools available for predicting the structure and function of proteins. Topics include protein database searching, protein physicochemical properties, secondary structure prediction and statistical verification. Also covered are graphic visualization of the different types of three-dimensional (3-D) folds and predicting 3-D structures by homology. Computer laboratories complement material presented in lectures.

410.640  Phylogenetics and Comparative Genomics
This course will provide a practical, hands-on introduction to the study of phylogenetics and comparative genomics. Theoretical background on molecular evolution will be provided only as needed to inform the comparative analysis of genomic data. The emphasis of the course will be placed squarely on the understanding and use of a variety of computational tools designed to extract meaningful biological information from molecular sequences. Lectures will provide further information on the conceptual essence of the algorithms that underlie various sequence analysis tools and the rationale behind their use. Only programs that are freely available, as either downloadable executables or as Web servers, will be used in this course. Students will be encouraged to use the programs and approaches introduced in the course to address questions relevant to their own work.

410.641  Clinical and Molecular Diagnostics
This course covers basic concepts and practical applications of modern laboratory diagnostic techniques. Topics include the principles of testing methodology, quality assurance and the application of molecular methods to the clinical and research laboratory. The test methods to be covered include nucleic acid based methods such as hybridization, amplification and sequencing; non-nucleic acid methods such as HPLC, GLC and protein analysis; and technologies such as PFGE, ribotyping, RFLP, and microarrays. In addition to the test procedures, students are exposed to aspects of statistics, quality control, regulatory issues and applications of these methods to the diagnosis and prognosis of human disease.

410.642  Economic Aspects of Biotechnology
This course considers a range of economic issues important in the emerging biotechnology industry. Subjects to be covered include financial planning, raising capital, assessing markets, forming corporate partnerships, licensing agreements, and CRADAs. (This course can be taken concurrently with the core courses.)

410.644  Marketing Aspects of Biotechnology
This course introduces students to the strategic and tactical approaches used in the marketing of biotechnological products and services. Students gain a thorough understanding of the
research and planning necessary to develop a marketing plan, the relationship between the marketing and sales functions, the difference between marketing a scientific product and a scientific service, pricing strategies, distribution alternatives, communications, promotion, and the importance of perception. Knowledge of marketing terminology and techniques will prove helpful to scientists interested in pursuing a career in this aspect of the industry. (This course can be taken concurrently with the core courses.)

410.645 Biostatistics
This course introduces statistical concepts and analytical methods as applied to data encountered in biotechnology and biomedical sciences. It emphasizes the basic concepts of experimental design, quantitative analysis of data, and statistical inferences. Topics include probability theory and distributions; population parameters and their sample estimates; descriptive statistics for central tendency and dispersion; hypothesis testing and confidence intervals for means, variances, and proportions; the chi-square statistic; categorical data analysis; linear correlation and regression model; analysis of variance; and nonparametric methods. The course provides students a foundation to evaluate information critically to support research objectives and product claims and a better understanding of statistical design of experimental trials for biological products/devices.
Prerequisites: Basic mathematics (algebra); scientific calculator

410.648 Clinical Trial Design & Statistical Analysis
Through a case study approach, this course will cover the basic design issues of clinical trials. The design of specific trials will be studied to illustrate the major issues in the design of these studies, such as end point definition, control group selection, and eligibility criteria. The course also covers the analysis of these studies, including approaches that are central to clinical trials, such as stratified analysis, adjustment factors, and “intention-to-treat” analyses. The analytical techniques to be covered will include the analysis of correlated data (i.e., clustered data, longitudinal data), survival analysis using the proportional hazards (Cox) regression model, and linear models. The course will also cover various aspects of statistical computing, including organizing data, data management, and performing analyses using computer software. The ethical reporting of clinical trial results will also be covered with reference to the medical research literature.

410.650 Legal Aspects of Biotechnology
In this course students gain a thorough understanding of the legal steps necessary to protect and market biotechnological inventions and of the procedures required to obtain the necessary permits and licenses from government agencies. Topics include inventorship and ownership issues in academia and industry; what can and should be patented in the United States and in other countries; how patents are granted; how to avoid losing patent rights; how to enforce and defend patents; and how to transfer rights to technology. (This course can be taken concurrently with the core courses.)

410.656 Recombinant DNA Laboratory
This laboratory course introduces students to methods for manipulating and analyzing nucleic acids. Students gain extensive hands-on experience with restriction mapping, ligations, bacterial transformations, eukaryotic gene-replacements, gel electrophoresis, non-isotopic hybridizations, as well as application of the polymerase chain reaction. This course is not recommended for students with substantial experience in these methodologies.
Prerequisites: 410.601-602 Advanced Biochemistry I and II.
Please be aware that lab coat and safety glasses are required even for the first class.

410.657 Recombinant Protein Expression, Production, and Analysis
This laboratory course introduces students to the construction, production, processing, and analysis of recombinant proteins from prokaryotic and eukaryotic sources. Concepts include the design, construction, and delivery of recombinant expression clones, expression of recombinant genes in host cells, propagation of recombinant clones using fermentors and bioreactors, protein purification, and protein analysis. Laboratory exercises use current techniques and approaches for the cloning, expression, production, purification, and analysis of recombinant proteins in bacteria, yeast, insect cells, and mammalian cells.
Prerequisites: 410.601-602 Advanced Biochemistry I and II; 410.656 Recombinant DNA Laboratory or laboratory experience.
Please note that students are required to have a lab coat and safety glasses even for the first meeting of the class.

410.658 Synthesis and Purification of Biochemical Products
This laboratory course familiarizes students with procedures necessary to synthesize biological molecules from bacteria and eukaryotic cells in response to heterologous plasmids. Using bacteria as model systems, students construct expression vectors, express heterologous proteins, purify these proteins, and evaluate the processes.
Prerequisites: 410.601-602 Advanced Biochemistry I and II.
Please note that lab coat and safety glasses must be worn even for the first class.

410.661 Methods in Proteomics
This course covers the analytical methods used to separate and characterize pharmaceutical compounds (predominately proteins) derived through biotechnology. While emphasis is
placed on the general principles and applicability of the methods, current protocols are discussed, and problem sets representing realistic developmental challenges are assigned. Topics include chromatography (HPLC, SEC, IEC), electrophoretic techniques (2-D gelelectrophoresis), spectroscopic methods (UV/Vis, Fluorescence, CD), analytical ultra-centrifugation, micro-arrays, mass spectroscopy, amino acid analysis, sequencing, and methods to measure protein-protein interactions.

**410.666 Genomic Sequencing and Analysis**
The completion of the human genome sequence is just the latest achievement in genome sequencing. Armed with the complete genome sequence, scientists need to identify the genes encoded within, to assign functions to the genes, and to put these into functional and metabolic pathways. This course will provide an overview of the laboratory and computational techniques beginning with genome sequencing and annotation, extending into bioinformatics analysis and comparative genomics and including functional genomics.

**410.671 Microarrays and Analysis**
This course will focus on the analysis and visualization of microarray data. The general aim is to introduce students to the various techniques and issues involved with analyzing multivariate expression data. Additionally, students will visualize the results in modern statistical scripting software. Topics include detecting and attributing sources of data variability, determining differentially expressed genes with relevant statistical tests and controlling for false positive discovery (multiple test corrections, permutations, etc.). An introduction to linear and non-linear dimension reduction methods (PCA, PLS, Isometric feature mapping, etc.) and an introduction to common pattern recognition (clustering), classification, and discrimination techniques will be included. Assignments and concepts will make use of publicly available Affymetrix and cDNA microarray data sets. Examples will mostly be demonstrated in S-plus and R (publicly available) code, with some in SAS. Free demo software tools such as Minitab, Spotfire, TreeView, Expression Profiler, and web UIs will also be utilized.

**410.698 Bioperl**
This course builds on the Perl concepts taught in 410.634 Practical Computer Concepts for Bioinformatics. Perl has emerged as the language of choice for the manipulation of bioinformatics data. Bioperl, a set of object-oriented modules that implements common bioinformatics tasks, has been developed to aid biologists in sequence analysis. The course will include an overview of the principal features of Bioperl and give students extensive opportunity to use Perl and the tools of Bioperl to solve problems in molecular biology sequence analysis.

**410.754 Comparative Microbial Genomics: From Sequence to Significance**
Hundreds of Bacterial and Archaeal genomes have been completely sequenced and thousands more will follow in near future. In this course we will learn how to make sense of this vast sea of information in order to understand the diversity of microbial life on earth: transforming DNA data into knowledge about the metabolism, biological niche and lifestyle of these organisms. The use and development of bioinformatic platforms for the sensible comparison of genetic function and context are essential for work in modern microbiology. Topics covered will include methods for sequencing, gene finding, functional prediction, metabolic pathway and biological system reconstruction, phylogenomics, ontologies, and high-throughput functional genomics. Particular attention will be paid to publicly available bioinformatics resources and their proper use. Examples will be drawn from microbes of importance to human health, industry, ecology, agriculture and biodefense. Lectures and discussions are integrated with computer exercises where appropriate.

**Prerequisites:** 410.601 Biochemistry; 410.602 Molecular Biology; 410.633 Computers in Molecular Biology.

**605.201 Introduction to Programming Using Java**
This course enables students without a background in software development to become proficient programmers who are prepared for a follow-on course in data structures. The Java language will be used to introduce foundations of structured, procedural, and object-oriented programming. Topics include I/O, data types, operators, operands, expressions, conditional statements, iteration, recursion, arrays, functions, parameter passing, and returning values. Students will also be introduced to classes, objects, object references, inheritance, polymorphism, and exception handling. Additional topics include file I/O, searching, sorting, Java Collections, and an introduction to Applets. Students will complete several programming assignments to develop their problem-solving skills and to gain experience in detecting and correcting software errors.

**Prerequisites:** One year of college mathematics.

**Note:** This course DOES NOT count toward the Master of Science in Bioinformatics degree.

Summer, Fall, Spring  Chittargi, Ferguson, Shyamsunder, Smith

**605.202 Data Structures**
This course investigates abstract data types (ADTs), recursion, algorithms for searching and sorting, and basic algorithm analysis. ADTs to be covered include lists, stacks, queues, priority queues, trees, sets, and dictionaries. The emphasis is on the trade-offs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

**Prerequisite:** One year of college mathematics; 605.201 Introduction to Programming using Java or equivalent.
Note: This course DOES NOT count toward the Master of Science in Bioinformatics degree.

Summer, Fall, Spring  Chlan, Resch, Tjaden

605.401  Foundations of Software Engineering
Fundamental software engineering techniques and methodologies commonly used during software development are studied. Topics include various life cycle models, project planning and estimation, requirements analysis, program design, construction, testing, maintenance and implementation, software measurement, and software quality. Emphasized are structured and object-oriented analysis and design techniques, use of process and data models, modular principles of software design, and a systematic approach to testing and debugging. The importance of problem specification, programming style, periodic reviews, documentation, thorough testing, and ease of maintenance are covered.

Summer, Fall, Spring  Chavis, Gieszl, Kalb, Scheppelle, Yufik

605.421  Foundations of Algorithms
This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), recursion and mathematical induction, algorithm analysis and computational complexity (recurrence relations, big-O notation, NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming, amortized analysis), and graph algorithms (depth-first and breadth-first search, connectivity, minimum spanning trees, network flow). Advanced topics are selected from among the following: randomized algorithms, information retrieval, string and pattern matching, and computational geometry.

Prerequisite: 605.202 Data Structures or equivalent

Summer, Fall, Spring  Boon, Chlan, Lew, Sadlowsky, Sheppard

605.441  Principles of Database Systems
This course examines the underlying concepts and theory of database management systems. Topics include database system architectures, data models, query languages, conceptual and logical database design, physical organization, and transaction management. The entity-relationship model and relational model are investigated in detail, object-oriented databases are introduced, and legacy systems based on the network and hierarchical models are briefly described. Mappings from the conceptual level to the logical level, data dependencies, and normalization are studied as a basis for formal design. Theoretical languages such as the relational algebra and the relational calculus are described, and high-level languages such as SQL and QBE are discussed. An overview of file organization and access methods is provided as a basis for discussion of heuristic query optimization techniques. Finally, transaction processing techniques are presented with a specific emphasis on concurrency control and database recovery.

Summer, Fall, Spring  Immer, Kung, Liu, Semmel

605.451  Principles of Computational Biology
This course is an interdisciplinary introduction to computational methods used to solve important problems in DNA and protein sequence analysis. The course focuses on algorithms but includes material to provide the necessary biological background for science and engineering students. Algorithms to be covered include dynamic programming for sequence alignment, such as Smith-Waterman, FASTA, and BLAST; hidden Markov models, such as the forward, Viterbi, and expectation maximization algorithms; and a range of gene-finding algorithms; phylogenetic tree construction; and clustering algorithms.

Prerequisites: Familiarity with probability and statistics; working knowledge of Java, C++, or C; a course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Fall  Przytycka

605.452  Biological Databases and Database Tools
The sequencing of the human genome and the emerging intense interest in proteomics and molecular structure have caused an enormous explosion in the need for biological databases. The first half of this course surveys a wide range of biological databases and their access tools and seeks to develop proficiency in their use. These include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISSPROT, and their analysis tools. Tools for accessing and manipulating sequence databases will be covered, such as BLAST, multiple alignment, Perl, and gene finding tools. Advanced, specialized and recent popular databases such as KEGG, BioCyc, HapMap, Allen Brain Atlas, Afcs, etc. will be surveyed for their design and use. The second half of this course focuses on the design of biological databases including the computational methods to create the underlying data, as well as the special requirements of biological databases such as: interoperability, complex data structures consisting of very long strings, object orientation, efficient interaction with computational operators, parallel and distributed storage, secure transactions and fast recall. Students will create their own small database as a project for the course as well as complete homework assignments using databases.

Prerequisites: 605.441 Principles of Database Systems or 410.634, or working knowledge of SQL and a prior course in molecular biology or cell biology (605.205 or 410.602).

Notes: Students who do not have a prior background in databases can succeed in this course by concurrent self study of relational databases and SQL using a book such as Database Solutions: A Step by Step Guide to Building Databases by Thomas Hobbs

Summer, Fall (online)
605.482 User Interface Development with the Java Foundation Classes
This course focuses on developing graphical user interfaces using the latest Java “Swing” tool kit. Topics include asynchronous event handling, “peerless” graphical objects, the 2-D drawing model windows (frames, panels, dialog boxes, etc.), GUI controls (such as buttons, menus, stylized text editors, fonts, and tables), layout managers to make page layout more flexible, Model-View-Controller architecture, printing services, and development of custom components. Advanced topics may include multi-threading issues and drag-and-drop support.

Prerequisite: Significant Java programming experience.
Summer, Fall, Spring Evans

605.704 Object-Oriented Analysis and Design
This course describes fundamental principles of object-oriented modeling, requirements development, analysis, and design. Topics include specification of software requirements; object-oriented analysis approaches, including dynamic and static modeling with the Unified Modeling Language (UML v2); object-oriented design; object-oriented reuse, including design patterns; and software implementation concerns. Optional topics include the Systems Modeling Language (SysML), Object-Oriented Systems Engineering Methodology (OOSEM), managing object-oriented projects, and the Object Constraint Language (OCL).

Prerequisite: Experience in object-oriented programming using a language such as Java or C++.
Summer, Fall, Spring Demasco, Ferguson, Pierson, Schappelle, Schepers

605.706 Software Systems Engineering
(formerly The Software Development Process)
Software Systems Engineering applies engineering principles and the system view to the software development process. The course focuses on the engineering of complex systems that have a strong software component. This course is based on the philosophy that the key to engineering a good software system lies just as much in the process that is followed as in the purely technical regime. The course will show how good a software development process is and how to make a software process better by studying successful techniques that have been employed to produce correct software systems within budget. Topics are explored in a sequence designed to reflect the way one would choose to implement process improvements. These topics include steps to initiate process change, methods to establish control over the software process, ways to specify the development process, methods for quantitative process control, and how to focus on problem prevention. Students will prepare term projects.

Prerequisite: One software engineering course beyond 605.401, Foundations of Software Engineering.
Fall, Spring Siegel and Donaldson, White

605.716 Modeling and Simulation of Complex Systems
(formerly 605.752 Simulation of Biological and Complex Systems)
This course focuses on the application of modeling and simulation principles to complex systems. A complex system is a large-scale nonlinear system consisting of interconnected or interwoven parts (such as a biological cell, the economy, or an ecological system). The course begins with an overview of complex systems, followed by modeling and simulation techniques based on nonlinear differential equations, networks, stochastic models, cellular automata, and swarm-like systems. Existing software systems will be used to illustrate systems and provide practical experience. During the semester, each student will complete a modeling project of a complex system. While this course is intended for computer science or engineering students interested in modeling any complex system, it may also be taken by Bioinformatics students interested in modeling complex biological systems. Students interested in bioinformatics will study a parallel track exposing them to existing whole cell modeling tools such as E-Cell, COPASI, and BioSpice.

Prerequisites: Knowledge of elementary probability and statistics and previous exposure to differential equations. Students applying this course to the MS in Bioinformatics should also have completed at least one Bioinformatics class prior to enrollment.

Note: This course may be counted toward a three-course concentration in Bioinformatics.
Fall (online) Addison

605.741 Distributed Database Systems on the World Wide Web
This course investigates principles of distributed database systems, including design and architecture, query processing, transaction management, locking, recovery, and RAID technology. The course also covers JDBC programming through a variety of interfaces including stand-alone Java programs, Java applets on web browsers, and Common Gateway Interface
605.743 The Semantic Web
The Semantic Web is an activity by the WWW Consortium to create a large set of XML-based languages, along with information on how various tags relate to real-world objects and concepts. This course covers Semantic Web technologies, including RDF (Resource Description Format—a structure for describing and interchanging metadata on the web) and OWL (Web Ontology Language), with domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies will be discussed. Students will complete a Semantic Web project in an application area of interest to them. Examples will be drawn from several application areas throughout the course, including the life sciences, knowledge management, electronic commerce and web services choreography. Domain-specific implementation strategies such as LSID (Life Sciences Identifier) and various vertical ontologies will be addressed.
Prerequisite: 605.742 XML: Technology and Applications or equivalent.
Summer, Fall (online) Addison

605.746 Machine Learning and Data Mining
How can machines improve with experience? How can they discover new knowledge from a variety of data sources? What computational issues must be addressed to succeed? These are questions that are addressed in this course. Topics range from determining appropriate data representation and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing performance. Specific approaches covered include statistical techniques (e.g., k-nearest neighbor and Bayesian learning), logical techniques (e.g., decision tree and rule induction), function approximation (e.g., neural networks and kernel methods), and reinforcement learning. The topics are discussed in the context of current machine learning and data mining research. Students will participate in seminar discussions and will complete and present the results of an individual project.
Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.
Fall (odd years) Sheppard

605.747 Evolutionary Computation
Recently, principles from the biological sciences have motivated the study of alternative computational models and approaches to problem solving. This course explores how principles from theories of evolution and natural selection can be used to construct machines that exhibit nontrivial behavior. In particular, the course covers techniques from genetic algorithms, genetic programming, and artificial life for developing software agents capable of solving problems as individuals and as members of a larger community of agents. Specific topics addressed include representation and schemata; selection, reproduction, and recombination; theoretical models of evolutionary computation; optimal allocation of trials (i.e., bandit problems); search, optimization, and machine learning; evolution of programs; population dynamics; and emergent behavior. Students will participate in seminar discussions and will complete and present the results of an individual project.
Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.
Fall (even years) Sheppard

605.751 Computational Aspects of Molecular Structure
This course focuses on computational methods for studying protein and RNA structure, protein-protein interactions and biological networks. Algorithms for prediction of RNA secondary structure, protein-protein interactions, annotation of protein secondary/tertiary structure and function are studied in depth. Students will apply various computer programs and structure-visualization software to secondary and tertiary protein structure prediction, structure-structure comparison, protein domain classification, annotation of functionally important sites and protein design. Interesting aspects of protein interaction and metabolic networks are also discussed.
Prerequisites: A course in molecular biology and a course in cell biology or biochemistry are highly recommended.
Spring Przytycka and Panchenko

605.753 Computational Genomics
This course focuses on current problems of computational genomics. Students will use bioinformatics software and learn the principles underlying a variety of bioinformatics algorithms. In addition, students will explore and discuss bioinformatics research, and develop software tools to solve bioinformatics problems. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes; finding genes in genomes and identifying their biological functions; predicting regulatory sites; assessing gene and genome evolution; and analyzing gene expression data.
Prerequisites: 605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.
Spring (online) Ermolaeva

605.754 Analysis of Gene Expression
The rapid popularization of microarray technology has led to an explosion in the collection of gene expression data. After a brief survey of existing gene expression software tools, this course emphasizes the development of original algorithms and data mining techniques for analyzing gene expression.
data. This course covers statistical and analytical methods and software development for the analysis of gene expression data. Topics include (1) a brief survey of existing software for microarray analysis (normalization, differential expression, and clustering); 2) algorithms, database design and data mining techniques for gene expression data; and 3) detailed coverage of analysis and reverse engineering of gene regulatory networks, including relevance networks, Boolean networks and continuous networks. Both static data and time series data will be considered. The student will develop sufficient expertise in both the underlying analysis and statistical theory to develop new algorithms and software to analyze gene expression data. Students will complete several software assignments including the design of a new algorithm for gene expression analysis.

**Prerequisites:** 605.205 or a course in molecular biology or cell biology, and a course in probability and statistics. Working knowledge of C or JAVA. JHU Online Orientation Course.

**Notes:** There are no exams, but programming assignments are intensive. Students in the MS Bioinformatics program may take both this course and 410.671 Microarrays and Analysis as the content is largely mutually exclusive.

**Spring (online)**

### 605.755 Systems Biology

During the last decade, systems biology has emerged as an effective tool for investigation of complex biological problems, placing emphasis on the analysis of large-scale datasets and quantitative treatment of experimental results. In this course students will explore recent advances in systems biology analysis of intracellular processes. Examples of modeling and experimental studies of metabolic, genetic, signal transduction and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite, or protein) driven approaches. Students will learn to use Boolean, differential equations, and stochastic methods of analysis and will become acquainted with several powerful experimental techniques, including basics of microfabrication and micro-fluidics. As a course project, students will develop a model of a signal transduction or metabolism pathway.

**Prerequisites:** Courses in molecular biology (605.205 or 410.602) and differential equations.

**Spring (even years)**

### 605.759 Independent Project in Bioinformatics

This course is for students who would like to carry out a significant project in bioinformatics as part of their graduate program. The course may be used to conduct minor research, an in-depth literature survey, or a software implementation related to recent developments in the field. Students who enroll in this course are encouraged to attend at least one industry conference in bioinformatics related to their area of study. To enroll in this course, the student must be within two courses of degree completion and must obtain the approval and support of a sponsoring faculty member.

**Staff**

### 605.781 Distributed objects

This course provides an introduction to the development of client/server and peer-to-peer applications using distributed technology. The course focuses on the services and facilities provided by object-oriented middleware systems such as CORBA, COM, and Java/RMI. Topics include interface definition languages (IDL), static and dynamic invocation interfaces, object references, distributed resource optimization, and concurrency control. Students will develop software in C++ for both homework and a project.

**Prerequisite:** 605.404 Object Oriented Programming with C++ or equivalent experience.

**Fall, Spring**

### 605.782 Web Application Development with Servlets and JavaServer Pages (JSP)

This project-oriented course investigates techniques for building server-side programs for dynamically-generated Web sites, electronic commerce, Web-enabled enterprise computing, and other applications that require WWW access to server-based resources. Particular attention will be paid to methods for making server-side applications efficient, maintainable, and flexible. Topics include handling HTTP request information, generating HTTP response data, processing cookies, tracking sessions, designing custom JSP tag libraries, and separating content from presentation through use of JavaBeans components and the MVC (Model 2) architecture.

**Prerequisite:** 605.481 or equivalent Java experience.

**Summer, Fall, Spring**

### 605.783 Reusable Software Components with JavaBeans

This course covers the architecture, design, and development of software components that can be instantiated, customized, and interconnected. The main topics include component architectures, design patterns, internal mechanisms of the Java Beans API, the bean development kit (BDK), bean properties, event handling, introspection, customization, the bean deployment mechanism, and persistence. In addition, advanced Java beans capabilities, distributed components, security issues, and printing will be discussed. A comparison of Java beans to other component-based technologies will be presented. This course demonstrates a variety of frameworks and applications built based on Java beans.

**Prerequisite:** 605.481 Distributed Development on the WWW or equivalent.

**Fall, Spring**
Chemical and Biomolecular Engineering

In the past decade, the scope of chemical and biomolecular engineering has expanded dramatically. While chemical engineers continue to work in the chemical and petroleum industries, they are just as likely to be employed in biotechnology or pharmaceutical companies, at electronics manufacturing facilities, or in the environmental divisions of corporations or government institutions. In each of these industries, the chemical engineering concepts of transport phenomena, reaction kinetics, and thermodynamics are fundamental to technical issues addressed by engineers.

To recognize the growing need for chemical and biomolecular engineers to acquire a broad range of skills in the basic sciences and related engineering fields, in addition to advanced training in core chemical and biomolecular engineering competencies, Johns Hopkins has developed a flexible Master of Chemical and Biomolecular Engineering program with concentrations in three defined areas: Biochemical Engineering, Environmentally Conscious Processing, and Polymer Engineering. Hopkins will also continue to offer the traditional Master of Chemical Engineering degree in which the student develops a core program in chemical and biomolecular engineering augmented with elective courses from related engineering fields, the basic sciences, and mathematics. This degree encompasses a professional, non-thesis curriculum for practicing engineers.

Program Committee
Denis Wirtz, Program Chair
Associate Professor of Chemical and Biomolecular Engineering
Michael J. Betenbaugh
Professor of Chemical and Biomolecular Engineering

Admissions Requirements
Applicants must be in the last semester of their undergraduate study or hold a bachelor’s degree in chemical engineering from an accredited college or university. They must have earned a grade point average of at least 3.0 on a 4.0 scale in upper-level undergraduate courses or hold a graduate degree in a technical discipline. Applicants with a bachelor’s degree in a related science or engineering field may be considered if they have taken a sufficient number of undergraduate chemical and biomolecular engineering courses. (See additional admission requirements for non-chemical engineering majors below.) All admission decisions are made by the program committee on a case-by-case basis.

Program Requirements
Students will complete a prospective program plan and submit it to the program chair for approval upon entering the program. The students who choose to pursue a Master of Chemical and Biomolecular Engineering with concentration in one of the three defined areas must select courses that do not overlap significantly in technical content with those courses that are part of the core curriculum. Faculty advisers will assist students in making this determination. As one of the program electives, students may complete a faculty-supervised Independent Project, involving indepth study or critical review of a chemical engineering subject area. Candidates must complete the required course work within five years of admission.

Core Courses
For all degree options in the part-time program in chemical and biomolecular engineering, students are required to take five core courses, including:

- 540.621-622 Advanced Chemical Engineering Thermodynamics I
- 540.651 Advanced Transport Phenomena
- 545.642 Advanced Chemical Kinetics and Reactor Design

And an Advanced Mathematics Course (selected from the following):

- 535.441 Mathematical Methods for Engineers
- 615.441 Mathematical Methods for Physics and Engineering
- 625.403 Statistical Methods and Data Analysis
- 625.411 Computational Methods

Another advanced mathematics course can be substituted with permission of program chair.

Additional Required Course
- One graduate level course in Chemical Engineering (selected from Group I offering)

Requirements for Master of Chemical and Biomolecular Engineering
To earn the Master of Chemical and Biomolecular Engineering degree, a student must complete at least 10 one-term courses approved by the student’s adviser. These include the five core courses listed above plus five additional courses (for which prerequisites have been met)—three to five selected from the Whiting School’s Engineering Programs for Professionals (EPP) and no more than two courses selected from the Krieger School of Arts and Sciences Advanced Academic Program in Biotechnology (courses listed under Group III).
Requirements for Master of C.B.E. with a Concentration in Biochemical Engineering

Within the past two decades, remarkable advances have taken place in the life sciences. Chemical and biomolecular engineers will be essential for putting many of these basic science discoveries into practical use. To accomplish these goals, chemical engineers must understand biology and communicate with the life scientists. As a result, we have developed a program which provides chemical engineering students with complementary exposure to the life sciences and biomedical engineering. To earn the Master of Chemical Engineering/Biochemical Engineering a student must complete the five core courses listed above plus two to three from the following biochemical engineering electives:

- 540.426 Introduction to Biomacromolecules
- 540.431 Biochemical Engineering/Biotechnology
- 540.433 Engineering Aspects of Drug Delivery
- 540.437 Application of Molecular Evolution to Biotechnology
- 585.608 Biomaterials

Additional Information
And two to three courses selected from Group III offerings of the Krieger School of Arts and Sciences Master of Science in Biotechnology program and/or Group II offerings of the Whiting School Master of Science in Applied Biomedical Engineering program.

Requirements for Master of C.B.E. with a Concentration in Environment Conscious Processing

Many chemical engineers employed in traditional areas of the profession are required to meet stringent environmental design criteria in addition to technical and economic criteria when designing new processes. Moreover, chemical engineers entering the job market today frequently find employment as environmental specialists, pollution prevention experts within chemical or petroleum companies, and environmental policy consultants within government agencies or engineering design firms. To earn the Master of Chemical Engineering/Environmentally Conscious Processing, the students must complete the five core courses, plus five electives:

- 545.447 System Safety and Risk Management

Four elective courses selected from offerings in the Whiting School of Engineering Environmental Engineering and Science program (Group IV).

Requirements for Master of C.B.E. with a Concentration in Polymer Engineering

The growth and diversity of polymer science and engineering has provided a wealth of opportunities for chemical engineers to develop new materials by manipulating chemical architecture or macromolecular morphology. Chemical engineers working in the polymer industry require a unique set of skills in the fundamentals of chemical engineering science and polymer science. To earn the Master of Chemical Engineer-

/ing/Polymer Engineering, students must complete the five core courses, plus five additional requirements, which must include:

- 540.426 Introduction to Biomacromolecules
- 540.427 Introduction to Polymer Science

In addition, three elective courses selected from other courses offered by Whiting School of Engineering’s Engineering Programs for Professionals or the Krieger School of Arts and Sciences Advanced Academic Programs in Biotechnology (courses listed under Group III, below).

Program Courses

Group I: Whiting School Chemical and Biomolecular Engineering Elective Courses

- 540.426 Introduction to Biomacromolecules
- 540.427 Introduction to Polymer Science
- 540.430 Protein Solution Thermodynamics
- 540.431 Biochemical Engineering/Biotechnology
- 540.433 Engineering Aspects of Drug Delivery
- 540.435 Genome Engineering
- 540.437 Application of Molecular Evolution to Biotechnology
- 540.438 Interfacial Phenomena in Nanotechnology
- 540.440 Micro and Nanotechnology
- 540.441 Topics in Cellular Engineering
- 540.473 Interfacial Phenomena
- 540.621-622 Advanced Chemical Engineering Thermodynamics I
- 540.623 Phase Equilibria
- 540.624 Applied Statistical Thermodynamics
- 540.651 Advanced Transport Phenomena
- 545.447 System Safety and Risk Management
- 545.449 Statistical Design of Experiments
- 545.451 Introduction to Colloids and Surface Science
- 545.642 Advanced Chemical Kinetics and Reactor Design

Group II: Whiting School Applied Biomedical Engineering Courses

- 580.625-626 Structure and Function of the Auditory and Vestibular Systems
- 580.632 Ionic Channels in Excitable Membranes
- 585.405-406 Physiology for Applied Biomedical Engineering
- 585.407 Molecular Biology
- 585.408 Medical Sensors and Devices
- 585.605 Medical Imaging
- 585.606 Medical Image Processing
- 585.608 Biomaterials
- 585.609 Cell Mechanics
- 585.610 Biochemical Sensors
- 585.618 Biological Fluid and Solid Mechanics
Group III: Krieger School Biotechnology Core
Courses and Elective Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>410.601</td>
<td>Advanced Biochemistry</td>
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<tr>
<td>410.602</td>
<td>Molecular Biology</td>
</tr>
<tr>
<td>410.603</td>
<td>Advanced Cell Biology I</td>
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<tr>
<td>410.624</td>
<td>Bioanalytical Chemistry</td>
</tr>
<tr>
<td>410.637</td>
<td>Bioethics</td>
</tr>
<tr>
<td>410.642</td>
<td>Economic Aspects of Biotechnology</td>
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<tr>
<td>410.644</td>
<td>Marketing Aspects of Biotechnology</td>
</tr>
<tr>
<td>410.645</td>
<td>Biostatistics</td>
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<tr>
<td>410.650</td>
<td>Legal Aspects of Biotechnology</td>
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<tr>
<td>410.656</td>
<td>Recombinant DNA Laboratory</td>
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<td>410.657</td>
<td>Recombinant Protein Expression,</td>
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<td>Production, and Analysis</td>
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Group IV: Whiting School Environmental Engineering and Science Courses

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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>575.423</td>
<td>Industrial Processes and Pollution</td>
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<td>Prevention</td>
</tr>
<tr>
<td>575.426</td>
<td>Hydrogeology</td>
</tr>
<tr>
<td>575.435</td>
<td>Environmental Law for Engineers and</td>
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<td></td>
<td>Scientists</td>
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<tr>
<td>575.443</td>
<td>Aquatic Chemistry</td>
</tr>
<tr>
<td>575.445</td>
<td>Environmental Microbiology</td>
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<tr>
<td>575.703</td>
<td>Environmental Biotechnology</td>
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<tr>
<td>575.706</td>
<td>Biological Processes for Water and</td>
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<td>Wastewater Treatment</td>
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<tr>
<td>575.714</td>
<td>Water Resources Management</td>
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<td>575.715</td>
<td>Subsurface Fate and Contaminant</td>
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<td>Transport</td>
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<tr>
<td>575.728</td>
<td>Sediment Transport and River Mechanics</td>
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</table>

Group V: Whiting School Non-Chemical Engineering Majors Prerequisite Courses

In some cases, undergraduate courses from other engineering or science disciplines may be substituted for these chemical engineering courses when there is significant overlap in course material. For those applicants who can demonstrate significant undergraduate preparation in a particular area, the related undergraduate course requirement may be waived. Permission to substitute other undergraduate courses or waive course requirements will be at the discretion of the program chair.

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>540.204</td>
<td>Applied Physical Chemistry</td>
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<tr>
<td>540.301</td>
<td>Kinetic Processes</td>
</tr>
<tr>
<td>540.303</td>
<td>Transport Phenomena I</td>
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<tr>
<td>540.304</td>
<td>Transport Phenomena II</td>
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Course Descriptions

540.202  Introduction to Chemical Engineering Process Analysis
Introduction to chemical engineering and the fundamental principles of chemical process analysis. Formulation and solution of material and energy balances on chemical processes. Reductionist approaches to the solution of complex, multiunit processes will be emphasized. Introduction to the basic concepts of thermodynamics and chemical reactions.

Prerequisites: 030.101 Introductory Chemistry, 171.101 General Physics for Physical Science Majors I

Staff

540.203  Engineering Thermodynamics
Formulation and solution of material, energy, and entropy balances with an emphasis on open systems. A systematic problem-solving approach is developed for chemical process-related systems. This approach consists of decoupling the process into its components, establishing relationships between the known and unknown variables, assembling the information needed to solve for the unknown variables, and then obtaining a physically meaningful solution. Extensive use is made of classical thermodynamic relationships and constitutive equations. Applications include the analysis and design of engines, refrigerators, heat pumps, compressors, and turbines.

Prerequisites: 030.101 Introductory Chemistry, 171.101 General Physics for Physical Science Majors I and either 540.202 or permission of instructor. Corequisite: 110.202 Calculus III (Calculus of Several Variables).

Staff

540.204  Applied Physical Chemistry
Introduction of the methods used to solve phase and chemical equilibria problems. The basic thermodynamic relationships to describe phase equilibrium of single-component and multicomponent systems are developed. Thermodynamic models for calculating fugacity are presented. These include equations of state, liquid solution models, and fugacity estimation methods. Multicomponent phase equilibrium problems addressed are cover liquid-vapor, liquid-liquid, liquid-liquid-vapor, and solid-vapor. Basic thermodynamic relationships to describe
chemical equilibria are also developed and the thermodynamic models for calculating fugacity are applied to their solution. 

**540.301 Kinetic Processes**

*Prerequisites:* 540.203 Engineering Thermodynamics and 540.303 Transport Phenomena I, and either 540.202 or permission of instructor.

**540.303 Transport Phenomena I**
Introduction to the field of transport phenomena. Molecular mechanisms of momentum transport (viscous flow), energy transport (heat conduction), and mass transport (diffusion). Isothermal equations of change (continuity, motion, and energy). The development of the Navier Stokes equation. The development of nonisothermal and multicomponent quations of change for heat and mass transfer. Exact solutions to steady state, isothermal unidirectional flow problems, to steady state heat and mass transfer problems. The analogies between heat, mass, and momentum transfer are emphasized throughout the course.

*Prerequisite:* a grade of C or better in Calculus I, II, and III and 540.202 or permission of instructor. *Corequisite:* 500.303 Applied Mathematics I

**540.304 Transport Phenomena II**

*Prerequisite:* 540.303 Transport Phenomena I, and either 540.202 or permission of instructor.

**540.306 Chemical and Biological Separations**
Principles of staged and continuous-contacting separation processes. Examples include adsorption, distillation, extraction, adsorption, and process synthesis.

*Prerequisites:* 540.202 Introduction to Chemical Engineering Process Analysis and 540.303 Transport Phenomena I

**540.311 Chemical Engineering Laboratory**
Students learn to characterize equipment whose operation is not well defined by identifying the important operating variables, deciding how best to obtain them, and using measured or calculated values of these operating variables to predict and improve performance. Each student analyzes four of the following experiments: distillation, gas absorption, liquid-liquid extraction, chemical kinetics in a tubular flow reactor, and fermentation. In addition to technical objectives, this course stresses oral and written communication skills and the ability to work effectively in groups.

*Prerequisites:* 540.301 Chemical Kinetics, 540.304 Transport Phenomena II, 540.306 Mass Transfer and either 540.202 or permission of instructor, and 540.490 Chemical and Laboratory Safety.

**540.314 Chemical Engineering Process Design**
Introduction to design methods for multiunit processes. Flowsheet development through reaction and separation-path synthesis; degree of freedom analysis for large systems. Equipment design and specification; estimation of capital costs, operating costs, and cash flow. Other topics include optimization techniques and energy integration. Simulation packages, such as ChemCAD, are introduced. Written reports and oral presentations are required on assigned design projects.

*Prerequisites:* 540.301, 540.304, 540.306, and either 540.202 or permission of instructor.

**540.426 Introduction to Biomacromolecules**
This course introduces modern concepts of polymer physics to describe the conformation and dynamics of biological macromolecules such as filamentous proteins and nucleic acids. We will introduce scattering techniques, micromanipulation techniques, as well as rheology, applied to the study of polymers.

*Staff*

**540.427 Introduction to Polymer Science**
Topics include bonding in polymers, polymer morphology, molecular weight characterization, polymer solubility and solutions, transitions in polymers, condensation and freeradical polymerization, copolymerization, rubber elasticity, viscoelasticity, polymer processing.

*Prerequisite:* Junior standing in engineering or the physical sciences.

**540.430 Protein Solution Thermodynamics**
Much of our current understanding of protein interactions has been from observations of bulk thermodynamic behavior, such as solubility, osmotic pressure, and adsorption.
recently, however, intermolecular forces have been measured directly for proteins using techniques such as surface force apparatus, atomic force microscopy, and osmotic pressure. The course will examine the relationship between forces in protein solutions and the macroscopic thermodynamic properties of protein solutions.

**540.431 Biochemical Engineering/Biotechnology**

Application of engineering principles in biochemistry and microbiology. Topics include a brief review of microbiology, fermentation kinetics, microbial growth models, recombinant DNA technology, cell line development, mass and energy balances, metabolic processes, transport phenomena in biotechnology systems, and recent advances in biotechnology.

Betenbaugh

**540.433 Engineering Aspects of Drug Delivery**

This course addresses the fundamental engineering behind the development and understanding of controlled drug delivery systems. Focus is placed on the encapsulation and delivery of therapeutic proteins and genes from polymeric devices due to their increasing prevalence and importance in pharmaceutical products. Routes of drug delivery to be covered include oral, transdermal, pulmonary, injection, and surgical implantation. Other topics to be covered include drug pharmacokinetics, protein, stability in polymers, and polymer encapsulation of cells for bioartificial organs.

*Prerequisite:* Junior standing or higher in engineering. Helpful background: polymer course (e.g., 540.427 or 580.440), transport phenomena (540.303), biochemistry, cell biology. This course is cross-listed with 540.633.

Hanes

**540.435 Genome Engineering**

The interpretation of cellular functions at the genetic level and the application of this knowledge for technological innovation. Topics include bioinformatics, combinatorial biochemistry, genome shuffling, metabolic engineering, and bioremediation.

Betenbaugh, Ostermeier

**540.437 Application of Molecular Evolution to Biotechnology**

One of the most promising strategies for successfully designing complex biomolecular functions is to exploit nature’s principles of evolution. This course provides an overview of the basics of molecular evolution as well as its experimental application to the engineering of proteins, DNA and RNA with functions of therapeutic, scientific, or economic value. The course will cover the generation of diversity (e.g., mutagenesis and DNA shuffling), the coupling of genotype and phenotype (e.g., surface display of proteins and peptides), and methods for screening and selection.

*Prerequisite:* Junior standing and a basic understanding of recombinant DNA technology.

Ostermeier

**540.438 Interfacial Phenomena in Nanotechnology**

Nanotechnology is a new field that is still being defined, with concepts ranging from nanorobotics to nanomaterials. Whatever the outcome, engineering at the nanoscale will be dominated by surface science, as surface to volume ratios become large. Furthermore, self-assembly techniques, with which molecules can spontaneously assemble in ordered structures with nanometer length scales are ripe for exploitation to create new materials. In this class, the fundamentals of interfacial thermodynamics, interfacial interactions (e.g., van der Waals interactions, electrostatics, steric interactions), adsorption, self assembly and specific interactions will be covered with an emphasis on how to exploit these ideas in application in nanotechnology.

Stebe

**540.439 Polymer Nanocomposites**

Polymers are ever increasing in importance in our world today and are found in everything from the clothes we wear and the foods we eat, to the vehicles we drive in and the materials used to build our houses. Polymers have come a long way from the discovery of nylon in the 1930s/1940s. Important factors in the continuous improvements in polymers is the ability to control polymer structure on the nanoscale size domain and modify polymers that have structure on the nanoscale level. In this course, we will review basic polymer science and engineering principles (including polymer chemistry and polymer physics) before engaging in a better understanding of what is meant by polymer nanotechnology, how these domains are structured on such a small scale what analytical methods are typically used to measure/detect these small structures, and how to modify materials on the nanoscale in order to modify polymer properties.

*Prerequisites:* 030.101, 030.104, 171.101, 171.102, 030.204.

**540.440 Micro and Nanotechnology**

Micro/Nanotechnology is the field of fabrication, characterization and manipulation of extremely small objects (dimensions on the micron to nanometer length scale). Microscale objects, because of their small size, are expected to be at the frontier of technological innovation for the next decade. This course will include a description of the materials used in microtechnology, methods employed to fabricate nanoscale objects, techniques involved in characterizing and exploiting the properties of small structures, and examples of how this technology is revolutionizing the areas of electronics and medicine. This course is cross-listed with 540.640.

Gracias

**540.441 Topics in Cellular Engineering**

540.441/641 Cellular Engineering Lectures will provide an overview of molecular biology fundamentals, an extensive review on extracellular matrix and basics of receptors, followed by topics on cell-cell and cell-matrix interactions at both the theoretical and experimental levels. Subsequent lectures will cover the effects of physical (e.g. shear, stress, strain), chemical
540.473 Interfacial Phenomena
Course provides an overview of colloid and surface science. Topics include surface and interfacial tension and surface energies (definitions and methods of measurement), interactions at solid/liquid interfaces, thermodynamics of fluid interfaces, hydrodynamics of interfacial systems, including Marangoni flows, and applications of colloid and surface science in the chemical industry.

Katz, Konstantopoulos, Yarema

540.621-622 Advanced Chemical Engineering Thermodynamics I
A comprehensive examination of the fundamental laws, principles, and concepts of classical statistical thermodynamics. Detailed discussion of various topics such as the properties of pure fluids, the thermodynamics of flow processed, chemical reaction equilibria, and equations of state, solutions, and phase behavior.

Donohue, Katz, McHugh, Paulaitis

540.623 Phase Equilibria
Equilibrium properties of pure and mixed fluids. Modern methods of applying classical and statistical thermodynamics to calculation of phase behavior of fluid mixtures. Molecular thermodynamics of multicomponent systems with applications to separation operations.

Stebe

540.624 Applied Statistical Thermodynamics
A review of introductory course concepts (i.e., the canonical ensemble, other ensembles, the ideal monatomic gas, ideal diatomic and polyatomic gases), imperfect gases, corresponding states, distribution functions, perturbation theories, nucleation.

Prerequisite: six weeks or more of introductory level statistical mechanics or statistical thermodynamics.

Katz

540.627 Microscopic and Macroscopic Analyses of Polymer Solution
The goal of this course is to develop a supramolecular to macromolecular to submacromolecular length scale description of the molecular thermodynamic principles that govern polymer solution behavior. Contemporary equations of state and simulation methodologies for modeling polymer solution behavior will be described with emphasis on the strengths and weaknesses of these approaches. An in-depth analysis of scattering techniques will be developed to yield insight into the interactions that occur in the solution at submacromolecular length scales.

Katz

540.633 Engineering Aspects of Drug Delivery
This course addresses the fundamental engineering behind the development and understanding of controlled drug delivery systems. Focus is placed on the encapsulation and delivery of therapeutic proteins and genes from polymeric devices due to their increasing prevalence and importance in pharmaceutical products. Routes of drug delivery to be covered include oral, transdermal, pulmonary, injection, and surgical implantation. Other topics to be covered include drug pharmacokinetics, protein, stability in polymers, and polymer encapsulation of cells for bioartificial organs.

Prerequisite: Junior standing or higher in engineering. Helpful background: polymer course (e.g., 540.427 or 580.440), transport phenomena (540.303), biochemistry, cell biology.

This course is cross-listed with 540.433.

Hanes

540.640 Micro and Nanotechnology
Micro/Nanotechnology is the field of fabrication, characterization and manipulation of extremely small objects (dimensions on the micron to nanometer length scale). Microscale objects, because of their small size, are expected to be at the frontier of technological innovation for the next decade. This course will include a description of the materials used in microtechnology, methods employed to fabricate nanoscale objects, techniques involved in characterizing and exploiting the properties of small structures, and examples of how this technology is revolutionizing the areas of electronics and medicine.

This course is cross-listed with 540.440.

Gracias

540.642 Advanced Chemical Kinetics and Reactor Design
Complex reaction networks; Wei-Prater analysis; the Himmelblau-Jones-Bischoff method. Detailed coverage of Hougen-Watson models for heterogeneous catalytic reaction kinetics; model discrimination and parameter estimation. Other topics include coupled heterogeneous reaction and transport, generalized moduli catalyst deactivation models, batch reactors, CSTRs, and PFRs; fixed bed reactors including stability criteria, and multibed optimization; residence time distributions and non-ideal reactor models; fluidized bed and multiphase reactors.

Prerequisite: Linear algebra.

540.651 Advanced Transport Phenomena
This course is a one semester survey of convection and convective transport. The convection equations of mass, linear momentum, angular momentum, and energy are derived for single component systems. Exact solutions to the Navier-Stokes equations are derived. The behavior of fluid particles in the creeping flow limit is studied in detail. Inertial effects in these systems are then discussed. Scaling arguments for non-dimensionalizing governing equations and asymptotic methods are introduced. The lubrication and boundary layer
equations are derived. Weak convective effects in heat and mass transfer are discussed.

545.447 System Safety and Risk Management
Methods, mathematics, and management approaches for evaluating the safety of complex technical systems are presented. Examples of risk assessments pertaining to the design, operation, siting, transportation, and emergency planning of both chemical and nuclear materials are studied. Topics include probability and reliability concepts; failure data analysis; FMEA (Failure Modes and Effects Analysis); fault-tree and event-tree techniques; human factors and human error models; multi-objective risk assessment, optimization, and display of information; safety goals; ethics; perceptual risk; reliability assurance and maintenance; cost-benefit and analysis for safety improvements; accident mitigation; and research priority setting. Also, radiological and toxicological aspects of consequence, and modeling for estimating environmental and public health impacts are reviewed.

545.449 Statistical Design of Experiments
This course introduces the basic concepts which underlie modern statistically designed experimental programs. These programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models which accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems and should be a part of every practicing engineer's repertoire. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional factorial designs; screening design; response surface and optimization methods; and application to plant operations.

545.451 Introduction to Colloids and Surface Science
The course provides an overview of colloid and surface science. Topics include surface and interfacial tension and surface energies (definitions and methods of measurement), interactions at solid-liquid interfaces, thermodynamics of fluid interfaces, phenomenology of colloidal systems (classification, preparation, and morphology), sedimentation and diffusion of fine particles in dispersed systems, and rheology of colloidal systems.

545.475 Spectroscopic and Analytical Methods
This is an advanced course in characterization of macromolecules using optical, thermal and mass spectrometric techniques. Microscopy and surface analysis methods will also be explored. The use of each method will be discussed in terms of the design, construction and operation of the instrumentation. This will be followed by application of the method to problems in macromolecular characterization.

545.642 Advanced Chemical Kinetics and Reactor Design
Complex reaction networks; Wei-Prater analysis; the Himmelblau-Jones-Bischoff method. Detailed coverage of Hougen-Watson models for heterogeneous catalytic reaction kinetics; model discrimination and parameter estimation. Other topics include coupled heterogeneous reaction and transport, generalized moduli catalyst deactivation models, batch reactors, CSTRs, and PFRs; fixed bed reactors including stability criteria, and multibed optimization; residence time distributions and non-ideal reactor models; fluidized bed and multiphase reactors.
Civil Engineering

The civil engineering profession is dedicated to developing and applying scientific and technological knowledge to serve the needs of our society. Buildings, power plants, roadways, bridges, water supply systems, wastewater systems and ocean and estuarine structures are all part of the infrastructure of society that comes under the purview of the civil engineering discipline. Increasingly, civil engineers are also involved in the development of less traditional structures and systems, such as mechanical prostheses and space vehicles. In addition, the scope of expertise of the modern civil engineer must include a concern for environment, social and economic issues.

Graduate courses in the focus areas of structural engineering, geotechnical engineering, and ocean engineering are offered in the Master of Civil Engineering Program. Additional courses are available in the areas of mechanics, probabilistic methods, mathematics, environmental engineering and other associated areas of technology.

Students may choose to specialize in one of the three focus areas (sample selections of courses in these areas are listed below) or in the general civil engineering area by selecting courses from any of the three focus areas and other approved courses listed in this catalog. With prior approval of the program chair, students may add breadth to their program by selecting three of their electives from other offerings of the Whiting School of Engineering.

The Department of Civil Engineering maintains fully equipped laboratories for structures and structural dynamics, soil mechanics, fluid mechanics and water-wave mechanics with supporting computational facilities. These laboratories are available for both demonstrations and independent study.

Program Committee

A. Rajah Anandarajah, Program Chair
Professor, Civil Engineering
Whiting School of Engineering

Robert A. Dalrymple
Professor, Civil Engineering
Whiting School of Engineering

Patrick J. Hudson
Senior Professional Staff,
National Security Technology Department
Applied Physics Laboratory

Benjamin Schafer
Assistant Professor, Civil Engineering
Whiting School of Engineering

Admission Requirements

Applicants must meet the general requirements for admission to graduate study outlined in this catalog. Each applicant must have a degree in civil engineering or an appropriate related field, which provides the necessary preparation for graduate-level courses. All admissions decisions are made by the Program Committee on an individual basis.

Course Requirements

The Master of Civil Engineering program emphasizes four focus areas: Structural Engineering, Geotechnical Engineering, Ocean Engineering and General Civil Engineering. Students may add breadth to their program by selecting three of their elective courses from other offerings of the Whiting School of Engineering.

Ten one-term courses, approved by the faculty adviser, must be completed within a period of five years. At least seven of the courses must be in civil engineering; however, appropriate courses from related or supporting fields are allowed with prior approval of the program chair. Up to two of the 10 required courses may be taken in research. Courses in the program must be at the 400-level or above. Unless prior approval is obtained from the program chair, at least five of the courses in the program must be 600-level or above.

Please refer to the Course Schedule published each term for exact dates, times, locations, fees and instructors. Courses numbered 600-level and above are open only to those students who are admitted to graduate study and to undergraduates who have satisfactorily completed appropriate prerequisites.

Core, Concentrations and Electives

The 10-course MCE Program consists of two parts: (1) the core of the program, consisting of two civil engineering courses and one course in applied mathematics, and (2) electives, consisting of seven courses. Sample selections of courses in the four concentrations are presented below. Additional civil engineering courses are listed in this catalog. While some of these course are offered in late afternoons and evening, the remaining courses are offered during the day. Most 600- and 700-level courses are offered on a two-year cycle.

Required Core

560.475 Advanced Soil Mechanics
560.729 Structural Mechanics

One of the following:

535.441 Mathematical Methods for Engineers or
615.441 Mathematical Methods for Physics and Engineering

Electives

Sample Structural Engineering Electives

560.730 Finite Element Methods
560.752 Structural Dynamics
565.430 Structural Design with Timber, Masonry, and Other Materials
565.492 Bridge Inspection Techniques
565.605 Advanced Reinforced Concrete Design
565.620 Advanced Steel Design
565.630 Prestressed Concrete Design
Sample Geotechnical Engineering Electives

560.742 Soil Dynamics
560.745 Retaining Structures and Slope Stability
560.770 Fundamentals of Soil Behavior
565.625 Advanced Foundation Design
565.635 Ground Improvement Methods
565.645 Marine Geotechnical Engineering

Sample Ocean Engineering Electives

560.780 Coastal Engineering
560.781 Introduction to Water Wave Mechanics
560.782 Advanced Ocean Hydrodynamics
565.625 Advanced Foundation Design
565.635 Ground Improvement Methods
565.645 Marine Geotechnical Engineering
565.650 Port and Harbor Engineering
565.655 Hydromechanics of Floating Structures—Platforms and Ships
565.660 Computer Methods for Design of Offshore Structures

General Civil Engineering Electives

Any seven courses, including at least four civil engineering courses listed in this catalog.

Course Descriptions

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors. Courses numbered 600-level and above are open only to those students who are admitted to graduate study and to undergraduates who have satisfactorily completed appropriate prerequisites.

560.435 Probability and Statistics in Civil Engineering
Development and applications of the analysis of uncertainty, including basic probability, statistics and decision theory, in civil engineering areas of soil mechanics, structures, transportation and water resources.

Prerequisite: 110.109.
Igusa

560.475 Advanced Soil Mechanics
Difference between soils and other materials, stresses in soils due to structural foundations, elastic, consolidation and secondary consolidation settlements of footings, shear strength and stress-strain behavior of clays and sands, approximate nonlinear elastic, Mohr-Coulomb, Ramberg-Osgood, and Hyperbolic stress-strain models for soils, nonlinear Winkler foundation analysis of piles, pile groups, and drilled shafts due to vertical and horizontal loads, foundation spring constraints for superstructure analysis.

Prerequisite: 560.305
Anandarajah

560.729 Structural Mechanics
Basic solid mechanics for structural engineers. Stress, strain, and constitutive laws. Linear elasticity and visco-elasticity. Introduction to nonlinear mechanics. Static, dynamic, and thermal stresses. Specialization of theory to one- and two-dimensional cases: plane stress and plane strain, rods, and beams. Work and energy principles; and variational formulations.

Staff

560.730 Finite Element Methods
The basic concepts of the FEM are presented for one-, two-, and three-dimensional boundary value problems (BVPs). Problems from heat conduction and solid mechanics are addressed. The key topics include relationships between strong, weak, and variational statements of BVPs, weighted residual methods with an emphasis on the Galerkin method, specialization of Galerkin approximations of weak statements and Ritz approximations of variational statements to obtain finite element formulations, specific element formulations, convergence properties, solutions of linear systems of equations, and time-dependent problems.

Staff

560.731 Theoretical Methods in Computational Mechanics
Basic mathematical tools required for research in computational mechanics. Emphasis is on numerical linear algebra and approximation theory. Specific topics include properties of linear models and procedures for their analysis, variational principles, numerical eigen-value problem, projections in finite dimensional spaces, least-squares problem, and iterative algorithms. Applications emphasize finite elements, dynamic systems, and signal analysis.

Prerequisite: Advanced calculus.
Staff

560.732 Numerical Methods in Geomechanics

Prerequisite: Background in finite element analysis or permission of instructor.
Anandarajah
560.735 Finite Element Methods in Solid Mechanics
The concepts of the finite element method (FEM) are extended to various classes of problems in solid mechanics including linear and nonlinear elastostatics, linear and nonlinear elastodynamics, linear structural dynamics, and problems with history-dependent materials. Topics include weak statements, analysis of convergence properties, solution of nonlinear systems of equations, and temporal integration methods. Both direct integration (implicit and explicit) and mode superposition are considered for linear dynamic problems, the former of which is extended to nonlinear problems.
*Prerequisite:* 560.730, 560.455 or equivalent. *Corequisite:* 560.731 or equivalent. *Staff*

560.736 Uncertain Systems: Prediction and Decision Analysis
Computational techniques for solving problems in stochastic mechanics: perturbation and averaging techniques, discrete representation of stochastic processes, Hilbert space techniques for stochastic operators, topics in the stochastic finite element method, signal analysis, simulation techniques.
*Prerequisite:* 560.730, 560.731, or equivalent. *Staff*

560.742 Soil Dynamics
Study of soil behavior under dynamic loading conditions: wave propagation and attenuation, field and laboratory techniques for determining dynamic soil properties and cyclic strength, cyclic stress strain behavior of soils, liquefaction and evaluation of liquefaction susceptibility, nondestructive evaluation of foundation systems, foundation design for vibratory loadings.
*Prerequisite:* 560.305 or equivalent. *Staff*

560.745 Retaining Structures and Slope Stability
*Prerequisite:* 560.305 or equivalent. *Staff*

560.752 Structural Dynamics
*Prerequisite:* Permission of instructor required. *Corequisite:* 560.445 Advanced Structural Analysis or 560.455 Structural Mechanics. *Igusa*

560.753 Advanced Structures Laboratory
Advanced-level laboratory course demonstrating experimental techniques in structural engineering, modal analysis, and earthquake and wind engineering. Topics include computer-aided analysis; digital data acquisition; forced, ambient, and random testing methods; wind tunnel testing; system identification.
*Prerequisites:* 560.455 and 560.752. *Schafer*

560.756 Earthquake Engineering
*Corequisite:* 560.752. *Staff*

560.757 Random Fields
Stochastic field theory, as applied to 1-, 2-, and n-dimensional random processes. Descriptors of homogeneous and non-homogeneous random fields. Study of load average processes. Review of various other topics in random field theory and applications. *Graham-Brady*

560.758 Random Vibration
*Prerequisite:* 560.752 or equivalent. *Igusa*

560.760 Structural Stability
*Prerequisite:* 560.445, 560.455, or equivalent. *Schafer*

560.765 Plates and Shells
Behavior and analysis of thin-walled structures. Tensor analysis and differential geometry. Thick, layered, and composite structures. Bending of circular and rectangular plates. Analytical methods for computing membrane and bending stresses and deformations of shells of revolution, with applications to domes and pressure vessels. Introduction to nonlinear and buckling behavior.
*Prerequisite:* Solid or structural mechanics. *Schafer*
560.770 Fundamentals of Soil Behavior

Prerequisite: 560.305.

Anandarajah

560.780 Coastal Engineering
Coastal processes and their influence on engineering at the shoreline. Waves and currents, equilibrium beach profiles, littoral transport, shoreline modeling, and the behavior of tidal inlets. Additionally the impact of structures on the coastline are discussed.

Dalrymple

560.781 Introduction to Water Wave Mechanics
The theories governing water waves are discussed. Linear wave will be explored in detail. Aspects of nonlinear waves will be presented.

Prerequisite: 535.119 Fluid Mechanics or equivalent.

Dalrymple

560.782 Advanced Ocean Hydrodynamics
Fundamentals of fluid mechanics in the context of naval architecture and ocean/science engineering. Emphasis on topics selected from potential flow, added mass, model testing, lifting surfaces, and others.

Prerequisite: 535.119 Fluid Mechanics or equivalent.

Shen

565.430 Structural Design with Timber, Masonry, and Other Materials
This course offers a review of the current requirements and techniques for the design of modern structures using materials such as engineered brick and concrete masonry, timber, aluminum, and plastics. Relevant design specifications and criteria are included.

Prerequisite: 560.301 Theory of Structures. In addition, one previous design course is preferred.

Staff

565.492 Bridge Inspection Techniques
This course will introduce and develop methods for the condition assessment of bridges and other civil structures. Theory and application of acoustic and electromagnetic techniques for the non-destructive evaluation of concrete, steel and wood. Topics will include wave propagation in isotropic solids, ferromagnetism and physical properties of civil materials. Sensors and instrumentation for health monitoring of civil structures will be introduced.

Washer

565.605 Advanced Reinforced Concrete Design
This intensive course covers reinforced concrete materials and specifications and includes the following topics: conception, analysis, and design of continuous beams and frames; building; bridges and shells; elements theory, with emphasis on the ultimate strength method; precast and prestressed concrete; and special topics.

Prerequisite: 565.126 Structural Design II or 560.325 Concrete Structures.

Taavoni

565.620 Advanced Steel Design
This course examines advanced designs of structural steel building, including consideration of hot-rolled and cold-formed steel shapes and overall concepts of the structural system.

Prerequisite: 565.125 Structural Design I or 560.320 Steel Structures.

Malushte

565.625 Advanced Foundation Design
This course covers performance requirements and review of soil mechanics; laboratory testing, subsurface investigation and in situ testing; bearing capacity and settlements of shallow foundations; design of spread footings and mat foundations; axial capacity of deep foundations; settlements of deep foundations; lateral capacity of deep foundations; weak, compressible, and expansible soils; earth pressure theories; cantilever and sheet-pile retaining structures.

Prerequisite: 565.475 Advanced Soil Mechanics.

565.630 Prestressed Concrete Design
Topics include prestressed concrete materials, prestressing systems, and loss of prestress; analysis and design of section for flexure, shear, torsion, and compression; consideration of partial prestress, composite sections, and slabs.

Prerequisite: 565.126 Structural Design II or 560.325 Concrete Structures.

Staff

565.635 Ground Improvement Methods
The course addresses the selection cost, design, construction, and monitoring of ground improvement methods for problematic soils and rock. Ground improvement methods covered include wick drains, micropiles, lightweight fill materials, soil nailing, mechanically stabilized slopes and walls, grouting, stone columns, dynamic compaction, and soil mixing.

Prerequisite: 560.330 Foundation Design and 560.475.

DiMaggio

565.645 Marine Geotechnical Engineering
This course introduces students to soil mechanics in the marine environment. Topics covered include the nature of marine sediments, soil behavior due to cyclic loading, marine geotechnical investigations, shallow foundations and dead-
weight anchors, pile foundations and anchors, penetration and breakout of objects on the seafloor, marine slope stability, soft ground improvement, marine dredging, and project planning.

Prerequisite: 565.121 Soil Mechanics or 560.305 Soil Mechanics.

Hudson

565.650 Port and Harbor Engineering
Planning and engineering of ports and harbors has received renewed worldwide interest as the newest super-large cargo ships push the envelope for channel depth and berth space. This course covers planning of marine terminals and small-craft harbors, ship berthing and maneuvering considerations, port navigation, marine structures, inland navigation, marine construction planning, sediment management, and port economics. A field trip to the Port of Baltimore provides practical application of course material and shows students firsthand the unique challenges of engineering on the waterfront.

Hudson

565.655 Hydromechanics of Floating Structures—Platforms and Ships
Course topics include resistance of floating structures; sea keeping of free-floating and moored structures; and maneuverability and control (including course keeping, hydrodynamic coefficients, and control surfaces).

Bhattacharyya

565.660 Computer Methods for Design of Offshore Structures
Course topics include design methodology, computational methods, conceptual design, preliminary design calculations, and computer graphics; mathematical techniques, parametric studies, and optimization techniques; and design applications to fixed, floating, and moored structures, including structural integrity, stability, and sea-keeping.

Bhattacharyya

565.670 Coastal Structures
This course covers the practical design and analysis of seawalls, breakwaters, groins, and jetties. Topics include wave forces, sediment transport, and coastal zone planning.

Prerequisite: 560.780 Coastal Engineering or 560.781 Introduction to Water Waves.

Hudson

565.675 Hydrodynamics of Estuaries
Topics applied to estuaries include tides, shallow water waves, dispersion, sedimentation, salinity stratification and mixing, pollution, and flushing, with a particular emphasis on the dynamics of the Chesapeake Bay.

Prerequisite: 535.119 Fluid Mechanics or equivalent.

Hudson

565.800 Independent Study in Civil Engineering
Permission of instructor required.

Staff

565.801 Independent Study in Civil Engineering
Permission of instructor required.

Staff
Computer Science

The proliferation of computers and the expanding scope of information technology has affected virtually every aspect of human society. As a discipline, computer science is concerned with the theory, analysis, design, and implementation of processes that describe and transform information. With roots in mathematics and engineering, computer science uses formal techniques and methodologies of abstraction to create models that can be automated to solve real-world problems.

The Master of Science in Computer Science program is designed to appeal to a broad range of individuals. The program balances theory with practice, offers an extensive set of traditional and state-of-the-art courses, and provides the necessary flexibility to accommodate students with various backgrounds. As a result, the program will appeal to computer professionals with undergraduate degrees in computer science seeking to broaden or deepen their understanding of the discipline as well as to scientists and engineers who wish to gain deeper insights into the field of computing.

Courses are offered across a wide variety of topic areas including artificial intelligence, bioinformatics, computer engineering, data communications and networking, database systems, distributed computing, information assurance, software engineering, systems, theory, and visualization and human-computer interaction. Research and development interests of the faculty span the entire spectrum of computer science.

Students may take courses at the Applied Physics Laboratory, the Montgomery County Campus, the Dorsey Center, and online. Extensive computing facilities, including a networked multiprocessor server, X-terminals, workstations, and personal computers are available and can be reached from any of the sites or from home via high speed modems. A variety of software systems, applications, development tools, and specialized lab facilities are also supported.

Program Committee

Ralph D. Semmel, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Robert S. Grossman, Program Vice-Chair
Principal Professional Staff
Applied Physics Laboratory

Eleanor Boyle Chlan
Senior Lecturer in Computer Science
Whiting School of Engineering

Marty Hall
President
Coreervlets.com, Inc.

Richard Nieporent
Senior Principal Engineer
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John A. Piorokowski
Principal Professional Staff
Applied Physics Laboratory

John Sadowsky
Scientist
Lending Edge Design and Systems

Vincent G. Sigillito
Principal Professional Staff (ret.)
Applied Physics Laboratory

Scott Smith
Professor and Chair, Computer Science Department
Whiting School of Engineering

J. Miller Whisnant
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must have received a grade of A or B in each of the prerequisite undergraduate computer science courses. Applicants must meet the general requirements for admission to a graduate program, as stated in this catalog (see page 3). In addition, computer science master’s degree candidates must have taken one year of calculus; a course in programming using a modern programming language such as Java or C++; a course in data structures; a course in computer organization; and a mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations). This is summarized below:

I. Computer Science Courses:

A. Introduction to Programming Using Java or C++, one term
B. Data Structures—one term
C. Computer Organization—one term

II. Mathematics Courses:

A. One year of calculus—2 semesters or 3 quarters
B. Additional mathematics course beyond calculus—one term

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing the specified courses with grades of A or B. The program offers the following undergraduate courses, which may be taken as needed to satisfy the computer science prerequisites and the requirement for a mathematics course beyond calculus:

605.201 Introduction to Programming Using Java
605.202 Data Structures
605.203 Discrete Mathematics
605.204 Computer Organization
Graduate Programs

Bioinformatics
Computer science students may pursue a Master of Science in Computer Science with a Concentration in Bioinformatics or an Advanced Certificate for Post-Master’s Study in Bioinformatics. The Advanced Certificate requires that students hold a Master of Science in computer science or a closely related discipline, such as electrical and computer engineering or applied and computational mathematics. The certificate requires six courses, four of which must be graduate courses selected from the Computer Science Bioinformatics Concentration Area. For both the concentration and certificate, students may take up to two electives from outside Computer Science. While these electives will typically be selected from programs in the Whiting School of Engineering, advisers can approve bioinformatics courses from other divisions of the university. Students who take electives from other programs must meet the requirements for the selected courses. Before taking any graduate Computer Science bioinformatics courses, students must have taken 605.205 Molecular Biology for Computer Scientists, or an equivalent course, and received a grade of A or B.

Students interested in a Master of Science in Bioinformatics with a focus on the interpretation of complex biological information and the analysis of sequence data using sophisticated bioinformatics software may be interested in the joint degree program offered by the Whiting School of Engineering and the Zanvyl Krieger School of Arts and Sciences.

Telecommunications and Networking Option
Computer science students may elect a telecommunications and networking option by taking seven courses in telecommunications and networking from the computer science and electrical and computer engineering programs. A maximum of three of those courses can be from the electrical and computer engineering area. Students are strongly encouraged to take courses from both the computer science and electrical and computer engineering areas. Students lacking an electrical engineering background or equivalent must take 625.260 Introduction to Linear Systems as an undergraduate prerequisite for taking electrical and computer engineering telecommunications and networking courses. The computer science and electrical and computer engineering telecommunications and networking courses for the telecommunications and networking option are listed on the Telecommunications and Networking Option page.

Course Requirements
Ten courses, approved by an adviser, must be completed within five years. At least eight courses must be from the computer science curriculum, and of those, three must be from the same concentration area. At least two of the computer science courses must be 700-level.

Students may take up to two electives from outside computer science. While electives will typically be selected from electrical and computer engineering and applied and computational mathematics, advisers can also approve electives from applied physics. Other electives require approval of the computer science program chair or vice-chair. Students who take electives from other programs must meet the specific course and program requirements listed for each course.

Graduate students not pursuing a master’s degree in computer science should consult with their adviser to determine what courses must be successfully completed before 400- or 700-level computer science courses may be taken. It should be noted that 700-level courses are open only to students who have been admitted with graduate status.

Please refer to the course schedule each term for dates, times, locations, fees, and instructors.

Foundation Courses
All students working toward a master’s degree in computer science are required to take the following three graduate foundation courses before taking other graduate courses:

- 605.401 Foundations of Software Engineering
- 605.411 Foundations of Computer Architecture
- 605.421 Foundations of Algorithms

Foundation Course Waivers
One or more foundation courses can be waived if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate computer science courses, and may take these courses after all remaining foundation course requirements have been satisfied.

Undergraduate Courses

I. Software Engineering

- 605.401 Foundations of Software Engineering
- 605.402 Software Analysis and Design
- 605.404 Object-oriented Programming with C++
- 605.405 Conceptual Design for High-Performance Systems
- 605.408 Software Project Management
- 605.702 Service-Oriented Architecture
- 605.703 Component-Based Software Engineering
- 605.704 Object-Oriented Analysis and Design
- 605.705 Software Safety
- 605.706 Software Systems Engineering
- 605.707 Software Patterns
- 605.708 Tools and Techniques of Software Project Management
- 605.709 Seminar in Software Engineering
II. Systems

605.411 Foundations of Computer Architecture
605.412 Operating Systems
605.414 System Development in the UNIX Environment (formerly 605.714)
605.415 Compiler Design (formerly 605.425 Compiler Theory and Design)
605.715 Software Development for Real-Time Systems
605.716 Modeling and Simulation of Complex Systems

III. Theory

605.421 Foundations of Algorithms
605.423 Applied Combinatorics and Discrete Mathematics
605.424 Logical Foundations of Computer Science
605.721 Design and Analysis of Algorithms
605.722 Computational Complexity
605.723 Signal Processing
605.725 Queueing Theory with Applications to Computer Science
605.727 Computational Geometry
605.728 Quantum Computation

IV. Information Assurance

605.431 Principles of Enterprise Security and Privacy
605.432 Public Key Infrastructure and Managing E-Security
605.433 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
605.434 WWW Security
605.731 Network Security
605.732 Cryptology
605.733 Java Security
605.734 Information Assurance Architectures and Technologies
605.735 Biometrics

V. Database Systems and Knowledge Management

605.441 Principles of Database Systems
605.445 Artificial Intelligence
605.447 Neural Networks
605.741 Distributed Database Systems on the World Wide Web
605.742 XML: Technology and Applications
605.743 The Semantic Web
605.744 Information Retrieval
605.745 Reasoning Under Uncertainty
605.746 Machine Learning and Data Mining
605.747 Evolutionary Computation

VI. Bioinformatics

605.451 Principles of Computational Biology
605.452 Biological Databases and Database Tools
605.751 Computational Aspects of Molecular Structure
605.753 Computational Genomics
605.754 Analysis of Gene Expression
605.755 Systems Biology
605.759 Independent Project in Bioinformatics

Additional choices:
The following courses may be counted toward a three-course concentration in Bioinformatics.

605.716 Modeling and Simulation of Complex Systems
605.743 The Semantic Web

VII. Visualization and Human-Computer Interaction

605.461 Principles of Computer Graphics
605.462 Data Visualization
605.463 Image Processing
605.465 Natural Language Processing
605.761 Applied Computer Graphics
605.766 Human-Computer Interaction

VIII. Data Communications and Networking

(For the telecommunications and networking options in electrical and computer engineering and computer science, please see the Telecommunications and Networking page of this catalog.)

605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.475 Protocol Design
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network Management
605.773 High-Speed Networking Technologies
605.774 Network Programming
605.775 Optical Networking Technology
605.777 Internetworking with TCP/IP II
605.778 Voice over IP

IX. Distributed Computing

605.481 Distributed Development on the World Wide Web
605.482 User Interface Development with the Java Foundation Classes
605.485 Electronic Commerce
605.781 Distributed Objects
Computer Science course offerings are numbered to indicate their primary concentration area.

605.201 Introduction to Programming Using Java
This course enables students without a background in software development to become proficient programmers who are prepared for a follow-on course in data structures. The Java language will be used to introduce foundations of structured, procedural, and object-oriented programming. Topics include I/O, data types, operators, operands, expressions, conditional statements, iteration, recursion, arrays, functions, parameter passing, and returning values. Students will also be introduced to classes, objects, object references, inheritance, polymorphism, and exception handling. Additional topics include file I/O, searching, sorting, Java Collections, and an introduction to Applets. Students will complete several programming assignments to develop their problem-solving skills and to gain experience in detecting and correcting software errors.

Prerequisites: One year of college mathematics.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Summer, Fall, Spring Chittargi, Ferguson, Shyamsunder, Smith

605.202 Data Structures
This course investigates abstract data types (ADTs), recursion, algorithms for searching and sorting, and basic algorithm analysis. ADTs to be covered include lists, stacks, queues, priority queues, trees, sets, and dictionaries. The emphasis is on the trade-offs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

Prerequisite: One year of college mathematics. 605.201 Introduction to Programming using Java or equivalent.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Summer, Fall, Spring Chlan, Resch, Tjaden

605.203 Discrete Mathematics
This course emphasizes the relationships between certain mathematical structures and various topics in computer science. Topics include set theory, graphs and trees, algorithms, propositional calculus, logic and induction, functions, relational algebra, and matrix algebra.

Prerequisites: Differential and integral calculus.

Note: A mathematics course beyond one year of calculus is needed for admission to the graduate computer science program. Students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of A or B. This course DOES NOT count toward the Master of Science in Computer Science degree.

605.204 Computer Organization
This course examines how a computer operates at the machine level. Students will develop an understanding of the hardware/software interface by studying the design and operation of computing system components. In addition, students will program at the assembly language level to understand internal system functionality. Finally, students will become familiar with the machine representations of programs and data as well as the influence of the underlying hardware system on the design of systems software such as operating systems, compilers, assemblers, and linkers and loaders.

Prerequisite: 605.202 Data Structures is recommended.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Summer, Fall, Spring Malcom, Schappelle, Snyder, White, Whisnant

605.205 Molecular Biology for Computer Scientists
This course is designed for students seeking to take bioinformatics courses, but who lack the biological prerequisites. The course will cover essential aspects of cell biology, biochemistry, and molecular biology. Topics include chemistry; macromolecules and organization of the cell; overview of enzymes, metabolism, cell cycle and signal transduction; DNA structure, central dogma of molecular biology, the genetic code, and gene expression and its regulation; and polymerase chain reaction and genome sequencing.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Fall Chan

605.401 Foundations of Software Engineering
Fundamental software engineering techniques and methodologies commonly used during software development are studied. Topics include various life cycle models, project planning and estimation, requirements analysis, program design,
construction, testing, maintenance and implementation, software measurement, and software quality. Emphasized are structured and object-oriented analysis and design techniques, use of process and data models, modular principles of software design, and a systematic approach to testing and debugging. The importance of problem specification, programming style, periodic reviews, documentation, thorough testing, and ease of maintenance are covered.

Summer, Fall, Spring  
Chavis, Gieszl, Kalb, Scheppelle, Yufik

605.402 Software Analysis and Design

This course offers a unified approach to analysis and design of complex software systems. Both structured and object-oriented techniques are discussed. Included are comprehensive studies of the rationale behind the use of design methods that have been demonstrated to produce effective designs for sequential and distributed concurrent systems. Real-time issues are considered. Insights gained in the course will enable students to critically evaluate the contribution of popular methodologies to the underlying problems of requirements analysis and software design.

Prerequisite: Recent professional experience in software development would be helpful.

Fall  
Young

605.404 Object-oriented Programming with C++

This course provides in-depth coverage of object-oriented programming principles and techniques using C++. Topics include classes, overloading, data abstraction, information hiding, encapsulation, inheritance, polymorphism, file processing, templates, exceptions, container classes, and low-level language features. The course briefly covers the mapping of UML design to C++ implementation and object-oriented considerations for software design and reuse. The course also relates C++ to GUI, databases, and real-time programming. Optional topics include the comparison of C++ with other OOP languages and techniques for interfacing C++ with Java.

Prerequisite: Knowledge of Java or C.

Summer, Fall, Spring  
Boon, DeMasco, Ferguson, Gustin, Pierson

605.405 Conceptual Design for High-Performance Systems

Recent data indicates that 80 percent of all new products or services in the U.S. fail within six months or fall significantly short of forecasted success. In the software industry, the average failure rate can be even higher, often entailing massive losses for both the developer, due to disappointing sales or excessive maintenance costs, and the user, due to learning difficulties and other performance problems. This course analyzes a set of issues critical to conceiving and executing a successful software product, with emphasis on complex dynamic applications. Topics are focused on three generic issues: 1) how to collect, organize, and formulate requirements encompassing both software and user performance; 2) how to define product-user interactions and design interfaces to satisfy performance requirements; and 3) how to assess the extent of requirements satisfaction (usability testing and analysis). In complex dynamic applications, user performance is particularly sensitive to design shortcomings. Discussion of such applications will concentrate on models of situation comprehension, image understanding, decision making under uncertainty, and other aspects of user performance that need to be considered to recognize and avoid typical design errors.

Fall  
Yufik

605.408 Software Project Management

(formerly 605.403)

This course describes the key aspects of a software project. It begins with the job description of a software manager and then addresses those topics germane to successful software development management including organizing the software development team; interfacing with other engineering organizations (systems engineering, quality assurance, configuration management, and test engineering); assessing development standards; selecting the best approach and tailoring the process model; estimating software cost and schedule; planning and documenting the plan; staffing the effort; managing software cost and schedule during development; risk engineering; and continuous process improvement. Personnel management topics, including performance evaluations, merit planning, skills building, and team building, are also covered. This course introduces software engineers aspiring to become technical team leaders or software project managers to the responsibilities of these roles. For those engineers who have advanced to a software development leadership position, this course offers formal training in software project management.

Fall, Spring  
Bowers, Winston

605.411 Foundations of Computer Architecture

This course provides a detailed examination of the internal structure and operation of modern computer systems. Each of the major system components is investigated including the following topics: the design and operation of the ALU, FPU, and CPU; microprogrammed vs. hardwired control, pipelining, and RISC vs. CISC machines; the memory system including caches and virtual memory; parallel and vector processing, multiprocessor systems and interconnection networks; superscalar and super-pipelined designs; and bus structures and the details of low level I/O operation using interrupt mechanisms, device controllers, and DMA. The impact of each of these topics on system performance is also discussed. The instruction set architectures and hardware system architectures of different machines are examined and compared. The classical Von Neumann architecture is also compared and contrasted with alternative approaches such as data flow machines and neural networks.

Summer, Fall, Spring  
Beser, Malcom, Snyder, Whisnant
Graduate Programs

**605.412 Operating Systems**
The theory and concepts related to operating system design are presented from both developer and user perspectives. Core concepts covered include process management, memory management, file systems, I/O system management including device drivers, distributed systems, and multi-user concepts including protection and security. Process management discussions focus on threads, scheduling, and synchronization. Memory management topics include paging, segmentation and virtual memory. Students will examine how these concepts are realized in several current open-source operating systems, including Linux. Students will complete several assignments that require the design and implementation of operating system programs using a high-level language.

Fall

Noble

**605.414 System Development in the UNIX Environment** (formerly 605.714)
This course describes how to implement software systems in a UNIX (POSIX-compliant) operating system environment. Students will discuss and learn the complexities, methodologies, and tools in the development of large systems that contain multiple programs. Topics include an overview of the UNIX system and its general-purpose tools, advanced makefile usage, UNIX system calls, UNIX process management, threads, and basic and advanced interprocess communication.

Prerequisites: Additional topics include source code configuration control, Perl, and debugging techniques. Familiarity with UNIX, experience with C++ or C.

Spring

Ching, Noble, Russell

**605.415 Compiler Design** (formerly 605.425 Compiler Theory and Design)
This course explores the principles, algorithms, and data structures involved in the design and construction of compilers. Topics include finite-state machines, lexical analysis, context-free grammars, push-down parsers, LR and LALR parsers, other parsing techniques, symbol tables, error recovery, and an introduction to intermediate code generation.

Spring

Behforooz

**605.421 Foundations of Algorithms**
This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), recursion and mathematical induction, algorithm analysis and computational complexity (recurrence relations, big-O notation, NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming, amortized analysis), and graph algorithms (depth-first and breadth-first search, connectivity, minimum spanning trees, network flow). Advanced topics are selected from among the following: randomized algorithms, information retrieval, string and pattern matching, and computational geometry.

Prerequisite: 605.202 Data Structures or equivalent.

Summer, Fall, Spring

Boon, Chlan, Lew, Sadowsky, Sheppard

**605.423 Applied Combinatorics and Discrete Mathematics**
Combinatorics and discrete mathematics are becoming increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving. (This course is the same as 625.417 Applied Combinatorics and Discrete Mathematics.)

Spring

Whisnant

**605.424 Logical Foundations of Computer Science**
The use of predicate logic for modeling information systems is widespread and growing. Knowledge representation, for example, has long been important in artificial intelligence applications, and is now emerging as a critical component of semantic web applications. Similarly, predicate logic is the basis for ontologies and inferential knowledge bases. This course teaches the fundamentals of propositional and predicate logic, with an emphasis on semantics. Modal logic is introduced as a tool to manage non-truth-functional systems, and dynamic logic is introduced to manage potentially inconsistent systems, such as may arise in merging disparate databases or in combining diagnostic models of related systems.

Summer

Waddell

**605.431 Principles of Enterprise Security and Privacy**
This course surveys the broad fields of enterprise security and privacy, concentrating on the nature of enterprise security requirements by identifying threats to enterprise information technology (IT) systems, access control and open systems, and product and system evaluation criteria. Policy considerations are examined with respect to the technical nature of enterprise security as represented by government regulations for software with cryptographic capability. The course develops the student’s ability to assess enterprise security risk and to formulate technical recommendations in the areas of hardware and software. Aspects of security-related topics to be discussed include network security, cryptography, IT technology issues, and database security. The course addresses evolving Internet, Intranet, and Extranet security issues that affect enterprise security. Additional topics include access control (hardware and software), communications security, and the proper use of system software (operating system and utilities). The course addresses the social and legal problems of individual privacy.
in a data processing environment, as well as the computer “crime” potential of such systems. The class examines several data encryption algorithms.

Fall, Spring Heinbuch, Podell

605.432 Public Key Infrastructure and Managing E-Security

This course describes public key technology and related security issues. Public Key Infrastructure (PKI) components are explained, and support for e business and strong security services required by various applications is described. The role of digital certificates, the importance of certificate policy and certification practices, and essential aspects of key management that directly impact assurance levels and electronic services are addressed. The capabilities of PKI and digital signatures are examined in the context of the business environment, including applicable laws and regulations. The essential elements for successful PKI planning and rollout are discussed, and the state of PKI and interoperability issues are presented.

Spring Kumar, Mitchel

605.433 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms

While most of the world is preoccupied with high-profile Network-based computer intrusions, this online course examines the potential for computer crime and the protection mechanisms employed in conjunction with the embedded computers that can be found within non-networked products (e.g., vending machines, automotive onboard computers, etc.). This course provides a basic understanding of embedded computer systems: differences with respect to network-based computers, programmability, exploitation methods, and current intrusion protection techniques along with material relating to computer hacking and vulnerability assessment. The course materials consist of a set of eight study modules and five case-study experiments (to be completed at a rate of one per week) and are augmented by online discussion forums moderated by the instructor. This course also includes online discussion forums that support greater depth of understanding of the materials presented within the study modules.

Prerequisite: Basic understanding and working knowledge of computer systems and access to Intel-based PC hosting a Microsoft Windows environment.

Fall, Spring Kalb

605.434 WWW Security

This course examines issues associated with making web applications secure. The principal focus is on server-side features such as CGI security, proper server configuration, and firewalls. The course also investigates protection of the connection between a client and server by encrypting the data stream (e.g., with SSL) or by keeping certain data private from the server system (e.g., via third party transaction protocol like SET or digital cash). Finally, the course explores client-side vulnerabilities associated with browsing the web, such as system penetration, information theft, identity spoofing, and denial of service attacks. Related topics such as malicious e-mails, web scripts, cookies, web bugs, spyware, and software security will also be discussed. Labs are included to enable students to probe more deeply into security issues and to develop and test potential solutions.

Prerequisite: Basic understanding of computer operating systems.

Fall, Spring Ching

605.441 Principles of Database Systems

This course examines the underlying concepts and theory of database management systems. Topics include database system architectures, data models, query languages, conceptual and logical database design, physical organization, and transaction management. The entity-relationship model and relational model are investigated in detail, object-oriented databases are introduced, and legacy systems based on the network and hierarchical models are briefly described. Mappings from the conceptual level to the logical level, integrity constraints, dependencies, and normalization are studied as a basis for formal design. Theoretical languages such as the relational algebra and the relational calculus are described, and high-level languages such as SQL and QBE are discussed. An overview of file organization and access methods is provided as a basis for discussion of heuristic query optimization techniques. Finally, transaction processing techniques are presented with a specific emphasis on concurrency control and database recovery.

Summer, Fall, Spring Immer, Kung, Liu, Semmel

605.445 Artificial Intelligence

The incorporation of advanced techniques in reasoning and problem solving into modern, complex systems has become pervasive. Often, these techniques fall within the realm of artificial intelligence. This course focuses on artificial intelligence from an agent perspective, and explores issues of knowledge representation and reasoning. Students will participate in lectures and discussions on various topics, including heuristic and stochastic search, logical and probabilistic reasoning, planning, learning, and perception. Advanced topics will be selected from areas such as robotics, vision, natural language processing, and philosophy of mind. Students will complete problem sets and small software projects to gain hands-on experience with the techniques and issues covered.

Summer, Fall Razi, Sheppard

605.447 Neural Networks

This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks.
Software for some networks is provided. (This course is the same as 625.438, Neural Networks.)

Spring  Whisnant

605.451 Principles of Computational Biology
This course is an interdisciplinary introduction to computational methods used to solve important problems in DNA and protein sequence analysis. The course focuses on algorithms but includes material to provide the necessary biological background for science and engineering students. Algorithms to be covered include dynamic programming for sequence alignment, such as Smith-Waterman, FASTA, and BLAST; hidden Markov models, such as the forward, Viterbi, and expectation maximization algorithms; and a range of gene-finding algorithms; phylogenetic tree construction; and clustering algorithms.

Prerequisites: Familiarity with probability and statistics; working knowledge of Java, C++, or C; a course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Fall  Przytycka

605.452 Biological Databases and Database Tools
The sequencing of the human genome and the emerging intense interest in proteomics and molecular structure have caused an enormous explosion in the need for biological databases. The first half of this course surveys a wide range of biological databases and their access tools and seeks to develop proficiency in their use. These include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISSPROT, and their analysis tools. Tools for accessing and manipulating sequence databases will be covered, such as BLAST, multiple alignment, Perl, and gene finding tools. Advanced, specialized and recent popular databases such as KEGG, BioCyc, HapMap, Allen Brain Atlas, Afcs, etc., will be surveyed for their design and use. The second half of this course focuses on the design of biological databases including the computational methods to create the underlying data, as well as the special requirements of biological databases such as: interoperability, complex data structures consisting of very long strings, object orientation, efficient interaction with computational operators, parallel and distributed storage, secure transactions and fast recall. Students will create their own small database as a project for the course as well as complete homework assignments using databases.

Prerequisites: 605.441 Principles of Database Systems or 410.634, or working knowledge of SQL and a prior course in molecular biology or cell biology (605.205 or 410.602).

Notes: Students who do not have a prior background in databases can succeed in this course by concurrent self study of relational databases and SQL using a book such as Database Solutions: A Step by Step Guide to Building Databases by Thomas.

Summer, Fall (online)  Hobbs

605.461 Principles of Computer Graphics
This course examines the principles of computer graphics, with a focus on the mathematics and theory behind 2D and 3D graphics rendering. Topics include graphics display devices, graphics primitives, 2D and 3D transformations, viewing and projection, color theory, visible surface detection and hidden surface removal, lighting and shading, and object definition and storage methods. Practical application of these concepts is emphasized through laboratory exercises and code examples. Laboratory exercises use the C++ programming language and OpenGL on a PC.

Prerequisite: Familiarity with linear algebra.

Fall  Nesbitt

605.462 Data Visualization
This course explores the underlying theory and practical concepts in creating visual representations of large amounts of data. It covers the core topics in data visualization: data representation, visualization toolkits, scientific visualization, medical visualization, information visualization, flow visualization, and volume rendering techniques. The related topics of applied human perception and advanced display devices are also introduced.

Prerequisite: Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.461) is recommended.

Spring  Chlan

605.463 Image Processing
Fundamentals of image processing are covered, with an emphasis on digital techniques. Topics include digitization, enhancement, segmentation, the Fourier transform, filtering, restoration, reconstruction from projections, and image analysis including computer vision. Concepts are illustrated by laboratory sessions in which these techniques are applied to practical situations, including examples from biomedical image processing.

Prerequisite: Familiarity with Fourier transforms.

Fall  Corrigan and Waters

605.465 Natural Language Processing
This course covers the concepts and methods for processing natural language by computer. Topics include pattern matching, parsing, the role of the dictionary and lexical acquisition, semantic interpretation, anaphoric reference, plan recognition, discourse analysis, and text generation. Applications are drawn from natural language interfaces, text processing systems, advisory systems, and interaction with speech recognizers. A “hands-on” natural language processing development tool is used.

Prerequisite: 605.445 Artificial Intelligence.

Spring (even years)  Whisnant
605.471 Principles of Data Communications Networks

This course provides an introduction to the field of data communications and computer networks. The course covers the principles of data communications, the fundamentals of signaling, basic transmission concepts, transmission media, circuit control, line sharing techniques, physical and data link layer protocols, error detection and correction, data compression, common carrier services and data networks, and the mathematical techniques used for network design and performance analysis. Potential topics include analog and digital signaling; data encoding and modulation; Shannon channel capacity; synchronous and asynchronous transmission; RS232 physical layer interface standards; FDM, TDM, and STDMA multiplexing techniques; inverse multiplexing; analog and digital transmission; V series modem standards; PCM encoding and T1 transmission circuits; LRC/ CRC and CRC error detection techniques; Hamming and Viterbi forward error correction techniques; BSC and HDLC data link layer protocols; Huffman, MNPS and V.42bis data compression algorithms; circuit, message, packet and cell switching techniques; ISDN, frame relay, SMDS and ATM networks; minimum spanning tree, Esau-Williams and Add network topology optimization algorithms; reliability and availability, TRIB, and queuing analysis topology optimization techniques; and circuit costing.

Summer, Fall, Spring

Boules, Nieporent, Smith

605.472 Computer Network Architectures and Protocols

This course provides a detailed examination of the conceptual framework for modeling communications between processes residing on independent hosts, and the rules and procedures that mediate the exchange of information between two communication processes. The Open Systems Interconnection Reference Model (OSIRM) is presented and compared with TCP/IP and other network architectures. The service definitions and protocols for implementing each of the seven layers of the Reference Model using both OSI and TCP/IP protocols are analyzed in detail. Internetworking among heterogeneous subnets is described in terms of addressing and routing, and techniques for identifying different protocol suites sent over the subnets are explained. The protocol header encoding rules are examined, and techniques for parsing protocol headers are analyzed. The application layer sub-architecture for providing common application services is described, and interoperability techniques for implementing multiprotocol internets are presented. Topics include layering, encapsulation, SAPs, and PDUs; sliding window protocols, flow and error control; virtual circuits and datagrams; routing and congestion control algorithms; internetworking; NSAP and IP addressing schemes; CLNP, IPv4 and the new IPv6 internet protocols; RIP, OSPF, ES-IS, and IS-IS routing protocols; TP4 and TCP transport protocols; dialog control, activity management, and the session layer protocol; ASN.1 encoding rules and the presentation layer protocol; application layer structure and the ACSE, CCR, ROSE and RTSE common application service elements; OSI VT, FTAM and MOTIS application protocols, TCP/IP TELNET, FTP and SMTP application protocols; and OSI transitioning tools, multiprotocol networks, and encapsulation, tunneling and convergence techniques.

Prerequisite: 605.471 Principles of Data Communications Networks.

Spring

Nieporent

605.475 Protocol Design

This course is an introduction to the formal design, specifications, and validation of computer protocols. The course focuses on the principles of protocol specification and validation. The following topics form the major part of the course: structured protocol design, protocol models, protocol validation, protocol correctness requirements, and protocol design.

Prerequisites: 605.471 Principles of Data Communications Networks and 605.771 Local Area Networks, or 605.472 Computer Network Architectures and Protocols, or 605.477 Internetworking with TCP/IP I.

Fall (even years)

Akin

605.477 Internetworking with TCP/IP I

This course investigates the detailed architecture, design, and technology that unifies various packet switching networks built around ARPA/NET technology and local area networks, such as Ethernet, into a common network known as the Internet. The common underlying internetworking concept that enables these disparate networks to function as a unified whole is manifested in the connectionless Internet Protocol (IP). IP and access mechanisms, such as SLIP and PPP, are examined in detail, and the error control message protocol (ICMP) is also described. The protocols used by the hosts and other devices attached to these networks that function above the IP are investigated. Communications-related protocols analyzed in detail include the connection oriented, reliable Transmission Control Protocol (TCP); and the connectionless User Datagram Protocol (UDP). Dynamic IP routing and subnet routing using protocols both interior and exterior to the autonomous systems (AS) are studied, including RIP, OSPF and BGP. The Application Programming Interface (API) in the form of Berkeley Sockets for TCP and UDP is also investigated. Finally, protocols for user applications are examined, such as the File Transfer Protocol (FTP), Simple Mail Transfer Protocol (SMTP), and TELNET remote login protocol.

Prerequisite: 605.471 Principles of Data Communications Networks.

Fall, Spring

Mirhakkak

605.478 Cellular Communications Systems

This course introduces the principles of cellular communications systems. Second generation (2G) digital, mobile cellular, and personal communications systems (PCS) concepts are discussed, including the cellular concept, frequency reuse, propagation, multiple access, power control, handoff, and traffic engineering. Limitations of 2G cellular systems are described, and improvements proposed by 2.5G and 3G cellu-
lar standards to support high-rate data services are presented. Emphasis is placed on layer 2 and above such as retransmission protocols, medium access control, call processing, interworking, radio resource management (e.g., frequency, time, and power), QoS provisioning, scheduling, and mobility management (e.g., mobile IP). The Wireless Local Area Networking IEEE 802.11 WLAN, the Wireless Metropolitan Area Networking IEEE 802.16 (Fixed and Mobile) WiMAX, and Wireless Personal Area Networking IEEE 802.15 Bluetooth are discussed for their roles in 3G. The Media Independent Handover standard IEEE 802.21 (e.g., integrating WLAN and 3G cellular networks to provide session/service continuity) is also introduced. Cellular standards are examined, including U.S. 2G code-division multiple access (CDMA) IS-95A, 2.5G IS-95B, 3G cdma2000 1x, and 1x-EVDO. Other standards discussed include European 2G time-division multiple access (TDMA) Global System for Mobile communication (GSM), 2.5G General Packet Radio Service (GPRS), 2.5G Enhanced Data Rates for GSM Evolution (EDGE), and 3G wideband-CDMA (W-CDMA).

**Prerequisite:** 605.471 Principles of Data Communications Networks.

**Summer, Fall**

**Shyam Sunder, Spiegel**

**605.481 Distributed Development on the World Wide Web**

This course examines three major topics in the development of applications for the World Wide Web. The first is web site development using HTML and related standards. The second is the implementation of client-side applications using the Java programming language, including user interface development, asynchronous event handling, multi-threaded programming, and network programming. Distributed object protocols via RMI or CORBA and distributed database access via JDBC may also be introduced. The third topic is the design of server-side web applications, for which students will examine the underlying Web protocol (HTTP), the development of client-side interfaces (e.g., via HTML forms), and the implementation of server-side programs (e.g., via Java servlets or traditional CGI).

**Summer, Fall, Spring**

**Hall, Shyam Sunder, Spiegel**

**605.482 User Interface Development with the Java Foundation Classes**

This course focuses on developing graphical user interfaces using the latest Java “Swing” tool kit. Topics include asynchronous event handling, “peerless” graphical objects, the 2-D drawing model windows (frames, panels, dialog boxes, etc.), GUI controls (such as buttons, menus, stylized text editors, fonts, and tables), layout managers to make page layout more flexible, Model-View-Controller architecture, printing services, and development of custom components. Advanced topics may include multi-threading issues and drag-and-drop support.

**Prerequisite:** Significant Java programming experience.

**Summer, Fall, Spring**

**Evans**

**605.485 Electronic Commerce**

This course covers the architecture and technologies required to build E-commerce systems. Basic concepts of e-commerce are introduced followed by coverage of the Internet backbone, including fundamental networking infrastructure. The course describes the inadequacy of current World Wide Web technology for e-commerce, which has resulted in the development of the concept of Service-Oriented Architecture (SOA) and its implementation in the form of an Enterprise Service Bus (ESB). SOA and ESB provide a robust and reliable way for service-to-service and business-to-business integration at the data, information and the application levels. Web Services provides the underlying messaging service and is built on four open standards, XML, SOAP, WSDL, and UDDI. The course also introduces the two major frameworks, J2EE and .NET, for building Web services. The critical security and governance issues in SOA implementation along with SOA design and implementation roadmaps are discussed. The second generation Web 2.0 and the AJAX technology are also covered. Finally a software architecture from Business Process Management (BPM) to Grid Computing is presented. (This course is the same as 635.483 Electronic Commerce.)

**Summer**

**Chi**

**605.702 Service-Oriented Architecture**

Service-Oriented Architecture (SOA) is a way to organize and use distributed capabilities that may be controlled by different owners. SOA provides a uniform means to offer, discover, interact with, and use capabilities to produce desired effects consistent with specified preconditions and requirements. This course describes SOA concepts and design principles, interoperability standards, security considerations, runtime infrastructure and web services as an implementation technology for SOA. Given the focus on shared capabilities, SOA involves more than technology. Therefore, additional topics will include the impact of SOA on culture, organization, and governance.

**Prerequisite:** 605.401 Foundations of Software Engineering; 605.481 Distributed Development on the World Wide Web and 605.704 Object Oriented Analysis and Design or equivalent experience are highly recommended.

**Fall**

**John, Pole**

**605.703 Component-Based Software Engineering**

(formerly 605.703 Software Reuse)

Component-Based Software Engineering (CBSE) is concerned with the development of software-intensive systems from reusable parts, the development of reusable parts, and with the maintenance and improvement of systems by means of component replacement and customization. In contrast to the opportunistic, “do it when you can” approach, this course is an introduction to the systematic application of CBSE to the development of software intensive systems. This course will cover both the consumer side of the CBSE model (the development of systems from components and frameworks) and the producer side of the CBSE model (developing components, creating design patterns, and building whole frameworks).
Though the course will focus primarily on CBSE theory and strategies, students will participate in a class project in which they will act as CBSE consumers or producers. The class project will require basic skills using the Microsoft Windows/Visual Studio.Net platform, which will be covered in an optional set of exercises and tutorials.

Prerequisite: Experience with an object-oriented language such as Java or C++.

Spring  Pole

605.704  Object-Oriented Analysis and Design
This course describes fundamental principles of object-oriented modeling, requirements development, analysis, and design. Topics include specification of software requirements; object-oriented analysis approaches, including dynamic and static modeling with the Unified Modeling Language (UML v2); object-oriented design; object-oriented reuse, including design patterns; and software implementation concerns. Optional topics include the Systems Modeling Language (SysML), Object-Oriented Systems Engineering Methodology (OOSEM), managing object-oriented projects, and the Object Constraint Language (OCL).

Prerequisite: Experience in object-oriented programming using a language such as Java or C++.
Summer, Fall, Spring  Demasco, Ferguson, Pierson, Schappelle, Schepers

605.705  Software Safety
This course describes how to develop and use software that is free of imperfections that could cause unsafe conditions in safety-critical systems. Systems engineering and software engineering techniques are described for developing “safe-ware,” and case studies are presented regarding catastrophic situations that resulted from software and system faults which could have been avoided. Specific techniques of risk analysis, hazard analysis, fault tolerance, and safety tradeoffs within the software engineering paradigm are discussed.
Fall  Gieszl

605.706  Software Systems Engineering
(formerly The Software Development Process)
Software Systems Engineering applies engineering principles and the system view to the software development process. The course focuses on the engineering of complex systems that have a strong software component. This course is based on the philosophy that the key to engineering a good software system lies just as much in the process that is followed as in the purely technical regime. The course will show how good a software development process is and how to make a software process better by studying successful techniques that have been employed to produce correct software systems within budget. Topics are explored in a sequence designed to reflect the way one would choose to implement process improvements. These topics include steps to initiate process change, methods to establish control over the software process, ways to specify the development process, methods for quantitative process control, and how to focus on problem prevention. Students will prepare term projects.

Prerequisite: One software engineering course beyond 605.401, Foundations of Software Engineering.
Fall, Spring  Siegel and Donaldson, White

605.707  Software Patterns
Software patterns encapsulate the knowledge of experienced software professionals in a manner that allows developers to apply that knowledge to similar problems. Patterns for software are analogous to the books of solutions that enable electrical engineers and civil engineers to avoid having to derive every new circuit or bridge design from first principles. This course will introduce the concept of software patterns, and explore the wide variety of patterns that may be applied to the production, analysis, design, implementation, and maintenance of software. The format of the course will emphasize the discussion of patterns and their application. Each student will be expected to lead a discussion and to actively participate in others. Students will also be expected to introduce new patterns or pattern languages through research or developed from their own experience. Programming exercises performed outside of class will be used enhance discussion and illustrate the application of patterns.

Prerequisite: 605.404 Object-Oriented Programming with C++ or permission of instructor.
Fall, Spring  Lindberg, Stanchfield

605.708  Tools and Techniques of Software Project Management
(formerly 605.701 Software Size and Cost Estimating)
This course examines tools and techniques used to lead software-intensive programs. Techniques for RFP analysis and proposal development are explored, and techniques of size estimation (function points, feature points, and lines-of-code estimation) and the use of models such as COCOMO to convert size to effort and schedule are described. In addition, conversion of estimated effort to dollars and the effects of fringe, overhead, skill mix profiles, and staffing profiles on total dollar cost are explained. Moreover, techniques for estimating effort and planning software COTS intensive development programs are described, and tools and techniques for measuring process maturity and process efficiency (e.g., CMMi, Lean, Six Sigma, and Kaizen) are addressed. The course also investigates Personal Process Improvement and the tools and techniques that can be used by an individual to monitor task performance. Finally, the course investigates personnel staffing, recruiting, and retention strategies in an environment where employee demographics are radically changing.
Fall  Bowers

605.709  Seminar in Software Engineering
This course examines the underlying concepts and latest topics in software engineering. Potential topics include effective software development techniques such as agile and extreme programming; use of UML to define testing strategies; useful
development tools and environments; patterns; metrics issues in system generation; teamwork in successful developments; and training aspects of CMM. Each student will select and report on a software engineering topic, perform independent reading, and prepare a paper describing a major software engineering issue. The course is taught using a seminar format in which significant portions of the class period are set aside for students to lead and actively participate in discussions.

Prerequisite: One software engineering course beyond 605.401 Foundations of Software Engineering.

Spring

605.715 Software Development for Real-Time Systems

This course examines the hardware and software technologies behind real-time, embedded computer systems. From smart kitchen appliances to sophisticated flight control for airliners, embedded computers play an important role in our everyday lives. Hardware topics include microcomputers and support devices (e.g., flash, ROM, DMA, timers, clocks, A/D, and D/A), as well as common applications (e.g., servo and stepper motor control, automotive sensors, and voice processing). Software topics focus on unique aspects of embedded programming and include interrupts, real-time control, communication, common design patterns, and special test considerations. The course also explores the unique tools that are used to develop and test embedded systems. Several labs using a popular robotics development system and Java reinforce the concepts presented.

Prerequisite: Programming experience with Java.

Fall

605.716 Modeling and Simulation of Complex Systems

(formerly 605.752 Simulation of Biological and Complex Systems)

This course focuses on the application of modeling and simulation principles to complex systems. A complex system is a large-scale nonlinear system consisting of interconnected or interwoven parts (such as a biological cell, the economy, or an ecological system). The course begins with an overview of complex systems, followed by modeling and simulation techniques based on nonlinear differential equations, networks, stochastic models, cellular automata, and swarm-like systems. Existing software systems will be used to illustrate systems and provide practical experience. During the semester, each student will complete a modeling project of a complex system.

While this course is intended for computer science or engineering students interested in modeling any complex system, it may also be taken by Bioinformatics students interested in modeling complex biological systems. Students interested in bioinformatics will study a parallel track exposing them to existing whole cell modeling tools such as E-Cell, COPASI, and BioSpice.

Prerequisites: Knowledge of elementary probability and statistics and previous exposure to differential equations. Students applying this course to the MS in Bioinformatics should also have completed at least one Bioinformatics class prior to enrollment.

Note: This course may be counted toward a three-course concentration in Bioinformatics.

Fall (online)

Addison

605.721 Design and Analysis of Algorithms

In this follow-on course to 605.421, Foundations of Algorithms, design paradigms are explored in greater depth, and more advanced techniques for solving computational problems are presented. Topics include randomized algorithms, adaptive algorithms (genetic, neural networks, simulated annealing), approximate algorithms, advanced data structures, online algorithms, computational complexity classes and intractability, formal proofs of correctness, sorting networks, and parallel algorithms. Students will read research papers in the field of algorithms and will investigate the practicality and implementation issues with state-of-the-art solutions to algorithmic problems. Grading is based on problem sets, programming projects, and in-class presentations.

Prerequisites: 605.421 Foundations of Algorithms or equivalent, and discrete mathematics.

Summer

Boon, Sadowsky

605.722 Computational Complexity

This course introduces the field of computational complexity and its applications in computer science and cryptography. The subject explores foundational questions of the relative costs, primarily in computation time and storage, for the computational solutions of different classes of problems, over all possible algorithms. Basic concepts of polynomial, NP, and NP—Complete problems are developed in both intuitive and rigorous forms. Methods for determining the tractability of problems, the polynomial hierarchy, techniques and complexity of approximation algorithms, and current topics in complexity are also covered. The course also covers complexity topics in cryptography, including classical cryptosystems, public key, one-way-function cryptosystems, the RSA system, protocols for impossible problems in communication, and zero-knowledge-based systems. All background in theoretical computer science is developed as needed in the course.

Prerequisites: Exposure to algorithm design heuristics and discrete mathematics would be helpful, but is not required.

Fall (Olympic years)

Zaret

605.723 Signal Processing

This course introduces signal processing, with an emphasis on digital signal processing, from the perspective of computer science, providing the theoretical and practical framework for understanding signal processing algorithms, architectures, and applications. Basic concepts for signal analysis, including signal presentation, time and frequency domains, spectral analysis, and noise are introduced. Components of signal processing, such as systems, filters, correlators and convolvers, and adaptive processes are defined. Architectures and algorithms, including
fast algorithms for Fourier transforms, correlation, convolution, spectral estimation, graphical techniques, and DSP processor devices are presented. Applications including speech, communications, music, and biological signal processing are surveyed. Students will complete several homework problem sets and a term project, and will program using Java, C, C++, or Matlab. No previous knowledge of signal processing, real analysis, complex analysis, or Fourier transforms is assumed.

**Prerequisites:** 605.421 Foundations of Algorithms, or equivalent, and linear algebra, or permission of instructor.

**Spring** Sadowsky

605.725 Queuing Theory with Applications to Computer Science

Queues are a ubiquitous part of everyday life. Common examples are supermarket checkout stations, help desk call centers, manufacturing assembly lines, wireless communication networks, and multitasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single and multiple server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations, but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary. (This course is the same as 625.734 Queuing Theory with Applications to Computer Science.)

**Prerequisite:** Multivariate calculus and a graduate course in probability and statistics (e.g., 625.403).

Blair

605.727 Computational Geometry

This course covers fundamental algorithms for efficiently solving geometric problems, especially ones involving 2D polygons and 3D polyhedrons. Topics include elementary geometric operations; polygon visibility, triangulation, and partitioning; computing convex hulls; Voronoi diagrams and Delaunay triangulations with applications; special polygon and polyhedron algorithms such as point containment and extreme point determination; point location in a planar graph subdivision; and robot motion planning around polygon obstacles. The course covers theory to the extent that it aids in understanding how the algorithms work. Emphasis is placed on implementation, and programming projects are an important part of the course work.

**Prerequisite:** Familiarity with linear algebra.

Spring Sunday

605.728 Quantum Computation

Polynomial time quantum algorithms, which exploit non-classical phenomena such as superposition and entanglement, have been developed for problems for which no efficient classical algorithm is known. The discovery of these fast quantum algorithms has given rise to the field of quantum computation, an emerging research area at the intersection of computer science, physics, and mathematics. This course provides an introduction to quantum computation for computer scientists. Familiarity with quantum mechanics is not a prerequisite. Instead, relevant aspects of the quantum mechanics formalism will be developed in class. The course begins with a discussion of the quantum mechanics formalism, and of relevant ideas from (classical) computational complexity. It then develops the idea of a quantum computer. This discussion provides the basis for a detailed examination of Shor’s polynomial time algorithm for integer factorization, and Grover’s search algorithm. The course concludes with a discussion of quantum cryptography. Required work will include problem sets and a research project.

**Prerequisite:** Some familiarity with linear algebra and with the design and analysis of algorithms.

Fall (Non-Olympic even years) Zaret

605.731 Network Security

This course discusses concepts and issues pertaining to network security; examines methods and technologies for securing wired and wireless computer and communications systems; and surveys network security standards. Topics include Next-Generation Networks (NGN) security architecture; applied cryptography for e-commerce; Wireless Local Area Network (WLAN) security; Cisco WLAN security countermeasures; wired and wireless Public Key Infrastructure (PKI); federated identity and secure network management; and security issues for IPv4 to IPv6 transition. Selected network security technologies will also be introduced including Virtual Private Networks (VPN); Multiprotocol Label Switching (MPLS); IP telephony and attacks against an IP telephony network; Session Initiation Protocol (SIP) and SIP Security; and Secure Blueprint for Enterprise Networks (SAFE). Network security examples that will be presented include developments in WLAN; Worldwide Interoperability for Microwave Access (WiMAX); Third Generation Partnership Project (3GPP); IP Multimedia Subsystem (IMS) Releases 5-7; IPv6 peer-to-peer (P2P) services; VPN key management; and Cisco CallManager (CCM).

Summer, Fall

605.732 Cryptology

This course provides an introduction to current research in cryptology. It begins with a survey of classical cryptographic techniques. It then develops the concepts from complexity theory and computational number theory that provide the foundation for much of the contemporary work in cryptology. The remainder of the course focuses on this contemporary work. Topics include symmetric block ciphers and the Advanced Encryption Standard, public key cryptosystems, digital signatures and authentication protocols, and quantum cryptography. All background in theoretical computer science is developed as needed in the course.

Fall, Spring May, Zaret
Graduate Programs

Computer Science

605.733  **Java Security**  
(formerly 605.733 Java and Web Services Security)
This course examines security topics in the context of the Java language with emphasis on security services such as confidentiality, integrity, authentication, access control, and non-repudiation. Specific topics include mobile code, mechanisms for building “sandboxes” (e.g., class loaders, namespaces, bytecode verification, access controllers, protection domains, policy files), symmetric and asymmetric data encryption, hashing, digital certificates, signature and MAC generation/verification, code signing, key management, SSL, and object-level protection. Various supporting APIs are also considered, including the Java Cryptography Architecture (JCA) and Java Cryptography Extension (JCE). Security APIs for XML and web services, such as XML Signature and XML Encryption, Security Assertions Markup Language (SAML), and Extensible Access Control Markup Language (XACML), are also surveyed. The course includes multiple programming assignments and a project.
Prerequisite: 605.481 Distributed Development on the WWW or equivalent. Basic knowledge of XML. 605.431 Enterprise Security and Privacy or 605.434 WWW Security would be helpful but is not required.
Fall, Spring  Llanso

605.734  **Information Assurance Architectures and Technologies**  
(formerly 605.734 Information Assurance)
Once only the concern of the military and financial communities, security has become a critical issue for reliable information systems. As a result, vendors are offering an array of security features and products to address system security concerns. Yet, as more security features and products become available, the number of system security failures continues to rise. The question that must be asked is how much can the security products be trusted to perform correctly and address system security requirements? This course will discuss the assurance issues associated with security technology ranging from formal models to design and development. The evolution of security criteria will also be addressed, from the development of the Orange Book to the Common Criteria, and the impact of those criteria on security developments will be described. High-assurance security projects will be reviewed to understand their security architectures, features, and development. These projects will be compared and contrasted with current commercial security products and efforts, such as Microsoft’s Trustworthy Computing effort. The course will also discuss how to build systems that avoid the various types of flaws which exist in current systems (e.g., buffer overflows, race conditions, and covert channels).
Prerequisite: 605.431 Principles of Security and Privacy is recommended but not required.
Fall, Spring  Ziegler

605.735  **Biometrics**  
Biometrics is the study of automated methods for the identification or authentication of individuals using biological characteristics (e.g., fingerprint, face, and iris images). Biometrics technology has the potential to solve key security challenges associated with information systems. This course explores the underlying technology, use, issues, and potential of biometrics for identification and authentication in information systems. Topics include legal and social aspects, including accessibility and privacy issues; psychological and usability issues; biometrics evaluation, including metrics and statistical analysis; enrollment and verification of biometrics, including data sampling, signal processing, template construction, and matching algorithms; and current standards and practices. Case studies of biometric implementations are presented, and background in related areas is covered to give students an understanding of biometric techniques and the requirements for using them in secure systems. Students will prepare and present a biometrics research project.
Prerequisite: 605.431 Principles of Enterprise Security and Privacy
Fall  Rhude

605.741  **Distributed Database Systems on the World Wide Web**  
This course investigates principles of distributed database systems, including design and architecture, query processing, transaction management, locking, recovery, and RAID technology. The course also covers JDBC programming through a variety of interfaces including stand-alone Java programs, Java applets on web browsers, and Common Gateway Interface programs on web browsers. The course blends theory with practice, and students will use distributed database concepts to develop JDBC applications and JDBC drivers for implementing web-based distributed databases.
Prerequisites: 605.441 Principles of Database Systems, and 605.481 Distributed Development on the World Wide Web or equivalent knowledge of Java and HTML.
Spring  Silberberg

605.742  **XML: Technology and Applications**  
This course covers the concepts, technology, and applications of XML (Extensible Markup Language), especially to Web-based technologies. The course concentrates on XML fundamentals and associated technologies, and processing XML using Java. Topics covered include the XML Specification; XML Namespaces; Document Type Definitions (DTDs); XML Schemas; XML Transformation (XSLT); XML Links and XML Pointers; and parsing XML using the Document Object Model (DOM) and Simple API (Application Programming Interface) for XML (SAX), the Java API for XML Processing (JAXP), and the Java Document Object Model (JDOM). Additional topics may be drawn from Cascading Style Sheets (CSS); XQuery; the Simple Object-Oriented Protocol (SOAP); Web Services Description Language (WSDL); Universal Description, Discovery and Integration (UDDI); applications
of XML such as RDF; and the architecture of Web Service, EAI, and B2B systems using XML. (This course is the same as 635.781 XML: Technology and Applications.)

Prerequisite: 605.481 Distributed Development on the World Wide Web or equivalent Java experience.

Summer, Fall  McNamee, Navarro

605.743 The Semantic Web
The Semantic Web is an activity by the WWW Consortium to create a large set of XML-based languages, along with information on how various tags relate to real-world objects and concepts. This course covers Semantic Web technologies, including RDF (Resource Description Format—a structure for describing and interchanging metadata on the web) and OWL (Web Ontology Language), with domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies will be discussed. Students will complete a Semantic Web project in an application area of interest to them. Examples will be drawn from several application areas throughout the course, including the life sciences, knowledge management, electronic commerce and web services choreography. Domain-specific implementation strategies such as LSID (Life Sciences Identifier), and various vertical ontologies will be addressed.

Prerequisite: 605.742 XML: Technology and Applications or equivalent.

Summer, Fall (online)  Addison

605.744 Information Retrieval
A multibillion-dollar industry has grown to address the problem of finding information. For example, the Excite search engine was sold for $6 billion in 1999, and Google achieved a market capitalization of more than $100 billion in 2005. The technology underlying commercial search engines is based on information retrieval, the field concerned with the efficient storage, organization, and retrieval of text. This course covers both the theory and practice of text retrieval. Topics include automatic index construction, formal models of retrieval, Internet search, text classification, multilingual retrieval, question answering, and related topics in NLP and computational linguistics. A practical approach is emphasized and students will complete several programming projects to implement components of a retrieval engine. Students will also give a class presentation based on an independent project or a research topic from the IR literature.

Fall, Spring  McNamee, Navarro

605.745 Reasoning Under Uncertainty
This course provides an introduction to current research in uncertainty management, which is one of the central research areas within artificial intelligence. The principal focus of the course is on Bayesian networks, which are at the cutting edge of this research. Bayesian networks are graphical models which, unlike traditional rule-based methods, provide techniques for reasoning under conditions of uncertainty in a consistent, efficient, and mathematically sound way. While Bayesian networks are the main topic, the course examines a number of alternative formalisms as well. Specific topics include foundations of probability theory, Bayesian networks (knowledge representation and inference algorithms), belief functions (Dempster-Shafer theory), graphical models for belief functions, and fuzzy logic. Pertinent background in probability and theoretical computer science is developed as needed in the course.

Fall (odd years)  Zaret

605.746 Machine Learning and Data Mining
How can machines improve with experience? How can they discover new knowledge from a variety of data sources? What computational issues must be addressed to succeed? These are questions that are addressed in this course. Topics range from determining appropriate data representation and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing performance. Specific approaches covered include statistical techniques (e.g., k-nearest-neighbor and Bayesian learning), logical techniques (e.g., decision tree and rule induction), function approximation (e.g., neural networks and kernel methods), and reinforcement learning. The topics are discussed in the context of current machine learning and data mining research. Students will participate in seminar discussions and will complete and present the results of an individual project.

Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.

Fall (odd years)  Sheppard

605.747 Evolutionary Computation
Recently, principles from the biological sciences have motivated the study of alternative computational models and approaches to problem solving. This course explores how principles from theories of evolution and natural selection can be used to construct machines that exhibit nontrivial behavior. In particular, the course covers techniques from genetic algorithms, genetic programming, and artificial life for developing software agents capable of solving problems as individuals and as members of a larger community of agents. Specific topics addressed include representation and schemata; selection, reproduction, and recombination; theoretical models of evolutionary computation; optimal allocation of trials (i.e., bandit problems); search, optimization, and machine learning; evolution of programs; population dynamics; and emergent behavior. Students will participate in seminar discussions and will complete and present the results of an individual project.

Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.

Fall (even years)  Sheppard
605.751 Computational Aspects of Molecular Structure
This course focuses on computational methods for studying protein and RNA structure, protein-protein interactions and biological networks. Algorithms for prediction of RNA secondary structure, protein-protein interactions, annotation of protein secondary/tertiary structure and function are studied in depth. Students will apply various computer programs and structure-visualization software to secondary and tertiary protein structure prediction, structure-structure comparison, protein domain classification, annotation of functionally important sites and protein design. Interesting aspects of protein interaction and metabolic networks are also discussed.
Prerequisites: A course in molecular biology and a course in cell biology or biochemistry are highly recommended.
Spring Przytycka and Panchenko

605.753 Computational Genomics
This course focuses on current problems of computational genomics. Students will use bioinformatics software and learn the principles underlying a variety of bioinformatics algorithms. In addition, students will explore and discuss bioinformatics research, and develop software tools to solve bioinformatics problems. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes; finding genes in genomes and identifying their biological functions; predicting regulatory sites; assessing gene and genome evolution; and analyzing gene expression data.
Prerequisites: 605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.
Spring (online) Ermolaeva

605.754 Analysis of Gene Expression
The rapid popularization of microarray technology has led to an explosion in the collection of gene expression data. After a brief survey of existing gene expression software tools, this course emphasizes the development of original algorithms and data mining techniques for analyzing gene expression data. This course covers statistical and analytical methods and software development for the analysis of gene expression data. Topics include (1) a brief survey of existing software for microarray analysis (normalization, differential expression, and clustering); 2) algorithms, database design and data mining techniques for gene expression data; and 3) detailed coverage of analysis and reverse engineering of gene regulatory networks, including relevance networks, Boolean networks and continuous networks. Both static data and time series data will be considered. The student will develop sufficient expertise in both the underlying analysis and statistical theory to develop new algorithms and software to analyze gene expression data. Students will complete several software assignments including the design of a new algorithm for gene expression analysis.
Prerequisites: 605.205 or a course in molecular biology or cell biology, and a course in probability and statistics. Working knowledge of C or JAVA. JHU Online Orientation Course.

Notes: There are no exams, but programming assignments are intensive. Students in the MS Bioinformatics program may take both this course and 410.671 Microarrays and Analysis as the content is largely mutually exclusive.
Spring (online) Addison

605.755 Systems Biology
During the last decade, systems biology has emerged as an effective tool for investigation of complex biological problems, placing emphasis on the analysis of large-scale datasets and quantitative treatment of experimental results. In this course students will explore recent advances in systems biology analysis of intracellular processes. Examples of modeling and experimental studies of metabolic, genetic, signal transduction and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite or protein) driven approaches. Students will learn to use Boolean, differential equations, and stochastic methods of analysis and will become acquainted with several powerful experimental techniques, including basics of microfabrication and microfluidics. As a course project, students will develop a model of a signal transduction or metabolism pathway.
Prerequisites: Courses in molecular biology (605.205 or 410.602) and differential equations.
Spring (even years) Levchenko

605.759 Independent Project in Bioinformatics
This course is for students who would like to carry out a significant project in bioinformatics as part of their graduate program. The course may be used to conduct minor research, an in-depth literature survey, or a software implementation related to recent developments in the field. Students who enroll in this course are encouraged to attend at least one industry conference in bioinformatics related to their area of study. To enroll in this course, the student must be within two courses of degree completion and must obtain the approval and support of a sponsoring faculty member.

605.761 Applied Computer Graphics
This course examines advanced rendering topics in computer graphics. The course focuses on the mathematics and theory behind 3D graphics rendering. Topics include 3D surface representations including fractal geometry methods; visible surface detection and hidden surface removal; and surface rendering methods with discussion of lighting models, color theory, texturing, and ray tracing. Laboratory exercises provide practical application of these concepts. The course also includes a survey of graphics rendering applications (animation, modeling and simulation, and realistic rendering) and software. Students perform laboratory exercises using the C++ programming language.
Prerequisite: 605.461 Principles of Computer Graphics or familiarity with three-dimensional viewing and modeling transformations.
Spring (even years) Nesbitt
605.766 Human-Computer Interaction
Well-designed human-computer interaction is critical to the success of computer and information systems. This course focuses on the HCI design process and covers the underlying scientific principles, HCI design methodology, and the user interface technology used to implement HCI. Topics include human cognition, HCI theories, user observation and task analysis, prototyping and evaluation techniques, user interface modalities and graphical user interface components, and accessibility. Selected additional topics may include HCI in web site design, support of collaborative work, human interaction with automation, and ubiquitous computing. Student design projects are an integral part of the course. Reading the current HCI research literature is also required. (This course is the same as 635.721 Human-Computer Interaction.)

Spring
Gersh

605.771 Wired and Wireless Local and Metropolitan Area Networks
(formerly 605.771 Local Area Networks)
This course provides a detailed examination of wired and wireless Local and Metropolitan Area Network technologies, protocols and the methods used for implementing LAN and MAN based enterprise intranets. The structure and operation of the IEEE 802 media access control (MAC) and physical layer protocols are examined in detail. The 802.2 logical link control, 802.3/Ethernet, 802.4 token bus, and the 802.5 token ring protocols are analyzed, and the construction of LAN-based enterprise intranets is examined through a detailed analysis of bridging, routing, and switching techniques. High-speed LAN technologies are discussed through an examination of FDDI, Fast Ethernet, 100VG AnyLAN, ATM LAN Emulation (LANE) and Fibre Channel protocols along with the new standards for Gigabit and 10 Gigabit Ethernet. In addition, the 802.6 DQDB and 802.17 Resilient Packet Ring MAN protocols are discussed. Finally, the new and emerging wireless LAN and MAN standards are examined. The 802.11 (WiFi) wireless LAN and 802.15 (Bluetooth) wireless PAN standards are discussed in detail along with the emerging 802.16 (WiMAX) wireless MAN standard. Topics include Manchester and Differential Manchester encoding techniques; bus, star, and ring topologies; optical fiber, coaxial cable, and UTP media; baseband, broadband, and carrierband bus networks; hubs, switched LANs and full duplex LANs; VLANs and prioritization techniques; transparent and source routing bridge algorithms; packet bursting and carrier extension schemes; wireless spread spectrum and frequency hopping transmission techniques; wireless collision avoidance media access control; and security schemes. Students may use the network lab to configure LAN switches and Cisco routers, as well as to observe the interconnection of LAN networks.

Prerequisite: 605.471 Principles of Data Communications
Summer, Fall, Spring
Hsu, Nieporent

605.772 Network Management
Network management (NM) refers to all the functions, facilities, tools, communications interfaces, protocols, and human resources necessary to monitor and maintain communications networks and plan for their growth and evolution. NM includes investigation of day-to-day operations and administration of the networks. Within this framework, various aspects of managing voice and data networks are covered in this course. Management of specific network elements such as circuit and packet switches, multiplexers, and modems are addressed. The course also covers the concepts and fundamentals of NM standards such as OSI management standards and Simple Network Management Protocol (SNMP), which is a de facto standard.

Prerequisites: 605.771 Local Area Networks, 605.472 Computer Network Architectures and Protocols, 605.477 Internetworking with TCP/IP, or 635.411 Foundations of Networking and Telecommunications.
Summer, Spring
Krishnan, Malik

605.773 High-Speed Networking Technologies
Network evolution has been driven by the need to provide multimedia (i.e., voice, data, video, and imagery) communications in an efficient and cost-effective manner. Data, video, and imagery particularly warrant high-speed and high-capacity network technologies. Moreover, the emergence of the Internet and Internet-based services such as the World Wide Web (WWW) and the current trend toward converging voice and video services have accelerated the demand for high-speed network technologies. This course provides an in-depth understanding of various existing and emerging high-speed networking technologies. Specific technologies covered include Digital Transmission System, Digital Subscriber Line (DSL), Integrated Service Digital Network (ISDN), Frame Relay, Asynchronous Transfer Mode (ATM), Synchronous Optical Network (SONET), Wavelength Division Multiplexing (WDM), Dense WDM (DWDM), and Optical Networking.

Prerequisite: 605.471 Principles of Data Communications.
Summer, Fall
Krishnan

605.774 Network Programming
Emphasis is placed on the theory and practice associated with the implementation and use of the most common process-to-process communications associated with Unix. The inter-process communications comprise both local and distributed architectures. The distributed communications protocols include those most widely implemented and used: the worldwide Internet protocol suite (the Transmission Control Protocol/Internet Protocol [TCP/IP], and the U.S. government-mandated International Organization for Standardization [ISO] protocol suite). Practical skills are developed, including the ability to implement and configure protocol servers (daemons) and their clients. Students are expected to have working knowledge of Unix.

Prerequisite: 605.471 Principles of Data Communications Networks
Summer, Fall, Spring
Hsu, Nieporent
Prerequisite: 605.471 Principles of Data Communications Networks, or 605.414 Software Development in the Unix Environment, or 605.714 System Development in the Unix Environment.  

Fall, Spring  Noble

605.775 Optical Networking Technology

The Internet has hundreds of millions of users, is growing rapidly, and continues to evolve to accommodate an increasing number of voice, data, video, and imagery applications with diverse service requirements. Internet Protocol (IP) is the primary unifying protocol converging these applications and services over the Internet. The Internet’s evolution has been accompanied by exponentially growing traffic volume on the network infrastructure. Optical networks are ideally suited to carry such large volumes of traffic, and the next generation of optical networks will be optimized for delivery of IP services while providing capacity in the range of terabits per second in a scalable and flexible way to support service such as Voice Over IP (VoIP) and IP Television (IPTV). This course provides an in-depth understanding of existing and emerging optical network technologies. Specific topics covered include basics of fiber optic communications, SONET, DWDM, optical Ethernet, FT TB, FT TH, optical wavelength switching, IP over optical networks, MPLS, and GMPLS. Additional topics that may be discussed include optical network standards, network control and management, static and dynamic service provisioning, optical network design, and future directions.  

Prerequisite: 605.773 High-Speed Networking Technologies or permission of the instructor.  

Spring  Krishnan

605.777 Internetworking with TCP/IP II

This course builds on the foundation established in 605.477, Internetworking with TCP/IP I. Changes are being made in the infrastructure, operation, and protocols of the Internet to provide the performance and services needed for real-time applications. This course first examines the current architecture and operation of the Internet. The classful addressing concept will be introduced and the mapping of Internet addresses to physical addresses is discussed along with the extensions that have been made to the addressing paradigm, including subnet addressing, classless addressing, and network address translation. The performance enhancements being developed to provide quality of service (QoS) over the Internet and to provide faster routing through the use of IP switching techniques are discussed. Techniques for providing multicasting and mobility over the Internet are examined. Security considerations are addressed by examining Virtual Private Networks and the use of IP Security (IPSec) protocols. The next generation IP protocol (IPv6) is introduced, and the changes and enhancements to the IP protocol operation and to the addressing architecture are discussed in detail. Finally, the development of the Voice Over IP (VoIP) application and the convergence of circuit switching and packet switching are discussed. Topics include subnet addressing, CIDR, DHCP, DNS, NAT, IntServ, DiffServ, RSVP, CIP, MPOA, IP Switching, Tag Switching, MPLS, IP Multicast, IGMP, Reliable Multicast, Multicast Routing Protocols, IP Mobility Home Agents and Foreign Agents, Message Tunneling, Proxy and Gratuitous ARP, VPN Tunneling, PPTP, L2F, L2TP and SOCKSv5, VPN security, IPsec, Encapsulating Security Payload header, Authentication Header, Security Association, IPv6 Addressing, IPv6 protocol and extension headers, Neighbor Discovery, IPv6 Stateless Address Autoconfiguration, DHCPv6, VoIP, H.323 Gateways and Gatekeeper, SIP, SDP, RTP, MGCP, Megaco/H.248.  

Prerequisite: 605.477 Internetworking with TCP/IP I.  

Summer, Fall, Spring  Nieporent

605.778 Voice over IP

The Internet has been growing exponentially and continues to evolve to accommodate an increasingly large number of applications with diverse service requirements. A remarkable aspect of this evolution is the convergence of real-time communications services with traditional data communications services over the Internet. In particular, Internet Telephony, or Voice over IP is one of the most promising services currently being deployed. While there are many benefits to Voice Over IP such as cost effectiveness and enhanced features, there exist a number of barriers to the widespread deployment of Internet Telephony. The purpose of this course is to provide in-depth understanding of the concept and operation of Voice Over IP and discuss issues and strategies to address the issues. In this course, students will gain understanding of how to adapt an IP packet network, which is basically designed for data, to provide wide-area voice communications. Topics include telephony fundamentals, Voice Over IP concepts, adapting IP networks to support voice, H.323 and SIP signaling protocols, QoS issues in IP networks, IETF standards, and network management.  

Prerequisite: 605.477 Internetworking with TCP/IP I, or 605.773 High-Speed Networking Technologies, or significant Internet technology-related work experience.  

Fall, Spring  Krishnan

605.781 Distributed objects

This course provides an introduction to the development of client/server and peer-to-peer applications using distributed technology. The course focuses on the services and facilities provided by object-oriented middleware systems such as CORBA, COM, and Java/RMI. Topics include interface definition languages (IDL), static and dynamic invocation interfaces, object references, distributed resource optimization, and concurrency control. Students will develop software in C++ for both homework and a project.  

Prerequisite: 605.404 Object Oriented Programming with C++ or equivalent experience.  

Fall, Spring  Lindberg, Pole
605.782 Web Application Development with Servlets and JavaServer Pages (JSP)

This project-oriented course investigates techniques for building server-side programs for dynamically generated Web sites, electronic commerce, Web-enabled enterprise computing, and other applications that require WWW access to server-based resources. Particular attention will be paid to methods for making server-side applications efficient, maintainable, and flexible. Topics include handling HTTP request information, generating HTTP response data, processing cookies, tracking sessions, designing custom JSP tag libraries, and separating content from presentation through use of JavaBeans components and the MVC (Model 2) architecture.

**Prerequisite:** 605.481 or equivalent Java experience.

Summer, Fall, Spring

Chittargi, Hall

605.783 Reusable Software Components with Java Beans

This course covers the architecture, design, and development of software components that can be instantiated, customized, and interconnected. The main topics include component architectures, design patterns, internal mechanisms of the Java Beans API, the bean development kit (BDK), bean properties, event handling, introspection, customization, the bean deployment mechanism, and persistence. In addition, advanced Java beans capabilities, distributed components, security issues, and printing will be discussed. A comparison of Java beans to other component-based technologies will be presented. This course demonstrates a variety of frameworks and applications built based on Java beans.

**Prerequisites:** 605.481 Distributed Development on the WWW or equivalent.

Fall, Spring

Chittargi, Hall

605.784 Enterprise Computing with Java

This course covers enterprise computing technologies using Java Enterprise Edition (Java EE). The course describes how to build multi-tier distributed applications, specifically addressing web access, business logic, data access, and applications supporting Enterprise Service technologies. For the web access tier, the focus will be on development using Servlets and JSP with an emphasis on integrating the web tier with enterprise applications. For the Business Logic Tier, session beans for synchronous business processing and message-driven beans and timers for asynchronous business processing will be described. The Data Access tier discussion will focus on Java Database Connectivity (JDBC), data access patterns, and the Java Persistence API. Finally, enterprise services will be discussed, including the Java Naming and Directory Interface (JNDI), the Java Message Service (JMS), Remote Method Invocation (RMI), Java Transaction API (JTA), and Java EE Security. Students will build applications using the technologies presented.

**Prerequisite:** 605.481 Distributed Development on the WWW or equivalent.

Summer, Fall, Spring

Felixson, Shyamsunder, Stafford, Weimer

605.785 Web Services: Framework, Process, and Applications

Web services is a technology, process, and software paradigm to extend the Web from an infrastructure that provides services for humans to one that supports business integration over the Web. This course presents concepts, features, and architectural models of web services from three perspectives: framework, process, and applications. Students will study the stack of three emerging standard protocols: Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL), and Universal Description, Discovery and Integration (UDDI). Students will also learn how to describe, expose, discover, and invoke software over the Web using the Java-centric technologies and APIs for XML for documents processing, JAXP, JAXRPC, SAAJ, JAXM, JAXR, and JAXB. A comparison of Java-based and other web services implementation platforms will also be presented. Finally, the course will review other web services specifications and standards, and it will describe the use of web services to resolve business applications integration issues. WSI Basic Profile and other guidance documents and recommended practices will be discussed in the context of achieving high levels of web services interoperability.

**Prerequisites:** 605.742 XML: Technology and Applications or equivalent XML and Java programming experience; knowledge of the J2EE platform and programming model is recommended.

Summer, Fall, Spring

Felixson

605.786 Enterprise System Design and Implementation

This course explores enterprise architectures for the development of scalable distributed systems. Effective patterns for distributed data access, MVC-based web tiers, and business logic components are explored as students build complex applications. Factors such as caching and clustering that enable distributed systems to scale to handle potentially thousands of users are a primary focus. In addition, creating a reusable blueprint for an enterprise architecture will be discussed. Applications developed utilizing these concepts are selected from current research topics in information retrieval, data visualization, and machine learning.

**Prerequisite:** 605.784 Enterprise Computing with Java. 605.707 Software Patterns or equivalent experience is recommended.

Spring

Weimer

605.791 New Technical Ventures

This course is intended for those who are considering forming their own high tech or Internet venture or developing new technical ventures within their existing organizations. The purpose of the course is to provide a basic understanding of the success factors of a new venture including personal, technical, and market factors. In addition, the course seeks to prepare potential entrepreneurs to plan a venture, write a business plan, assemble a team, and secure financing. Course topics include the traits of an entrepreneur, market analysis, product
positioning, competitive advantage, securing venture capital and funding, corporate partners and joint ventures, building organizations, and managing growth. The course will draw heavily on case studies of technology-based businesses. Students will work individually or in small groups to develop a product concept and a business plan around a new innovation in their concentration area.

Prerequisite: Students should be in the second half of their MS degree, or enrolled in the Certificate for Technical Innovation and New Ventures, and have two years of work experience.

Summer, Fall, Spring

605.801 Independent Study in Computer Science I

This course permits graduate students in computer science to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper or project.

Prerequisites: Seven computer science graduate courses including the foundation courses, three concentration area courses, and two courses numbered 605.7xx; or admission to the advanced certificate for post-master's study. Students must also have permission from the instructor.

605.802 Independent Study in Computer Science II

Students wishing to take a second independent study in computer science should sign up for this course.

Prerequisites: 605.801 and permission of a faculty mentor, the student’s academic adviser, and the program chair.
Electrical and Computer Engineering

Electrical and computer engineering is concerned with the use of electrical phenomena for communication, computation, information transformation, measurement, and control. Within these broad categories there exist application areas affecting nearly every facet of society. Electrical engineering draws upon mathematics and the basic sciences of physics, chemistry, and materials in developing the technology leading to new devices, and the techniques for describing and designing the processes that take place in electrical systems. The strength of the Hopkins program lies in the active involvement of the faculty in research and development, and the faculty’s commitment to fostering students’ understanding of the theory and practice of the discipline.

Within the Whiting School of Engineering, two master’s degree programs are offered in electrical and computer engineering, the Master of Science and the Master of Science in Engineering.

The Master of Science (M.S.) degree is offered through the part-time programs and is administered by a program committee. The M.S. program course requirements are described in detail below. It provides graduate education in both the fundamentals of various branches of electrical engineering and in the more specific aspects of current technologies of clear importance. The aim is to serve working engineers primarily; nearly all students participate part-time. All courses are offered in evening hours at the Applied Physics Laboratory and at the Dorsey Center and Montgomery County Campus. The faculty are drawn from the technical staff of the Applied Physics Laboratory, from government and local industry, and from the full-time faculty of the Department of Electrical and Computer Engineering.

The areas of interest within the M.S. program span a broad spectrum of specialties. Courses are offered within the general areas of telecommunications, computer engineering, RF and microwave engineering, photonics, electronics, and the solid state, signal processing, and systems and control.

The Master of Science in Engineering (M.S.E.) degree is offered and administered by the Department of Electrical and Computer Engineering. Courses are offered during the day and late afternoon hours, mainly at the Homewood campus. Admission and graduation requirements are similar to those of the M.S. program, and interactions are possible. The M.S.E. program provides graduate education in the context of an academic department. The aim is to provide master’s level work in closer contact with full-time faculty and Ph.D. candidates than is the case in the M.S. program. The faculty are drawn primarily from the Department of Electrical and Computer Engineering, but also from the technical staff of the Applied Physics Laboratory. Additional information concerning the M.S.E. program, including the catalog and admission materials, may be obtained from the Department of Electrical and Computer Engineering.

Program Committee

Dexter G. Smith, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Brian K. Jennison, Program Vice Chair
Senior Professional Staff
Applied Physics Laboratory

Charles Alexander
Senior Electrical Engineer
Department of Defense

Robert S. Bokulic
Principal Professional Staff
Applied Physics Laboratory

Ralph Etienne-Cummings
Associate Professor, Electrical and Computer Engineering
Whiting School of Engineering

Andrew D. Goldfinger
Principal Professional Staff
Applied Physics Laboratory

Daniel G. Jablonski
Principal Professional Staff
Applied Physics Laboratory

Richard I. Joseph
Professor, Electrical and Computer Engineering
Whiting School of Engineering

Jim Ung Kang
Professor, Electrical and Computer Engineering
Whiting School of Engineering

John E. Penn
Senior Professional Staff
Applied Physics Laboratory

Michael E. Thomas
Principal Professional Staff
Applied Physics Laboratory

Douglas S. Wenstrand
Senior Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to graduate programs outlined in this catalog. In addition, applicants are expected to have (1) majored in an Accreditation Board for Engineering and Technology (ABET)-accredited electrical engineering program and (2) compiled an average of B (3.0 on a 4.0 scale) or above for all courses in mathematics, engineering, and the physical sciences. Applicants who majored in a related science or engineering field may also be accepted as candidates, provided their background is judged by the admissions committee to be equivalent to that stated above.
Telecommunications Option

Electrical and computer engineering students who select the telecommunications option must complete the standard program requirements above with the following additional requirements. Of the minimum of seven electrical engineering courses at least five must be telecommunications courses. Of the maximum of three electives, at least two must be from the computer science networking option courses. See the Telecommunications and Networking Option page for a complete description of the telecommunications and networking option and the courses that apply.

Photonics Option

The M.S. in Electrical and Computer Engineering degree may be attained with a special option in photonics. This option will be noted on the student’s transcript. The photonics option comprises a required core of three optics courses (525.413, 525.425, and 525.491), combined with three additional optics courses selected from the list below (“Photonics”). The four courses needed to complete the degree may be any courses approved by the adviser, selected so as to fulfill the general requirements for the M.S. described below. Applicants for the M.S. who desire to participate in the photonics option should so note on their application form.

Course Requirements

Each degree candidate for the M.S. is assigned an adviser. Attainment of the degree requires completion of 10 one-term courses, specifically approved by the adviser, at least seven of which must be in electrical engineering. All courses must be numbered at or above the 400-level. At least four of the 10 required courses must be at the 700-level or above. At most, one course with a grade of C may be used and no course with a grade lower than C. The electrical engineering courses may be selected from among those offered through the M.S. degree program, distinguished by the course prefix 525, and listed below, or from among courses offered in the M.S.E. program of the Department of Electrical and Computer Engineering. These latter are distinguished by the prefix 520. and are listed in the Arts and Sciences/Engineering Undergraduate and Graduate Programs Catalog. Limited opportunity is available for replacement of course work by appropriate project work (see the courses 525.801 and 525.802 below).

At most, three of the 10 courses required for the M.S. degree may be selected with adviser approval from outside electrical and computer engineering. Students in the telecommunications and networking option must select at least two from the computer science networking electives. Although most students who desire an elective course select from among the offerings of the applied mathematics, applied physics, and computer science sections of this catalog, advisers have broad flexibility to approve other suitable courses in science or engineering. (Note that the courses 615.441 Mathematical Methods for Physics and Engineering, 615.442 Electromagnetics, 615.780 Optical Detectors and Applications, and 625.743 Stochastic Optimization and Control are treated as electrical engineering courses rather than as electives).

For convenient reference, the course offerings of the Master of Science in Electrical and Computer Engineering program are listed below in technology groupings. Although most students choose from within one or two groupings, no particular restrictions apply.

I. Telecommunications

525.408 Digital Telephony
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.437 Telecommunications Signal Processing
525.438 Introduction to Wireless Technology
525.439 Introduction to High-Speed Networks
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.444 Introduction to ATM Networks and Video Applications
525.707 Error Control Coding
525.722 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.747 Speech Processing
525.754 Wireless Communication Circuits I
525.755 Wireless Communication Circuits II
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread Spectrum Communications
525.789 Digital Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems
525.795 Advanced Communications Laboratory

Note: Computer science course electives accepted for the telecommunications and networking option are listed on the Telecommunications and Networking page.

II. Computer Engineering

525.411 Theory of Digital Systems
525.412 Computer Architecture
525.415 Microprocessor Systems
525.417 Computer-Aided Engineering of Digital Systems
525.434 High Speed Digital Design and Signal Integrity
III. RF and Microwave Engineering

- 525.418 Antenna Systems
- 525.420 Electromagnetic Transmission Systems
- 525.423 Principles of Microwave Circuits
- 525.445 Modern Navigation Systems
- 525.484 Microwave Systems and Components
- 525.731 Principles of Radar I
- 525.732 Principles of Radar II
- 525.738 Advanced Antenna Systems
- 525.774 RF and Microwave Circuits I
- 525.775 RF and Microwave Circuits II
- 525.787 Microwave Monolithic Integrated Circuit (MMIC) Design
- 525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design
- 525.791 Microwave Communications Laboratory
- 615.442 Electromagnetics

IV. Photonics

- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
- 525.573 Laser Systems and Applications
- 525.576 Optical Propagation, Sensing, and Backgrounds
- 525.772 Fiber-Optic Communication Systems
- 525.792 Electro-Optical Systems
- 525.796 Introduction to High-Speed Electronics and Optoelectronics
- 525.797 Advanced Optics and Photonics Laboratory

Note: 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.

Electives appropriate to the Photonics Option:
- 615.471 Principles of Optics
- 615.472 Optical Remote Sensing
- 615.751 Modern Optics
- 615.752 Statistical Optics
- 615.778 Computer Optical Design

V. Electronics and the Solid State

- 525.406 Electronic Materials
- 525.407 Introduction to Electronic Packaging
- 525.421 Introduction to Electronics and the Solid State I
- 525.422 Introduction to Electronics and the Solid State II
- 525.424 Analog Electronic Circuit Design I
- 525.428 Introduction to Digital CMOS VLSI
- 525.429 Theory and Design of Active Analog Filters
- 525.432 Analog Electronic Circuit Design II
- 525.705 Micropower VLSI System Design
- 525.713 Micropower Integrated Circuit Design
- 525.725 Power Electronics
- 525.794 Advanced Topics in VLSI Technology

VI. Signal Processing

- 525.419 Introduction to Digital Image and Video Processing
- 525.427 Digital Signal Processing
- 525.430 Digital Signal Processing Lab
- 525.431 Adaptive Signal Processing
- 525.446 DSP Hardware Lab
- 525.467 Applied Bayesian and Entropic Methods
- 525.718 Multi-Rate Digital Signal Processing
- 525.721 Advanced Digital Signal Processing
- 525.724 Introduction to Pattern Recognition
- 525.728 Detection and Estimation Theory
- 525.745 Applied Kalman Filtering
- 525.746 Image Engineering
- 525.747 Speech Processing
- 525.762 Signal Processing with Wavelets
- 525.780 Multidimensional Digital Signal Processing

VII. Systems and Control

- 525.409 Continuous Control Systems
- 525.414 Probability and Stochastic Processes for Engineers
- 525.466 Linear System Theory
- 525.763 Applied Nonlinear Systems
- 525.769 Digital and Sampled-Data Control
- 525.770 Intelligent Algorithms
- 525.777 Control System Design Methods
- 525.786 Model Building for Dynamic Systems
- 615.441 Mathematical Methods for Physics and Engineering
- 625.743 Stochastic Optimization and Control
Course Descriptions

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

**525.406 Electronic Materials**
Materials and the interfaces between them are the key elements in determining the functioning of electronic devices and systems. This course develops the fundamental parameters of the basic solid material types and their relationships to electrical, thermal, mechanical, and optical properties. The application of these materials to the design and fabrication of electronic components is described, including integrated circuits, passive components, and electronic boards, modules, and systems.

**Prerequisites:** An undergraduate degree in engineering, physics, or materials science; familiarity with materials structures and electronic devices.

Charles

**525.407 Introduction to Electronic Packaging**
Topics include fundamentals of electronic packaging engineering and basic concepts in thermal, mechanical, electrical, and environmental management of modern electronic systems. Emphasis is on high-frequency (and high-speed) package performance and its achievement through the use of advanced analytical tools, proper materials selection, and efficient computer-aided design. Packaging topics include die and lead attachment, substrates, hybrids, surface-mount technology, chip and board environmental protection, connectors, harnesses, and printed and embedded wiring boards.

**Prerequisite:** An undergraduate degree in a scientific or engineering area, including familiarity with computer-aided design and engineering analysis methods for electronic circuits and systems.

Charles

**525.408 Digital Telephony**
This course examines communication techniques for the transmission in voice of various channels. Topics include characteristics of speech and voice digitization; bandwidth minimization and voice compression; digital modulation and standards; transmission via fiber, terrestrial microwave, and satellite channels; cellular telephone architectures and networks; and digital switching architectures and networks.

**Prerequisites:** Either an undergraduate degree in electrical engineering or 525.416 Communications Systems Engineering, or consent of the instructor.

Harshbarger, Blodgett

**525.409 Continuous Control Systems**
This course examines classical methods of analysis and design of continuous control systems. Topics include system representation by linear time invariant ordinary differential equations, performance measures, sensitivity, stability, root locus, frequency domain techniques, and design methods. Several practical examples are considered. Matlab is used as a computational tool.

**Prerequisites:** Matrix theory and linear differential equations.

Palumbo

**525.411 Theory of Digital Systems**
This course covers modern digital theory, finite automata theory, and the design of digital systems for the implementation of computation schemes. Topics include number and algebraic systems; representation of algorithmic state machines; Reed-Muller algebraic descriptions and linear sequential circuits; threshold gates and multiple-valued switching circuits; and advanced design methods using programmable logic arrays, LSI building blocks, and VLSI gate arrays. Design of sequential circuits, parallel processing circuits, serial processing circuits, and implementation of high speed logic with cellular and modular systems are also covered.

**Prerequisite:** An undergraduate degree in electrical engineering or equivalent.

Note: This course is not recommended for students who have completed an undergraduate course in digital systems or have equivalent experience.

Veronis

**525.412 Computer Architecture**
This course covers organization, structure, and design of computers, starting with a review of the original Von Neumann machine. Major architectural improvements since 1950 are reviewed, and the contemporary view of multilevel, virtual machines is introduced. Topics include instruction set designs including RISC, addressing, interrupt and trap handling, stacks, data paths control, horizontal and vertical microprogramming, busses, paging, segmentation, and cache. Mapping of twos complement arithmetic onto register level hardware, including simple control units for Booth’s algorithm and non-restoring division, is also covered.

**Prerequisite:** A senior-level course in digital design.

Cameron

**525.413 Fourier Techniques in Optics**
In this course, the study of optics is presented from a perspective which uses the electrical engineer’s background in Fourier analysis and linear systems theory. Topics include scalar diffraction theory, Fourier transforming and imaging properties of lenses, spatial frequency analysis of optical systems, spatial filtering and information processing, and holography. The class discusses applications of these concepts in non-destructive evaluation of materials and structures, remote sensing, and medical imaging.

**Prerequisites:** An undergraduate background in Fourier analysis and linear systems theory.

Young
525.414 Probability and Stochastic Processes for Engineers
This course provides a foundation in the theory and applications of probability and stochastic processes and an understanding of the mathematical techniques relating to random processes in the areas of signal processing, detection, estimation, and communication. Topics include the axioms of probability, random variables, and distribution functions, functions and sequences of random variables; stochastic processes; and representations of random processes.
Prerequisite: An undergraduate degree in electrical engineering.
   R. Lee, Murphy, Ambrose

525.415 Microprocessor Systems
This course applies microprocessors as an integral element of system design. Techniques required for successful incorporation of microprocessor technology are studied and used. Hardware and software design considerations which affect product reliability, performance, and flexibility are covered. Students use hardware to gain familiarity with machine and assembly language for software generation, interfacing to a microprocessor at the hardware level, and emuiration to check out system performance.
Prerequisite: Some experience in designing and building digital electronic systems and 525.411 Theory of Digital Systems or equivalent knowledge.
   Wenstrand, Haber

525.416 Communication Systems Engineering
In this course, students receive an introduction to the principles of communication systems engineering. Students examine analog and digital communication including linear (AM, DSB, SSB) and exponential (PM, FM) modulation, sampling, noise and filtering effects, quantization effects, detection error probabilities, and coherent and noncoherent communication techniques.
Prerequisite: A working knowledge of Fourier transforms, linear systems, and probability theory.
   Alexander, R. Lee

525.417 Computer-Aided Engineering of Digital Systems
This course introduces design automation techniques for digital hardware designers. Topics include schematic capture, hierarchical design, simulation models, logic and fault simulation, testability analysis, programmable logic design and automatic test equipment. The students work with computer-aided engineering software in the lab to design digital subsystems. This course is intended for students without previous computer-aided engineering experience.
Prerequisite: 525.411 Theory of Digital Systems or the equivalent.
   DeMatt

525.418 Antenna Systems
This course develops fundamental antenna concepts and uses them to analyze basic antenna systems. Physical as well as electrical characteristics are considered for a variety of applications. Examples of actual systems are presented and recent advances discussed. Topics include physical principles of radiation and dipole and loop polarization. Basic antenna concepts include wire radiators, linear and planar arrays, horns, reflecting and nonreflecting apertures, lenses, broad-band systems, printed circuit antennas, and antenna measurements.
Prerequisite: A course in microwave engineering, such as 525.423 Principles of Microwave Circuits or 525.420 Electromagnetic Transmission Systems.
   Weiss

525.419 Introduction to Digital Image and Video Processing
This course provides an introduction to the basic concepts and techniques used in digital image and video processing. Two-dimensional sampling and quantization are studied, and the human visual system is reviewed. Edge detection and feature extraction algorithms are introduced for dimensionality reduction and feature classification. High-pass and bandpass spatial filters are studied for use in image enhancement. Applications are discussed in frame interpolation, filtering, coding, noise suppression, and video compression. Some attention will be given to object recognition and classification, texture analysis in remote sensing, and stereo machine vision.
Prerequisite: 525.427 Digital Signal Processing.
   Nasrabadi

525.420 Electromagnetic Transmission Systems
This course examines transmission systems used to control the propagation of electromagnetic traveling waves with principal focus emphasizing microwave and millimeter-wave applications. The course reviews standard transmission line systems together with Maxwell’s equations and uses them to establish basic system concepts such as reflection coefficient, characteristic impedance, input impedance, impedance matching, and standing wave ratio. Specific structures are analyzed and described in terms of these basic concepts, including coaxial, rectangular, and circular waveguides, surface waveguides, striplines, microstrips, coplanar waveguides, slotlines, and finlines. Actual transmission circuits are characterized using the concepts and analytical tools developed.
Prerequisite: An undergraduate degree in electrical engineering or equivalent.
   Sequeira, Jablonski

525.421 Introduction to Electronics and the Solid State I
Fundamentals of solid state and device physics are presented. Topics in solid state physics include crystal structure, lattice vibrations, dielectric and magnetic properties, band theory, and transport phenomena. Concepts in quantum and statisti-
525.422 Introduction to Electronics and the Solid State II
This course reviews the fundamentals of device physics and electronics. Topics in device electronics include bipolar and MOS transistors, Schottky barriers, transferred electron and tunnel devices, semiconductor lasers, and solar cells. Concepts in device structure, modeling, and performance are described.

Prerequisite: 525.421 Introduction to Electronics and the Solid State I or approval of the instructor.
Note: Interested students should note the availability of the elective course 615.764 Solid State Materials and Devices Laboratory.

525.423 Principles of Microwave Circuits
This course addresses foundational microwave circuit concepts and engineering fundamentals. Topics include electromagnetics leading to wave propagation and generation, the transmission line, and impedance/admittance transformation and matching. Mapping and transformation are presented in the development of the Smith Chart. The Smith Chart is used to perform passive microwave circuit design. Microwave networks and s-matrix are presented; Mason’s Rules are introduced. Circuits are physically designed using microstrip concepts, taking into consideration materials properties, connectors, and other components.

525.424 Analog Electronic Circuit Design I
This course examines the use of passive and active components to perform practical electronic functions. Simple circuits are designed and evaluated emphasizing the characteristics and tolerances of actual components. Devices studied include diodes and bipolar and field effect transistors. Circuit designs are studied in relation to the device characteristics, including small signal amplifiers and oscillators and linear power supply and amplifier circuits. SPICE modeling is available to students.

Prerequisites: Undergraduate courses in electricity and magnetism, circuit theory, and linear analysis.

525.425 Laser Fundamentals
This course reviews electromagnetic theory and introduces the interaction of light and matter with an emphasis on laser theory. A fundamental background is established, necessary for advanced courses in optical engineering. Topics include Maxwell’s equations, total power law, introduction to spectroscopy, classical oscillator model, Kramers-Kroenig relations, line broadening mechanisms, rate equations, laser pumping and population inversion, laser amplification, laser resonator design, and Gaussian beam propagation.

Prerequisite: An undergraduate course in electromagnetic theory.

525.427 Digital Signal Processing
Basic concepts of discrete linear shift-invariant systems are emphasized, including sampling, quantization, and reconstruction of analog signals. Extensive coverage of the Z-transform, discrete Fourier transform, and fast Fourier transform is given. An overview of digital filter design includes discussion of impulse invariance, bilinear transform, and window functions. Filter structures, finite length register effects, roundoff noise, and limit cycles in discrete-time digital systems are also covered.

Prerequisites: A working knowledge of Fourier and Laplace transforms.

525.428 Introduction to Digital CMOS VLSI
The objective of this course is to familiarize the student with the process of implementing a digital system as a full custom, integrated circuit. Upon completion, the student will be capable of completing skills to perform basic VLSI design from circuit concept to mask layout and simulation. Students will have the opportunity to have their projects fabricated at no cost through the MOSIS educational program. Topics include device fabrication, mask layout, introductory MOSFET physics, standard CMOS logic design, hierarchical IC design, and circuit simulation. Students will design, simulate, and do mask level layout of a circuit using a modern CMOS process.

Prerequisite: 525.411 Theory of Digital Systems or equivalent background in digital design.

525.429 Theory and Design of Active Analog Filters
Analog filters play an important role in numerous electronic systems. This course introduces the concepts of analog filters such as basic filter functions, transfer functions, response and phase shift, filter order, log scales, filter types, filter approximations, principles of op amps. As well as, differences between analog and digital filters. The student will be exposed to a number of freeware filter design programs and will be asked to use these programs to demonstrate knowledge gained throughout the course.

Prerequisite: An undergraduate degree in electrical engineering and basic knowledge of the theory of electronic circuits.
525.430 Digital Signal Processing Lab
This course builds on the theory of digital signal processing. Opportunities are provided to work on specific applications of digital signal processing involving filtering, de-convolution, spectral estimation, and a variety of other techniques. Students may also suggest their own laboratory topics. Laboratory work involves developing signal processing systems on a personal computer and using them with both real and simulated data. Questions related to hardware realizations are also considered.
Prerequisite: 525.427 Digital Signal Processing.
Fry

525.431 Adaptive Signal Processing
This course examines adaptive algorithms (LMS, sequential regression, random search, etc.) and structures (filters, control systems, interference cancellers), and properties and uses of performance surfaces. Adaptive systems are implemented as part of the course work. Problem exercises and a term project require computer use.
Prerequisite: 525.427 Digital Signal Processing. Some knowledge of probability helpful.
Costabile

525.432 Analog Electronic Circuit Design II
This course extends the fundamental concepts of practical electronic circuit design developed in the course 525.424 Analog Electronic Circuit Design I. The general feedback method is reviewed. Students examine a wide range of devices, including operational amplifiers, A/D and D/A converters, switching regulators and power supplies. Applications include low noise amplification and sensor conditioning, nonlinear transfer functions, analog computation, and power control.
Prerequisite: 525.424 Analog Electronic Circuit Design I or permission of the instructor.
Darlington

525.434 High Speed Digital and Signal Integrity
This course will discuss the principles of signal integrity and its applications in the proper design of high-speed digital circuits. Some of the topics discussed are the following: the definition and fundamentals of signal integrity, the fallacies believed by digital designers, ground/power planes, PCI series termination resistors, simulation software and signal integrity, ground bounce calculations, power bus noise, high-speed return signals, transmission lines, gate delay, differential pair skew, bypass capacitor layout, cable shield grounding, power-ground source impedance, open drain lines, series termination, equivalent circuit source impedance, terminators, crosstalk and SSO noise, gigabit ethernet specification, and short transmission line model.
Prerequisite: Thorough knowledge of digital design and basic circuit theory.
Veronis

525.436 Optics and Photonics Laboratory
The objective of this course is to develop laboratory skills in optics and photonics by performing detailed experimental measurements and comparing these measurements to theoretical models. Error analysis is used throughout to emphasize measurement accuracy. A partial list of topics includes geometric optics, optical properties of materials, diffraction, interference, polarization, non-linear optics, fiber optics, non-linear fiber optics, optical detectors (pin, APD, PMT), optical sources (lasers, blackbodies, LED’s), phase and amplitude modulators, lidar, fiber-optic communications, IR radiometry. The specific experiments will depend on hardware availability and student interest.
Prerequisite: 525.491 Fundamentals of Photonics or 615.751 Modern Optics or equivalent.
Sova, Terry

525.437 Telecommunications Signal Processing
This course integrates and extends the fundamental concepts in communications and signal processing to telecommunications signal processing (TSP). Analysis and design methods are developed and compared for several theoretical and practical TSP systems. Topics include data and voice communications, echo cancellers and suppressors, channel filter banks, adaptive arrays, transmultiplexers, delta/sigma modulation, and speech compression. Students examine industrial applications, and they gain experience from practical examples and an assigned class project.
Prerequisite: 525.416 Communication Systems Engineering or equivalent.
Alexander

525.438 Introduction to Wireless Technology
This course introduces students to the modern technology involved with commercial wireless communications systems such as digital cellular, personal communications systems (PCS), wireless local area networks (WLAN), code division multiple access (CDMA) systems, and other topics. Various multiple access methods and signal formats are considered. Hardware implementations of system components are presented and analyzed. Modulation and demodulation architectures are introduced and modeled using PC-based tools.
Prerequisites: An undergraduate degree in electrical engineering or the equivalent. Experience with Matlab and Simulink will be helpful.
DeCiccio, Roddewig

525.439 Introduction to High-Speed Networks
This course provides a broad introduction to the basic concepts of high-speed wide area networks, such as frame relay, FDDI and FDDI-II, DQDB, SMDS, ATM, fast Ethernet, and 100VG-AnyLAN. The concepts and architecture of SONET/SDH are also reviewed. The principal parameters, formats, protocol layers, physical layers, and interfaces of these network architectures are discussed. The course begins by reviewing circuit switching, packet switching, and cell switching con-
cepts, as well as ISDN and X.25. Frame relay protocol, traffic rate management, and network congestion management are also covered. High speed MANs, such as FDDI, FDDI-II, and DQDB are introduced and their operations are described. SMDS service is reviewed and compared with frame relay service. Key features of ATM are discussed, such as cell formats, asynchronous multiplexing to mix different traffic types, congestion control, and traffic policing. Finally, the course explores emerging high speed LANs and virtual LANs.

Prerequisite: A basic course in data communications, such as 525.441 Computer and Data Communication Networks I, or an introductory course in local area networks.

Nasrabadi

525.440 Satellite Communications Systems

This course presents the fundamentals of satellite communications link design and provides an overview of practical considerations. Existing systems are described and analyzed, including direct broadcast satellites, VSAT links, and Earth-orbiting and deep space spacecraft. Topics include satellite orbits, link analysis, antenna and payload design, interference and propagation effects, modulation techniques, coding, multiple access, and Earth station design.

Prerequisite: 525.416 Communication Systems Engineering.

DeBoy, Carmody

525.441 Computer and Data Communication Networks I

This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks. Networking principles covered include layered network architecture, data encoding, static and multiaccess channel allocation methods (for LAN and WAN), ARQ retransmission strategies, framing, routing strategies, transport protocols, and emerging high speed networks.

Prerequisites: 525.414 Probability and Stochastic Processes for Engineers and 525.416 Communication Systems Engineering, or equivalents.

Nasrabadi, Hanson

525.442 VHDL/FPGA Microprocessor Design

This lab-oriented course covers the design of digital systems using VHDL Hardware Description Language and their implementation in Field Programmable Gate Arrays. This technology allows cost-effective unique system realizations by enabling design reuse and simplifying custom circuit design. The design tools are first introduced and used to implement basic circuits. Simple microprocessors are then introduced, followed by more advanced processor concepts, including processors with unique instructions, different architectures, and unique peripherals. Projects will be assigned for course evaluation. Individual projects will be encouraged. The issue of intellectual property will also be introduced since this is a major concern as design complexity increases.

Prerequisite: 525.415 Microprocessor Systems is suggested but not required, as well as an understanding of digital logic fundamentals.

Wenstrand, Haber

525.444 Introduction to ATM Networks and Video Applications

This course provides an introduction to the basic concepts and techniques used in asynchronous transfer mode (ATM) communications networks. The course reviews circuit and packet switching techniques, local area networks (LAN), N-ISDN, B-ISDN, and high speed local and metropolitan area networks (MAN). Other topics covered include introduction to ATM standards and protocols; ATM layer, ATM adaptation layer, and physical layer; ATM switching architectures; call and connection control, traffic control, and network management; packet video, including characterization of video sources, signal modeling for prediction of statistical multiplexing, packet loss protection and recovery, and layered video coding with prioritized packets.

Prerequisite: 525.441 Computer and Data Communication Networks I or 605.471 Principles of Data Communication Networks.

Nasrabadi

525.445 Modern Navigation Systems

This course explores the use of satellite, terrestrial, celestial, radio, magnetic, and inertial systems for the real-time determination of position, velocity, acceleration, and attitude. Particular emphasis is on the historical importance of navigation systems; avionics navigation systems for high performance aircraft; the Global Positioning System; the relationships between navigation, cartography, surveying, and astronomy; and emerging trends for integrating various navigation techniques into single, tightly coupled systems.

Jablonski

525.446 DSP Hardware Lab

This course develops expertise and insight into the development of DSP processor solutions to practical engineering problems through hands-on experience. Structured exercises using DSP hardware are provided and used by the student to gain practical experience with basic DSP theory and operations. Course focus is on real-time, floating-point applications. This course is intended for engineers having EE or other technical backgrounds who desire to obtain practical experience and insight into the development of solutions to DSP problems requiring specialized DSP architectures.

Prerequisite: 525.427 Digital Signal Processing and C programming experience.

Wenstrand, Haber

525.466 Linear System Theory

This course covers the structure and properties of linear dynamic systems with an emphasis on the single-input, single-output case. Topics include the notion of state-space,
state variable equations, review of matrix theory, linear vector spaces, eigenvalues and eigenvectors, the state transition matrix and solution of linear differential equations, internal and external system descriptions, properties of controllability and observability and their applications to minimal realizations, state-feedback controllers, asymptotic observers, and compensator design using state-space and transfer function methods. An introduction to multi-input, multi-output systems is also included, as well as the solution and properties of time-varying systems.

**Prerequisites:** Courses in matrix theory and linear differential equations.

**525.467 Applied Bayesian and Entropic Methods**

This course introduces Bayesian and entropic methods and their signal processing applications in the treatment of random phenomena. The common logical foundations of the two classes of methods are discussed. Probability represents degree of belief on the part of a decision maker, while entropy indicates the degree of utility of questions posable by an observer. Practical examples and applications illustrating these concepts are given in conjunction with related Matlab homework assignments. The course objective is to convey a logical methodology of problem solving applicable to a wide domain of technical and non-technical disciplines.

**Fry**

**525.484 Microwave Systems and Components**

This course deals with the practical aspects of microwave systems and components. An overview of communication systems is followed by an introduction to radar systems and electronic systems operating in heavily interfering environments. The majority of the course treats the linear and nonlinear characteristics of individual components and their relation to system performance. Amplifiers, mixers, filters, and frequency sources are studied, as well as their interactions in cascade. Performance specification and testing are considered, using actual receiver designs as examples. Some homework problems may require use of computer-aided design software provided at the Dorsey Center.

**Prerequisite:** An undergraduate degree in electrical engineering or equivalent.

**Marks, McClaning**

**525.705 Micropower VLSI System Design**

This course considers micropower circuits with emphasis at the level of system integration. Topics discussed include mixed digital and analog/digital components on a single chip, A/D and D/A converters, design for testability, and fault tolerance. The course requires a final project involving a small system that is fabricated through MOSIS, as well as laboratory experiments on previously fabricated circuits and small systems.

**Prerequisite:** 525.713 Micropower Integrated Circuit Design.

**Eaton**

**525.707 Error Control Coding**

This course presents error-control coding with a view toward applying it as part of the overall design of a data communication or storage and retrieval system. Both block and convolutional codes and decoding are covered. Topics include system models, introduction to linear and abstract algebra, generator and parity check matrix representation of block codes, general decoding principles, BCH and Reed-Solomon codes, analytical and graphical representation of convolutional codes, performance bounds, examples of good codes, threshold decoding, Viterbi decoding, sequential decoding, burst-control techniques, applications, and cost trade-offs.

**Prerequisites:** Background in linear algebra, such as 625.409 Linear Algebra, and in digital communications, such as 525.416 Communication Systems Engineering.

**Hammons**

**525.712 Advanced Computer Architecture**

This course covers topics essential to modern superscalar processor design. A review of pipelined processor design and hierarchical memory design is followed by advanced topics including the identification of parallelism in processes; multiple diversified functional units in a pipelined processor; static, dynamic, and hybrid branch prediction techniques; the Tomasulo algorithm for efficient resolution of true data dependencies; advanced data flow techniques with and without speculative execution; multiprocessor systems; and multithreaded processors.

**Prerequisite:** 525.412 Computer Architecture or equivalent.

**Cameron**

**525.713 Micropower Integrated Circuit Design**

This course focuses on devices and circuit techniques for micropower applications, such as biomedical instrumentation, implantable devices, and space applications. Both voltage and current mode techniques are introduced for the implementation of analog signal processing functions. The design of precision micropower circuits in the standard CMOS process is stressed. Design tools for layout, simulation, and verification are also introduced. A final project involves the design of a small circuit that will be fabricated through MOSIS.

**Prerequisites:** Undergraduate courses in systems and electronics.

**Eaton**
Graduate Programs

525.718  **Multi-Rate Digital Signal Processing**
Multi-rate signal processing techniques find applications in many areas including speech and image compression, digital audio, and adaptive signal processing. This course provides an in-depth treatment of both the theoretical and practical aspects of multi-rate signal processing. The course begins with a review of discrete-time systems and the design of digital filters. Additional topics discussed are: polyphase realizations of discrete systems; multistage filter design; and the design of filter banks, including perfect reconstruction, alias-free, and quadrature mirror filter types. Each student is required to complete a comprehensive individual project on some aspect of multi-rate signal processing.

*Prerequisites:* 525.427 Digital Signal Processing or equivalent and working knowledge of Matlab.

Jennison

525.719  **Parallel Processing Systems**

This course introduces parallel hardware/software computing structures. Topics include pipelining and vector machines, architectures and algorithms for array processors, multiprocessor architectures and control, data flow machines, and VLSI parallel computing structures.

*Prerequisite:* 525.412 Computer Architecture or equivalent undergraduate background.

Pascale, Darling

525.721  **Advanced Digital Signal Processing**

The fundamentals of discrete-time statistical signal processing are presented in this course. Topics include optimal linear filtering, classical and modern spectrum analysis, adaptive filtering, and the singular value decomposition and its application to least squares problems. Basic concepts of super-resolution methods are described, including an introduction to array processing. Computer experiments using Matlab illustrate some of the signal processing techniques.


Sadler, Najmi

525.722  **Wireless and Mobile Cellular Communications**

In this course, students examine fundamental concepts of mobile cellular communications and specifics of current and proposed U.S. cellular systems. Topics include frequency reuse; call processing; propagation loss; multipath fading and methods of reducing fades; error correction requirements and techniques; modulation methods; FDMA, TDMA, and CDMA techniques; microcell issues; mobile satellite systems; and IMT-2000.

*Prerequisites:* 525.414 Probability and Stochastic Processes for Engineers or equivalent and 525.416 Communication Systems Engineering.

Zuelsdorf

525.723  **Computer and Data Communication Networks II**

This course emphasizes the mathematical analysis of communication networks. Queuing theory and its applications are covered extensively, including the topics of M/M/1 systems, M/G/1 systems, Burke's theorem, and Jackson's theorem. Multiaccess communication is discussed, including the topics of Aloha systems and packet radio networks. Students also explore network routing including the Bellman-Ford algorithm, Dijkstra's algorithm, and optimal routing.

*Prerequisite:* 525.441 Computer and Data Communication Networks I.

Hanson

525.724  **Introduction to Pattern Recognition**

Both statistical and nonstatistical methods are covered. The statistical methods are subdivided into parametric and nonparametric methods. The parametric methods are limited to the Bayes criterion. The nonparametric methods include linear, nonlinear, and piecewise linear discriminant functions, estimation of unknown density functions, and nearest neighbor classification rules. The second part of the term emphasizes unlabeled samples. While statistical methods have some utility in this area, clustering techniques are emphasized. Included in these techniques are similarity measures, hierarchical clustering, minimal spanning tree, and multidimensional scaling.

*Prerequisite:* 525.414 Probability and Stochastic Processes for Engineers or equivalent.

Trunk

525.725  **Power Electronics**

This course covers the design and analysis of DC to DC switching converters. Topics include topology selection for various applications, steady state operation including continuous versus discontinuous operation, fundamentals of control loop design including both voltage mode and current mode control, fundamentals of magnetic design including how to minimize losses, input and output filter design, pulse-width modulation chip selection, diode and transistor part selection and the associated effects of part non-idealities on the converter performance, as well as simulation and modeling of the converter. The complete process of converter design and implementation is presented including requirement specification and testing verification needed to evaluate the converter performance such as efficiency, regulation, line rejection, EMI/EMC measurements, and stability measurements. DC to AC converters and the AC to DC converters will also be discussed. A lab, which will give the student hands-on experience with design and testing of a typical DC to DC converter, is part of the course.

*Prerequisites:* 525.424 Analog Electronic Circuit Design I or equivalent.

Marcus, Temkin
525.728 Detection and Estimation Theory
Both hypothesis testing and estimation theory are covered. The course starts with a review of probability distributions, multivariate Gaussians, and the central limit theorem. Hypothesis testing areas include simple and composite hypotheses and binary and multiple hypotheses. In estimation theory, maximum likelihood estimates and Bayes estimates are discussed. Practical problems in radar and communications are used as examples throughout the course.
Prerequisite: 525.414 Probability and Stochastic Processes for Engineers or equivalent.

525.731 Principles of Radar I
This course emphasizes the systems aspects of radar, an important example of an electrical engineering system application. After introducing the basic concept of radar, the course describes the detection of radar signals in noise, methods for the prediction of radar performance, and the propagation of radar waves in the atmosphere. The use of the Doppler frequency shift in radar to detect moving targets in land and sea clutter is discussed, including what is known as MTI (moving target indication) radar and pulse Doppler radar. Methods for the tracking of targets by radar are also covered, especially monopulse and automatic detection and tracking (ADT) with surveillance radars. If time permits, the subject of radar antennas will be introduced.
Prerequisite: This course assumes no prior knowledge of radar, but the student is expected to be familiar with the basic concepts of electrical engineering as covered by a good undergraduate program. Some knowledge of simple Fourier transforms would also be helpful.

525.732 Principles of Radar II
The second term of the course covers radar detection theory, the radar matched filter, information from radar signals, accuracy of radar measurements, the radar ambiguity diagram, pulse compression, nature of radar clutter, design of an air-traffic control radar, and a brief review of other current radar interests. A term paper involving the conceptual design of a radar system will be part of the course.
Prerequisite: 525.731 Principles of Radar I or permission of the instructor.

Skolnik

525.738 Advanced Antenna Systems
This course is designed to follow Antenna Systems 525.418. Advanced techniques needed to analyze antenna systems are studied in detail. Fourier transforms are reviewed and applied to antenna theory and array distributions. The Method of Moments is studied and used to solve basic integral equations employing different basis functions. Green’s functions for patch antennas are formulated in terms of Sommerfeld-like integrals. Techniques such as saddle-point integration are presented. Topics addressed include computational electromagnetics, Leaky and surface waves, mutual coupling, and Floquet modes. Students should be familiar with complex variables (contour integration), Fourier transforms, and Electromagnetics from undergraduate studies.
Prerequisite: 525.418 Antenna Systems.

525.739 Computer Systems Performance Analysis
This course provides an overview of computer system performance analysis using experimental measurements, simulations, and modeling. Queuing models and queuing networks are used to model computer systems, analyze system performance, and establish performance bounds. Specific computer subsystems are modeled, including memory, I/O and processors. Limitations of queuing models are discussed. Markov models are described, as well as experimental performance techniques such as benchmarking and performance monitoring.
Prerequisites: 525.412 Computer Architecture or consent of instructor.

525.745 Applied Kalman Filtering
Theory, analysis, and practical design and implementation of Kalman filters are covered, along with example applications to real-world problems. Topics include a review of random processes and linear system theory; Kalman filter derivations; divergence analysis; numerically robust forms; suboptimal filters and error budget analysis; prediction and smoothing; cascaded, decentralized, and federated filters; linearized, extended, second order, and adaptive filters; and case studies in GPS, inertial navigation, and ballistic missile tracking.
Prerequisites: 525.414 Probability and Stochastic Processes for Engineers and 525.466 Linear System Theory or equivalents.

Levy

525.746 Image Engineering
Optical, photographic, analog, and digital image processing are highlighted. Topics include image input, output, and processing devices; visual perception; video systems; and fundamentals of digital image enhancement, processing, and understanding. Coding, filtering, transform, restoration, and segmentation techniques are covered, as well as applications to remote sensing and biomedical problems.
Prerequisites: 525.427 Digital Signal Processing or equivalent and knowledge of linear systems.

Goldfinger

525.747 Speech Processing
This course emphasizes processing of the human speech waveform, primarily using digital techniques. Theory of speech production and speech perception as related to signals in time and frequency-domains is covered, as well as the measurement of model parameters, short-time Fourier spectrum, and linear predictor coefficients. Speech coding, recognition, speech synthesis, and speaker identification are discussed. Application areas include telecommunications telephony, INTERNET VOIP, and man-machine interfaces. Considerations for embedded realization of the speech processing system will be
covered as time permits. Several application-oriented software projects will be required.

**Prerequisites:** 525.427 Digital Signal Processing and 525.414 Probability and Stochastic Processes for Engineers. Background in Linear Algebra and Matlab helpful.

**525.753 Laser Systems and Applications**

This course provides a comprehensive treatment of the generation of laser light, its properties, and applications. Topics include specific laser systems and pumping mechanisms, nonlinear optics, temporal and spatial coherence, guided beams, interferometric and holographic measurements, and remote sensing.

**Prerequisite:** 525.425 Laser Fundamentals.

Thomas Bankman

**525.754 Wireless Communication Circuits I**

In this course, students examine modulator and demodulator circuits used in communication and radar systems. A combination of lectures and laboratory experiments address the analysis, design, fabrication, and test of common circuits. Signal formats considered include phase and frequency shift keying, pseudo-random codes, and the linear modulations used in analog systems.

**Prerequisite:** 525.416 Communication Systems Engineering or 525.484 Microwave Systems and Components or permission of the instructor.

Kaul, McClaning, Tobin, Houser

**525.755 Wireless Communication Circuits II**

This is a lab-based course in which students will design, build, and test a communications-related system. The nature and extent of the project will be negotiated between the student and instructors during the first week of class. Candidate projects include spread spectrum systems, PSK modulators and demodulators, m-ary FSK modulators and demodulators, and others. Students will be expected to procure any unusual components they require for their project (i.e., specialized ICs, unusual development systems, etc.).

**Prerequisites:** 525.754 Wireless Communication Circuits I or permission of the instructor. Students are required to assemble circuitry outside the course hours, thus reserving class time for debugging, testing, and instructor interaction.

Kaul, McClaning, Tobin, Houser

**525.756 Optical Propagation, Sensing, and Backgrounds**

This course presents a unified perspective on optical propagation in linear media. A basic background is established using electromagnetic theory, spectroscopy, and quantum theory. Properties of the optical field and propagation media (gases, liquids, and solids) are developed, leading to basic expressions describing their interaction. The absorption line strength and shape and Rayleigh scattering are derived and applied to atmospheric transmission, optical window materials, and propagation in water-based liquids. A survey of experimental techniques and apparatus is also part of the course. Applications are presented for each type of medium, emphasizing remote sensing techniques and background noise. Computer codes such as LOWTRAN, FASCODE, and OPTIMATR are discussed.

**Prerequisites:** Undergraduate courses on electromagnetic theory and elementary quantum mechanics. A course on Fourier optics is helpful.

Thomas

**525.759 Image Compression, Packet Video, and Video Processing**

This course provides an introduction to the basic concepts and techniques used for the compression of digital images and video. Video compression requirements, algorithm components, and ISO Standard video processing algorithms are studied. Image compression components that are used in video compression methods are also identified. Since many of the capabilities of these standards are still being developed, and have not been integrated into computer and communication systems, the study of the component technologies will provide guidelines for evaluation and selection when the standards are approved. Topics to be covered include introduction to video systems, Fourier analysis of video signals, properties of the human visual system, motion estimation, basic video compression techniques, video communication standards, and error control in Video Communications. A mini-project is required.

**Prerequisites:** 525.427 Digital Signal Processing.

Besser

**525.761 Wireless and Wireline Network Integration**

This course investigates the integration of wireless and wireline networks into seamless networks. The current telecommunications environment in the U.S. is first discussed, including the state of technology and regulations as they apply to the wireless and wireline hybrid environment. Then each type of these hybrid networks is discussed, including its components, network services, architecture, and possible evolution, as well as important concepts that support the evolution of networks. The integration of wired network advance intelligence, wireless network mobility, and long distance capabilities are shown to provide many new combinations of wired and wireless services to users.

**Prerequisite:** 525.408 Digital Telephony, or 525.416 Communication Systems Engineering, or permission of instructor.

Beser

**525.762 Signal Processing with Wavelets**

This course presents the fundamentals of wavelets as a signal processing tool. Topics include continuous and discrete-time wavelets, time-frequency transient analysis, wavelet bases, wavelet packets, and approximations with wavelets. Applications include signal and image denoising (filtering), and compression. Computer experiments using Matlab illustrate the techniques studied.
Prerequisites: 525.427 Digital Signal Processing and the basics of linear systems.

Najmi

525.763 Applied Nonlinear Systems

This course examines techniques available for the analysis and control of nonlinear physical systems. Topics include modeling of nonlinear systems, state variable representation and solutions of piecewise linear and nonlinear differential equations, phase plane analysis, linearization, equilibrium points, stability of nonlinear systems, Aizerman’s conjecture, Popov and circle criteria, and describing function techniques. Matlab and ProtoSim are used as computational tools.

Prerequisites: 525.409 Continuous Control Systems or equivalent.

Ambrose

525.769 Digital and Sampled-Data Control

This course covers analysis and design of control systems that include both continuous-time and discrete-time elements such as samplers, A/D and D/A converters, and digital computers. Topics include sampling, difference equations, z- and w-transforms, block diagram analysis, system stability, classical design by root-locus and frequency response methods, state-space analysis and design, system identification, and optimal estimation and control. Application of theory to practical analysis and design problems is emphasized.

Prerequisite: Familiarity with Laplace transforms, linear systems, and techniques for analyzing and designing continuous-time control systems is assumed.

Duven

525.770 Intelligent Algorithms

This course investigates several techniques commonly referred to as intelligent algorithms, and takes a pragmatic engineering approach to the design, analysis, evaluation, and implementation of intelligent systems. Fuzzy systems concepts are discussed, and several engineering applications are presented, including fuzzy control and fuzzy estimation and prediction. The role of Expert (rule-based) Systems is discussed within the context of fuzzy systems. In addition, neural networks and genetic algorithms are introduced, and their relationships to fuzzy systems are highlighted. A fuzzy systems computer project must be selected and implemented by the student. Student familiarity of system-theoretic concepts is desirable.

Palumbo

525.771 Propagation of Radio Waves in the Atmosphere

This course examines various propagation phenomena that influence transmission of radio frequency signals between two locations on earth and between satellite-earth terminals, with a focus on applications. Frequencies above 30 MHz are considered with emphasis on microwave and millimeter propagation. Topics include free space transmission, propagation, and reception; effects on waves traversing the ionosphere; and attenuation due to atmospheric gases, rain, and clouds. Brightness temperature concepts are discussed, and thermal noise introduced into the receiver system from receiver hardware and from atmospheric contributions are examined. Also described are reflection and diffraction effects by land terrain and ocean, multipath propagation, tropospheric refraction, propagation via surface and elevated ducts, scatter from fluctuations of the refractive index, and scattering due to rain. Atmospheric dynamics are described which contribute to the various types of propagation conditions in the troposphere.

Prerequisite: An undergraduate degree in electrical engineering or equivalent.

Dockery

525.772 Fiber-Optic Communication Systems

This course investigates the basic aspects of fiber-optic communication systems. Topics include sources and receivers, optical fibers and their propagation characteristics, and optical fiber systems. The principles of operation and properties of optoelectronic components, as well as the signal guiding characteristics of glass fibers, are discussed. System design issues include terrestrial and submerged point-to-point optical links and fiber-optic networks.

Prerequisite: 525.491 Fundamentals of Photonics.

Sova

525.774 RF and Microwave Circuits I

In this course, students examine RF and microwave circuits appropriate for wireless communications and radar sensing. It emphasizes the theoretical and experimental aspects of microstrip design of highly integrated systems. Matrix analysis and computer-aided design techniques are introduced and used for the analysis and design of circuits. Circuits are designed, fabricated, and tested, providing a technically stimulating environment in which to understand the foundational principles of circuit development. Couplers, modulators, mixers, and calibrated measurements techniques are also covered.

Prerequisite: 525.423 Principles of Microwave Circuits or equivalent.

Penn, Thompson

525.775 RF and Microwave Circuits II

This course builds upon the knowledge gained in 525.774 RF and Microwave Circuits I. Here there is a greater emphasis on designs involving active components. Linear and power amplifiers and oscillators are considered, as well as stability, gain, and their associated design circles. The course uses computer-aided design techniques and students fabricate and test circuits of their own design.

Prerequisite: 525.774 RF and Microwave Circuits I.

Penn, Thompson

525.776 Information Theory

Course topics include measure of information, noiseless coding, communication channels and channel capacity, the noisy channel coding theorem, bounds on the performance of communications systems, the Gaussian and binary symmetric
channels, feedback communications systems, and rate distortion theory.

Prerequisite: 525.414 Probability and Stochastic Processes for Engineers or equivalent.

Benedict

525.777 Control System Design Methods

This course examines recent multivariable control system design methodologies and how the available techniques are synthesized to produce practical designs. Both the underlying theories and the use of computational tools are covered. Topics include review of classical control system design and linear system theory, eigenstructure assignment, the linear quadratic regulator, the multivariable Nyquist criterion, singular value analysis, stability and performance robustness measures, loop transfer recovery, H-infinity design, and μ-synthesis. An introduction to nonlinear techniques includes sliding mode control and feedback linearization. Recent papers from the literature are discussed. Each student will be assigned a design project using PC-based design and analysis software.

Prerequisites: 525.466 Linear System Theory and 525.409 Continuous Control Systems or the equivalent.

Pue

525.778 Design for Reliability, Testability, and Quality Assurance

The design of reliable and testable systems, both analog and digital, is considered at the component, circuit, system, and network levels. Using numerous real-world examples, the tradeoffs between redundancy, testability, complexity, and fault tolerance are explored. Although the emphasis is predominantly on electronics, related examples from the aerospace and software industries are included. The concepts of fault lists, collapsed fault lists, and other techniques for reducing the complexity of fault simulation are addressed. A quantitative relationship between information theory, error correction codes, and reliability is developed. Finally, the elements of a practical quality assurance system are presented. In addition to homework assignment, students will conduct an in-depth, quantitative case study of a practical system of personal interest.

Prerequisite: 525.411 Theory of Digital Systems or equivalent.

Jablonski

525.780 Multidimensional Digital Signal Processing

The fundamental concepts of multidimensional digital signal processing theory as well as several associated application areas are covered in this course. The course begins with an investigation of continuous-space signals and sampling theory in two or more dimensions. The multidimensional discrete Fourier transform is defined, and methods for its efficient calculation are discussed. The design and implementation of two-dimensional non-recursive linear filters are treated. The final part of the course examines the processing of signals carried by propagating waves. This section contains descriptions of computed tomography, and related techniques and array signal processing. Several application oriented software projects are required.

Prerequisites: 525.414 Probability and Stochastic Processes for Engineers and 525.427 Digital Signal Processing or equivalents. Knowledge of linear algebra and Matlab is helpful.

Jennison

525.783 Spread Spectrum Communications

This course presents an analysis of the performance and design of spread-spectrum communication systems. Both direct-sequence and frequency-hopping systems are studied. Topics include pseudonoise sequences, code synchronization, interference suppression, and the application of error-correcting codes. The use of code-division multiple access in digital cellular systems is examined. The relationships between spread spectrum, cryptographic, and error correction systems are explored. The mathematics of pseudo-random sequences used as spreading codes are compared with the mathematics of complex numbers with which students are already familiar.

Prerequisites: 525.416 Communication Systems Engineering.

Jablonski

525.786 Model Building for Dynamic Systems

The course presents the theory and practice of system identification, which is the process of estimating statistical system models from data. State-space methods are used in discussing both adaptive filtering and control, where the system model must be estimated online, and off-line model building, for simulation development and validation, and test and evaluation. Practical implementations are covered along with example applications to real-world problems. Methods include nonlinear extended Kalman, residual analysis, and multiple model adaptive filters; the eigensystem realization algorithm; canonical variate analysis; and subspace model identification, as well as simultaneous perturbation stochastic approximation and maximum likelihood, prediction error minimization, and model structure estimation methods. Applications include adaptive control of a farm vehicle, urban traffic control, missile inertial guidance modeling, and GPS receiver modeling.

Prerequisite: 525.745 Applied Kalman Filtering or equivalent.

Levy

525.787 Microwave Monolithic Integrated Circuit (MMIC) Design

This course is for advanced students who have a background in microwave circuit analysis and design techniques and are familiar with modern microwave computer-aided engineering tools. The course covers the monolithic implementation of microwave circuits on GaAs substrates including instruction on processing, masks, simulation, layout, design rule checking, packaging, and testing. The first part of the course includes information and assignments on the analysis and design of MMIC chips. The second part consists of projects in which a chip is designed, reviewed, and evaluated in an
525.788  Power Microwave Monolithic Integrated Circuit (MMIC) Design

The Power MMIC course covers additional circuit design techniques applicable to MMICs (and microwave circuits in general). It is an extension of RF and Microwave Circuits I and II and Microwave Monolithic Integrated Circuit (MMIC) Design, although these particular courses are not prerequisites. The topics covered include broadband matching; optimum loads for efficiency and low intermodulation products; odd mode oscillations; details of nonlinear modeling; time domain simulation of nonlinear circuits; and thermal effects. The course is for advanced students who have a background in microwave measurements and microwave CAD tools. There is not a project, but there is structured homework involving power MMIC design completed by the student using a foundry library. The course is given in the spring; it is not given every year.

Dawson

525.789  Digital Satellite Communications

This course covers advanced topics in satellite communications systems, with emphasis on digital communications. After a review of basic concepts, the following topics are addressed: the distinctions between digital and nondigital communications systems; reasons for preferring some forms of modulation and coding over others for spacecraft implementation; the relationships between spectrum management, signal propagation characteristics, orbitology, constellation design, and communications system design; the use of spread spectrum (CDMA and frequency-hopping), TDMA, and FDMA architectures; protocol design and usage; GPS; digital audio radio satellites; the use of geostationary satellites for mobile telephone systems; satellite television; and VSAT terminals.

Prerequisite: 525.416 Communication Systems Engineering is required, and 525.440 Satellite Communications Systems is recommended.

Jablonski

525.792  Electro-Optical Systems

This course covers the analysis and conceptual design of practical electro-optical (EO) systems. Although EO technology is emphasized, the fundamentals of radiometry and optical radiation are also described to provide a fundamental understanding of the essential physics, whereas background characterization and atmospheric propagation are only briefly covered. Basic EO system component performance is characterized parametrically for detection, tracking, communications, and imaging. Passive (infrared imaging) and active (laser radar and laser communication systems) are stressed. Components considered in these systems include basic telescopes and optics, focal plane arrays, laser diodes, photodiode receivers, and laser scanners.

Prerequisite: 615.751 Modern Optics or the equivalent.

Boone

525.793  Advanced Communication Systems

In this course, students receive an introduction to digital baseband and bandpass modulation and demodulation/detection. Digital communication system performance is then evaluated using link budget analysis. Additional topics may include channel coding, equalization, synchronization, modulation and coding trade-offs, multiplexing, and multiple access.

Prerequisite: 525.414 Probability and Stochastic Processes for Engineers; 525.416 Communication Systems Engineering

Carmody

525.794  Advanced Topics in VLSI Technology

This course will concentrate on advanced concepts in VLSI design. Additional emphasis will be put on system architecture, circuit analysis, device modeling, simulation, and optimization. Topics include advanced logic techniques, parasitic circuit elements, advanced simulation techniques, temperature effects, and circuit and device performance limits. Additional topics may include low-power/low-energy design techniques, performance limits, radiation effects and cryogenic VLSI.

Prerequisite: 525.428 Introduction to Digital CMOS VLSI, or equivalent background in digital design.

Martin

525.795  Advanced Communications Laboratory

This course offers the student an opportunity for hands-on experience with advanced digital signal processing techniques used in modern mobile communications systems. Topics include automatic gain control, synchronization and carrier phase estimation, channel and source coding, and frequency-selective channel equalization. Assignments will focus primarily on Matlab programming of various receiver signal processing methods.

Prerequisite: 525.427, 525.414, and 525.416 (or equivalent advanced undergraduate/first year graduate courses in Digital Signal Processing, Stochastic Processes, and Communication Systems). Basic concepts of communication and linear systems, transforms, and probability theory are required.

Sadler
**525.796  Introduction to High-Speed Electronics and Optoelectronics**

This course provides the student with the fundamentals concepts needed to address issues in both the design and test of high-speed electronic and optical systems. Topics include electronic devices and circuits used at microwave and millimeter frequencies, optical active devices and waveguide technology, electronic and optical pulse generation techniques, high-speed packaging design and testing techniques.

*Prerequisite:* Undergraduate courses in circuits and systems.

Sova, Vichot

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**525.797  Advanced Optics and Photonics Laboratory**

The objective of this course is to develop advanced experimental techniques in optics and photonics. Students will work in teams of two or three on in-depth optical experiments consisting of multiple parts that include constructing experimental apparatus and developing data acquisition and analysis software. Example experiments include coherent and incoherent laser radar, laser vibrometry, fiber lasers dynamics, high-resolution microscopy using Fourier optics, 3D interferometric imaging, optical properties of materials, 10 Gbps WDM fiber communication system, optical tomographic imaging in highly diffuse media, speckle interferometry, mode-locked and soliton lasers, and non-linear fiber optics. The specific experiments will depend on hardware availability and student interest.

*Prerequisite:* 525.436 Optics and Photonics Laboratory or equivalent.

Sova, Terry

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**525.801  Special Project I**

In individual cases, special arrangements can be made to carry out a project of significant scope in lieu of a formal course. Further information is available from the program committee chair. Such arrangements are made relatively infrequently. This course number should be used for the first registration of a student in any special project.

*Note:* To be assured consideration for any term, project proposals should reach the program chair by the end of the mail-in registration period.

Staff

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**525.802  Special Project II**

This course number should be used for the second registration of a student in any special project. (See course 525.801 Special Project I for a further description.)

*Note:* To be assured consideration for any term, project proposals should reach the program chair by the end of the mail-in registration period.

Staff
Environmental Engineering, Science and Management

In a world undergoing rapid ecological transformation, the role of environmental engineers, scientists and planners has become increasingly prominent. In the Johns Hopkins tradition of excellence, the graduate Part-Time Program in Environmental Engineering, Science and Management is one of the most comprehensive and rigorous professional environmental engineering, science, technology, planning and management programs in the nation. The program accommodates working professionals who wish to complete graduate degree requirements without interrupting their careers and provides them with skills necessary to address a broad array of modern environmental issues and capitalize on environmental protection and remediation opportunities presented by technology. Common to all program activities is recognition of the importance of obtaining a strong quantitative background in the environmental engineering, science and management principles that govern environmental processes.

In the program, students obtain an up-to-date level of understanding in the following interrelated academic fields:

• Study of physical, chemical, and biological processes fundamental to understanding the environment fate and engineered treatment of environmental contaminants
• Understanding the source and nature of waste materials that contribute to air, soil, and water pollution and relevant management and control technologies
• Study of the transport and transformation of contaminants through environmental pathways
• Knowledge of the pollution prevention and technologies and designs associated with the treatment and disposal of waste materials
• Rigorous study of the connection between the engineering and scientific aspects of environmental problems and decision-making processes

Improved understanding in all of these areas is achieved through a quantitative program built around the common theme of engineering and science in support of environmental decision making and management.

Program Committee

Hedy V. Alavi, Program Chair
Environmental Engineering, Science and Management, Engineering and Applied Science Programs for Professionals
Whiting School of Engineering

William P. Ball
Professor, Geography and Environmental Engineering
Whiting School of Engineering

John J. Boland
Professor Emeritus, Geography and Environmental Engineering
Whiting School of Engineering

Edward J. Bouwer
Professor, Geography and Environmental Engineering
Whiting School of Engineering

J. Hugh Ellis
Department Chair and Professor, Civil Engineering
Whiting School of Engineering

Charles R. O’Media
Department Chair and Abel Wolman Professor, Geography and Environmental Engineering
Whiting School of Engineering

Peter R. Wilcock
Professor and Departmental Associate Chair, Geography and Environmental Engineering
Whiting School of Engineering

Program Advisory Board

An external Advisory Board provides oversight, vision, input, and perspective from the professional, technical, and business communities. The Board consists of distinguished representatives from professional environmental organizations, state and federal agencies, prominent environmental consulting firms/industry, part-time faculty, and part-time students. The Advisory Board is co-chaired by William C. Anderson, executive director, Council of Engineering and Scientific Specialty Boards, and George A. Frigon, president of Newfields Corporation. Please see the Appendix for the list of the Advisory Board members and their affiliations.

Faculty

The program features about 50 highly qualified faculty members. Each is a distinguished and experienced professional with the highest academic degree in their field of expertise, and each has demonstrated a strong commitment to excellence in teaching. Many of the outstanding full-time faculty from the nationally renowned Department of Geography and Environmental Engineering at Johns Hopkins participate as program instructors. In addition, the program includes several directors, senior scientists, engineers, researchers, and attorneys affiliated with the U.S. Environmental Protection Agency, Maryland Department of the Environment, U.S. Department of Energy, National Research Council, U.S. Department of Defense, U.S. Department of Agriculture, National Institute of Standards and Technology, U.S. Army Corps of Engineers, and many leading environmental consulting companies such as Post, Buckley, Schuh & Jernigan, Environmental Resource Management, EA Engineering and Science and Technology, Bechtel Corporation, CH2M Hill, Lockheed Martin Corporation, and Northrop-Grumman. Please see the Appendix for the list of active faculty members and their affiliations.
Degrees and Certificates
The program offers professional non-thesis degrees in the following three areas of study and their corresponding Advanced Certificate for Post-Master’s Study as well as Graduate Certificates.

- Master of Environmental Engineering
- Master of Science in Environmental Engineering and Science
- Master of Science in Environmental Planning and Management
- Advanced Certificate for Post-Master’s Study
- Graduate Certificate

Master of Environmental Engineering
This area of study focuses on the design of collection and treatment processes for air, water, wastewater, and solid and hazardous waste, including study of the conceptual principles underlying biological, physical, and chemical treatment.

Admission Requirements
Prospective students must hold an Accreditation Board for Engineering and Technology (ABET)-accredited undergraduate degree or demonstrated equivalent in an engineering discipline from a four-year college or university to be considered for the Master of Environmental Engineering degree. Moreover, applicants must meet the following criteria:

1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in an engineering discipline.
2. Successful completion of college-level calculus sequence through differential equations.
3. Successful completion of a course in fluid mechanics or hydraulics.
4. Successful completion of a course in statistics (recommended).

Applicants with an undergraduate degree in natural sciences may be admitted as provisional students to complete additional undergraduate course work in engineering fundamentals and design prior to full admission to the program.

Course Requirements
Attainment of the Master of Environmental Engineering degree requires completion of 10 one-term courses, including at least four courses at the 700-level or above, within five years.

At least five of the required 10 courses must be taken in the Master of Environmental Engineering area of study.

Up to five additional elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, Master of Science in Environmental Planning and Management).

Up to two elective courses, subject to prerequisite restrictions, compatibility in the number of credit hours, and adviser approval, may be taken from select related courses offered through all different schools of the Johns Hopkins University.

Master of Science in Environmental Engineering and Science
This area of study stresses the fundamental concepts of physics, chemistry, biology, and geology as applied in the context of environmental issues, with less emphasis on design and management.

Admission Requirements
Prospective students must hold an undergraduate degree in either engineering or natural science from a four-year college or university to be considered for the Master of Science in Environmental Engineering and Science degree. Moreover, applicants must meet the following criteria:

1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in an engineering or a natural science discipline.
2. Successful completion of one year of college-level calculus and a course in differential equations.
3. Successful completion of college-level courses is recommended in physics, chemistry, biology, geology, and statistics.

Course Requirements
Attainment of the Master of Science in Environmental Engineering and Science degree requires completion of 10 one-term courses, including at least four courses at the 700-level or above, within five years.

At least five of the required 10 courses must be taken in the Master of Science in Environmental Engineering and Science area of study.

Up to five additional elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, Master of Science in Environmental Planning and Management).

Up to two elective courses, subject to prerequisite restrictions, compatibility in the number of credit hours, and adviser approval may be taken from select related courses offered through all different schools of the Johns Hopkins University.

Master of Science in Environmental Planning and Management
This specialty emphasizes the relationships between environmental engineering/science and public policy with a focus on decision-making tools and policy analysis, as well as emphasis on the role of economic factors in environmental management and water resources planning. This is a professional non-thesis curriculum that encompasses the analytical and conceptual tools to identify, formulate, and evaluate complex environmental and water resources projects and systems, considering the interdisciplinary aspects of the technical, environmental, economic, social, and financial constraints.
Admission Requirements
Prospective students must hold an undergraduate degree in engineering, natural science, economics, planning, management, or other related disciplines from a four-year college or university to be considered for the Master of Science in Environmental Planning and Management degree. Moreover, applicants must meet the following criteria:

1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in engineering, natural science, economics, planning, management, or other related disciplines.
2. Successful completion of one year of college-level calculus.
3. Successful completion of college-level courses is recommended in physics, chemistry, biology, geology, and statistics.

Course Requirements
Attainment of the Master of Science in Environmental Planning and Management degree requires completion of 10 one-term courses, including at least four courses at the 700-level or above, within five years.

At least five of the required 10 courses must be taken in the Master of Science in Environmental Planning and Management area of study.

Up to five additional elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, Master of Science in Environmental Planning and Management).

Up to two elective courses, subject to prerequisite restrictions, compatibility in the number of credit hours, and adviser approval may be taken from select related courses offered through all different schools of the Johns Hopkins University.

Advanced Certificate for Post-Master’s Study
This certificate is awarded to students who complete six graduate-level courses beyond the master’s degree in an environmental engineering, science, or management discipline. The program is intended to add depth and/or breadth in the discipline of the student’s master’s degree, or a closely related one. At least three of the required six courses must be at the 700-level or above. All grades for the six courses must be A or B.

After the review of student’s academic credentials by the admission committee and admittance to the Advanced Certificate for Post-Master’s Study program, each student is assigned an adviser with whom he or she jointly designs a program tailored to individual educational goal.

Students must complete the Advanced Certificate for Post-Master’s Study within three years of the first enrollment in the program.

Graduate Certificate
The Graduate Certificate is directed toward students who may not need a master’s degree, may not have the opportunity to pursue the entire master’s degree, or may wish to focus their studies to a set of courses in a specific subject area.

The certificate consists of six courses. All grades for the six courses must be A or B. If, in the future, the student decides to pursue the full master’s degree, all courses will apply provided they meet the program requirements and fall within the five-year limit, and the student declares her/his intention prior to award of the certificate.

Students must meet the master’s degree admission requirements of the desired area of study. After the review of student’s academic credentials by the admission committee and admittance to the Graduate Certificate program, each student is assigned an adviser with whom he or she jointly designs a program tailored to individual educational goal.

Students must complete the Graduate Certificate within three years of the first enrollment in the program.

Program Plan
Each student admitted to a degree or certificate program is assigned an academic adviser with whom he or she jointly designs a Program Plan tailored to individual educational objectives and the degree provisions. After admission to the degree program, students must submit an initial Program Plan indicating the courses they wish to take to fulfill the degree requirements. This plan, and subsequent changes to it, must be approved by the student’s adviser.

Special Student
Students who satisfy the admission requirements but do not wish to receive a degree or certificate may also apply to be designated as Special Students to take graduate level courses for which they have satisfied the relevant prerequisites. If the student is subsequently accepted to a degree or certificate program, the admissions committee will determine whether these courses may be counted in fulfillment of degree requirements.

Graduate Certificate
The Graduate Certificate is directed toward students who may not need a master’s degree, may not have the opportunity to pursue the entire master’s degree, or may wish to focus their studies to a set of courses in a specific subject area.

The certificate consists of six courses. All grades for the six courses must be A or B. If, in the future, the student decides to pursue the full master’s degree, all courses will apply provided they meet the program requirements and fall within the five-year limit, and the student declares her/his intention prior to award of the certificate.

Students must meet the master’s degree admission requirements of the desired area of study. After the review of student’s academic credentials by the admission committee and admittance to the Graduate Certificate program, each student is assigned an adviser with whom he or she jointly designs a program tailored to individual educational goal.

Students must complete the Graduate Certificate within three years of the first enrollment in the program.

Program Plan
Each student admitted to a degree or certificate program is assigned an academic adviser with whom he or she jointly designs a Program Plan tailored to individual educational objectives and the degree provisions. After admission to the degree program, students must submit an initial Program Plan indicating the courses they wish to take to fulfill the degree requirements. This plan, and subsequent changes to it, must be approved by the student’s adviser.

Special Student
Students who satisfy the admission requirements but do not wish to receive a degree or certificate may also apply to be designated as Special Students to take graduate level courses for which they have satisfied the relevant prerequisites. If the student is subsequently accepted to a degree or certificate program, the admissions committee will determine whether these courses may be counted in fulfillment of degree requirements.
Environmental Engineering, Science and Management

Course Offerings
Courses are offered at Homewood campus in Baltimore, Montgomery County Campus in Rockville, Dorsey Center in Elkridge, Applied Physics Laboratory in Laurel, Washington, D.C. Center, and online.

Note that some of the courses have prerequisites. Students should refer to the course schedule published each term for exact dates, times, locations, fees, and instructors.

Classified by the area of study, the courses offered include:

Master of Environmental Engineering
575.404 Principles of Environmental Engineering
575.405* Principles of Water and Wastewater Treatment
575.406 Water Supply and Wastewater Collection
575.407 Radioactive Waste Management
575.420 Solid Waste Engineering and Management
575.423 Industrial Processes and Pollution Prevention
575.703 Environmental Biotechnology
575.706 Biological Processes for Water and Wastewater Treatment
575.715 Subsurface Fate and Contaminant Transport
575.721 Air Quality Control Technologies
575.745 Physical and Chemical Processes for Water and Wastewater Treatment
575.746 Water and Wastewater Treatment Plant Design
575.801 Independent Project in Environmental Engineering, Science and Management

Master of Science in Environmental Engineering and Science
575.401* Fluid Mechanics
575.415* Ecology
575.426 Hydrogeology
575.429 Modeling Contaminant Migration through Multimedia Systems
575.443* Aquatic Chemistry
575.445* Environmental Microbiology
575.704* Applied Statistical Analyses and Design of Experiments for Environmental Applications
575.708* Open Channel Hydraulics
575.713 Field Methods in Habitat Analysis and Wetland Delineation
575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
575.717 Hydrology
575.727 Environmental Monitoring and Sampling
575.728 Sediment Transport and River Mechanics
575.730 Geomorphic and Ecoligic Foundations of Stream Restoration
575.744 Environmental Organic Chemistry
575.801 Independent Project in Environmental Engineering, Science and Management

*Offered in an online format as well.

Master of Science in Environmental Planning and Management
575.408* Optimization Methods for Public Decision Making
575.411* Economic Foundations for Public Decision Making
575.419 Principles of Risk Assessment and Management
575.428 Business Law for Engineers
575.435* Environmental Law for Engineers and Scientists
575.437* Environmental Impact Assessment
575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
575.707* Environmental Compliance Management
575.710 Financial and Environmental Projects
575.714* Water Resources Management
575.720 Air Resources Modeling and Management
575.731 Water Resource Planning
575.733 Energy Planning and the Environment
575.741 Seminar in National Water Resources Planning
575.747* Environmental Project Management
575.759* Environmental Policy Analysis
575.801 Independent Project in Environmental Engineering, Science and Management

*Offered in an online format as well.

Cross-listed Courses from the Bloomberg School of Public Health Departments of Environmental Health Sciences and Epidemiology
180.601 Environmental Health
180.611 The Global Environment and Public Health
180.630 Public Health Aspects of Environmental Law
182.625 Principles of Industrial Hygiene
182.626 Tropical Environmental Health
183.639 Food- and Water-borne Diseases
183.641 The Health Effects of Indoor and Outdoor Air Pollution
186.601 Introduction to Radiation Health Sciences
187.610 Principles of Toxicology
Course Descriptions

575.401 Fluid Mechanics
The course introduces the principles of continuity, momentum, and energy applied to fluid motion. Topics include hydrostatics; ideal-fluid flow; laminar flow; turbulent flow; form and surface resistance with applications to fluid measurement; and flow in conduits and channels, pumps, and turbines.

Hag

575.404 Principles of Environmental Engineering
This course provides knowledge of environmental elements with insight into quantitative analysis and design where applicable. Topics include mass and energy transfer and balances; environmental chemistry; mathematics of growth and decay; risk assessment and management; surface water pollutants, biological and chemical oxygen demands, eutrophication; water supply systems and drinking water standards; wastewater treatment systems and effluent standards; groundwater flow, contaminant transport, and remediation technologies; hazardous waste and pollution prevention; remedial and corrective actions at contaminated sites; air pollution sources, control technologies, and atmospheric stability; ambient air quality standards, indoor air quality; global temperature, greenhouse effect and warming potential; global energy balance, carbon emission, and stratospheric ozone depletion; solid waste management, landfill disposal, combustion, composting, and recycling; medical waste; and environmental law, ethics, and justice. Field trips are integrated into the classes.

Movahed

575.406 Water Supply and Wastewater Collection
This course covers the design of reservoirs, conduits, water distribution systems, well fields, sewers, and drains. Included is a study of population growth and its effects on water supply requirements and sewage flows as well as techniques for analyzing rainfall, runoff, fluid flow, reservoir siting, and groundwater flows.

Prerequisite: 575.403 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

575.407 Radioactive Waste Management
This course covers fundamental aspects of radioactive substances in the environment; remediation processes for these substances; and their eventual storage, processing, and disposal. It provides a basic understanding of radioactivity and its effect on humans and the environment, and the techniques for their remediation and disposal. Topics include radioactivity, the nucleides, interaction of radiation with matter, shielding, dosimetry, biological effects, protection standards, sources of environmental radiation, risk evaluation, fate and transport analysis, cleanup standards, legal requirements, cleanup technologies, waste disposal, and case studies.

Lightner
575.408 Optimization Methods for Public Decision Making

This course is an introduction to applied operations research, that is, the development of optimization and simulation models intended to help people make decisions involving complex problems. The concepts and tools that we work with include linear and nonlinear optimization, dynamic programming, multiobjective optimization, integer programming, stochastic programming, and Markov decision processes. The material is presented in an environmental engineering-relevant context, with practical engineering problems frequently serving as both the motivation and the means through which the concepts of the course are taught. Such problems span a diverse array of timely issues involving water and air pollution control, logistical planning, and resource allocation.

Ellis, Williams

575.411 Economic Foundations for Public Decision Making

The course examines intermediate level price theory and surveys applications to public sector decision making. Topics include demand, supply, behavior of the market, and introductory welfare economics. Applications include forecasting, benefit-cost analysis, input-output analysis, and economic modeling.

Boland, Hobbs, Cantor, Nieberdin

575.415 Ecology

Course topics include an introduction to the organization of individual organisms into populations, communities, and ecosystems; interactions between individual organisms, groups of organisms and the environment (including competition, natural selection, adaptation, diversity, and the role of climate change on migration and extinction); the effect of acidification of the environment (including deforestation); and other human impacts on species diversity, community structure, and ecosystem stability.

Hillgartner

575.419 Principles of Risk Assessment and Management

Risk assessment and risk management have become central tools in continued efforts to improve public safety and the environment within the limited resources available. This course introduces the basic concepts of environmental risk assessment, relative risk analysis, and risk perception, including identifying and quantifying human health impacts, and evaluating ecological risk. The course describes legislative and regulatory initiatives that are attempting to base decisions on risk assessment, along with the controversy that surrounds such approaches. It also addresses specific federal requirements for risk analysis by industry. The course discusses the realities of using risk assessments in risk management decisions, including the need to balance costs and benefits of risk reduction, issues of environmental equity, accounting for the uncertainties in risk estimates, effective risk communication, and acceptable risk.

Dellarco

575.420 Solid Waste Engineering and Management

This course covers advanced engineering and scientific concepts and principles applied to the management of municipal solid waste (MSW) to protect human health and the environment and the conservation of limited resources through resource recovery and recycling of waste material. Topics include regulatory aspects and hierarchy of integrated solid waste management; characterization and properties of MSW; municipal wastewater sludge utilization; hazardous waste found in MSW; collection, transfer, and transport of solid waste; separation, processing, combustion, composting, and recycling of waste material; the landfill method of solid waste disposal which encompasses guidelines for design, construction, operation, siting, monitoring, remedial actions, and closure of landfills. Permitting and public participation processes, current issues, and innovative approaches are also addressed.

Alavi

575.423 Industrial Processes and Pollution Prevention

This course presents the pollution prevention and waste minimization concepts, terminologies, life cycle impacts, and management strategies. The course introduces available remediation techniques for industrial pollution control and prevention and examines specific applications to industries including biological, chemical, physical, and thermal techniques. Topics include current state of knowledge of pollution prevention approaches to encourage pollution prevention strategies, highlights of selected clean technologies and clean products, technical and economical issues, incentives and barriers to pollution prevention, and the role of different sectors in promoting pollution prevention. Pollution prevention and waste minimization techniques such as waste reduction, chemical substitution, production process modification, reuse and recycling will be addressed to selected industries such as textiles, electroplating, pulp and paper, and petroleum refining.

Engel-Cox

575.426 Hydrogeology

This course is an introduction to groundwater and geology and to the interactions between the two. The course provides a basic understanding of geologic concepts and processes, focusing on understanding the formation and characteristics of water-bearing formations. The course also addresses the theory of groundwater flow, the hydrology of aquifers, well hydraulics, groundwater-resource evaluation, and groundwater chemistry. The relationship between the geologic concepts/processes and the groundwater resource are discussed. Examples include a discussion of the influence of the geologic environment on the availability and movement of groundwater and on the fate and transport of groundwater contaminants. Geotechni-
575.428 Business Law for Engineers
This course introduces engineers to the basic legal principles they will encounter throughout their careers. Course discussions cover contracts (formation, performance, breach, and termination), corporations and partnerships, insurance, professional liability, risk management, environmental law, torts, property law, and evidence and dispute resolution. The course emphasizes those principles necessary to provide engineers with the ability to recognize issues which are likely to arise in the engineering profession and introduces them to the complexities and vagaries of the legal profession.

575.429 Modeling Contaminant Migration through Multimedia Systems
This course addresses contamination that can affect many media as it migrates through the environment. Typically, contaminant sources occur in soil, from which the chemicals then migrate to air, surface water, and groundwater. Predicting the movement of contaminants through these media requires addressing the fate and transport processes that predominate in each media and integrating the interactions between the media. The course presents the basic principles and numerical methods for simulation contaminant migration from soil into and through surface-water bodies, air, and groundwater. The basic processes of fate and transport in the various media will be addressed: entrainment; adsorption; volatilization; chemical reactions such as degradation and photolysis; convection; and Gaussian dispersion and deposition. Selected public-domain numerical models will be used to simulate the fate and transport processes. Central to the course will be a project that integrates multimedia environmental modeling through a case study.

575.435 Environmental Law for Engineers and Scientists
This course explores fundamental legal concepts relevant to environmental issues, including the relationship between statutes, regulations, and court decisions. Also, included are various forms of enforcement used in environmental rules: command and control, liability, and information disclosure. Specific issues include criminal enforcement; a survey of environmental statutes; regulations and case law; the purpose and misconceptions surrounding environmental audits and assessments; the concept of attorney-client privilege; unauthorized practice of law; and ethical conflicts between the attorney and engineer/scientist roles.

575.437 Environmental Impact Assessment
This course examines principles, procedures, methods, and applications of environmental impact assessment. The goal of the course is to promote an understanding of how environmental impact assessment is conducted and used as a valuable tool in the engineering project management decision-making process. Topics include overview of environmental impact assessment; selection of scientific, engineering, and socioeconomic factors in environmental impact assessment; identification of quantitative and qualitative environmental evaluation criteria; application of traditional and other techniques for assessing impacts of predicted changes in environmental quality; approaches for identifying, measuring, predicting, and mitigating environmental impacts; modeling techniques employed in environmental impact assessment; environmental standards and the environmental impact assessment process; and methodologies for incorporating environmental impact assessment into management decision making. Students learn to prepare an environmental impact assessment, review and critically analyze an environmental impact statement, use mathematical models for environmental impact prediction, and apply environmental impact assessment as a tool in management decision making. Case studies of environmental impact assessment for several types of engineering projects are employed.

575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
Through lectures and laboratory exercises, this course illustrates the fundamental concepts of GIS and remote sensing technologies in the context of environmental engineering. Topics include the physical basis for remote sensing, remote sensing systems, digital image processing, data structures, database design, and spatial data analysis. The course is not intended to provide students with extensive training in particular image processing or GIS packages. However, hands-on computer laboratory sessions re-enforce critical concepts. Working knowledge of personal computers and completion of a term project is required.

575.443 Aquatic Chemistry
Thermodynamics and equilibrium are applied to processes in natural waters, water supply systems, wastewater treatment systems, and other water-based systems. Topics include the chemistry of electrolyte solutions, acids and bases, dissolved carbonate and other pH-buffering solutes, the precipitation and dissolution of inorganic solids, complex formation and chelation, and oxidation-reduction reactions. Quantitative problem solving and the visualization of chemical speciation are emphasized.
575.445  **Environmental Microbiology**
This course covers fundamental aspects of microbial physiology and ecology. Specific areas of focus include energetics and yield, enzyme and growth kinetics, cell structure and physiology, metabolic and genetic regulation, microbial/environmental interactions, and biogeochemical cycles. The goal of this course is to provide a basic understanding and appreciation of microbial processes which may be applicable to the environmental biotechnology.

Wilson-Durant

575.703  **Environmental Biotechnology**
This course examines current applications of biotechnology to environmental quality evaluation, monitoring, and remediation of contaminated environments. The scale of technology ranges from the molecular to macrobiotic. Relevant topics of microbiology, plant biology topics are presented. These provide a foundation for subsequent discussions of microbial removal and degradation of organics, phytoremediation of soil and water contaminated with toxic metals and radionuclides, wetlands as treatment processes, biofilms/biofilters for vapor-phase wastes, and composting. Emphasis is placed on modeling and design. Advantages and disadvantages of each application are compared. Case studies are presented in the areas of biosensors in environmental analysis; molecular biology applications in environmental engineering; and genetic engineering of organisms for bioremediation.

Prerequisite: Prior course work in environmental microbiology or biochemical engineering is recommended but not required.

Wilson-Durant, Lasat

575.704  **Applied Statistical Analyses and Design of Experiments for Environmental Applications**
This course introduces statistical analyses and techniques of experimental design appropriate for use in environmental applications. The methods taught in this course allow the experimenter to discriminate between real effects and experimental error in systems which are inherently noisy. Statistically designed experimental programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models which accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional factorial designs; screening designs; response surface and optimization methods; and applications to pilot plant and waste treatment operations. Particular emphasis is placed on analysis of variance, prediction intervals, and control charting for determining statistical significance as currently required by federal regulations for environmental monitoring.

575.706  **Biological Processes for Water and Wastewater Treatment**
This course develops the fundamentals and applications of aerobic and anaerobic biological unit processes for the treatment of municipal and industrial wastewater. The principles of activated sludge, aeration and clarifier design, fixed film reactors, anaerobic treatment, solids handling and treatment, land treatment, and nutrient removal are presented. This course uses concepts from microbiology and the basic principles of stoichiometry, energetics and microbial kinetics are used to support the design of biological unit processes.

Prerequisites: 575.405 Principles of Water and Wastewater Treatment.

Weiss

575.707  **Environmental Compliance Management**
The course covers compliance with environmental laws and regulations by industry, small business, government facilities and others. It includes legal responsibilities, environmental management systems and practices such as audits and information systems, and development of corporate policies and procedures that rise to the daunting challenge to harmonize the institution’s primary goals with its environmental obligations. Several dimensions of environmental management are discussed: federal, state and local regulation; scientific/technical factors; public relations and the press; institutional objectives including economic competitiveness.

575.708  **Open Channel Hydraulics**
The course covers application of the principles of fluid mechanics to flow in open channels. Topics include uniform flow, flow resistance, gradually varied flow, flow transitions, and unsteady flow. The course also addresses flow in irregular and compound channels, backwater and 2-D flow modeling, and applications to channel design and stability.

Prerequisites: Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

575.710  **Financing Environmental Projects**
This course treats the financing of projects from two complementary perspectives: that of a government agency funding source, and that of an environmental utility (water, wastewater, solid waste) that needs funds for its project. It discusses grants, concessionary loans, market loans, and loan guarantees; their relative desirability and efficiency. Since grant funding is never available for all projects, the course deals extensively with borrowing/lending. It discusses strategies for maximizing utility income, including appropriate tariff structures and the reform of government subsidy policy from supply-based general subsidies to demand-based targeted subsidies. Operational strategies to maximize income are also discussed such as techniques to improve billing and collections, reduce losses and reduce energy costs. Traditional cash flow analyses are used to determine debt service capabilities. Various project cost reduction strategies, such as staging and scaling, are introduced. Grants in the form of upfront project cost buy-
downs vs. annual debt service subsidies are compared. Finally, several examples of project financings combining many of the elements introduced during the course are presented and analyzed.

Curley

575.713 Field Methods in Habitat Analysis and Wetland Delineation
The course provides students with practical field experience in the collection and analysis of field data needed for wetland delineation, habitat restoration, and description of vegetation communities. Among the course topics are sampling techniques for describing plant species distributions and community structure and diversity, including the quadrant and transect-based, point-intercept, and plotless methods; identification of common and dominant indicator plant species of wetlands and uplands; identification of hydric soils; use of soil, topographic, and geologic maps and aerial photographs in deriving a site description and site history; and graphic and statistical methods including GIS applications for analyzing and presenting the field data. The classes consist of field studies to regional and local sites.

Prerequisite: 575.415 Ecology.

Hilgartner

575.714 Water Resources Management
This course examines watershed approaches to maintenance of the hydrological, chemical, and biological integrity of the nation’s waters. Water supply topics include rainfall-runoff relationships, probabilistic flow analysis, multiple-objective reservoir siting and operation, and safe yield analysis. Water quality topics include regulatory requirements; non-point source runoff; point source discharge; water quality analysis of streams, lakes, and estuaries (including waste heat, conventional pollutants, and toxic chemicals); and in-stream biological resource requirements and assessment. Both the water supply and water quality discussions provide an overview of current computer simulation models. The course concludes with new integrated approaches for watershed management, including Waste Load Allocation and Total Maximum Daily Loss (TMDL) analysis for pollutants entering water bodies.

Summer, Cardwell

575.715 Subsurface Fate and Contaminant Transport
The course covers the nature and sources of chemicals in the subsurface, the role of groundwater and soil water in mobilizing and spreading contamination, the processes that control distribution and fate of subsurface contamination, the accepted methods of investigating and analyzing contamination, and contaminant transport. The course also considers surface water contamination caused by contamination in the groundwater. Computer laboratories of groundwater model simulations and solute transport solutions are used.

Durant, Barranco

575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
The course examines the basic physical, chemical, and biological components of the Chesapeake Bay ecosystem and how they interrelate in both healthy and degraded states of an estuary. The course centers around the tidal waters of the Chesapeake Bay and its tributaries while also including relationships with the surrounding watershed, atmosphere, and ocean and relevance to other coastal systems. Particular emphasis is given to anthropogenic stresses such as nutrient and contaminant pollution, habitat modification, and harvest of fish and shellfish. The most current Chesapeake Bay management issues and policies being pursued at the federal, state, and local levels of government are discussed in depth, including their scientific foundation.

Brush

575.717 Hydrology
This course reviews components of the hydrologic cycle, including precipitation, evapotranspiration, infiltration, subsurface flow, and runoff. Analysis of hydrologic data, including frequency analysis and the use of stochastic models for describing hydrologic processes, is also covered.

Prerequisite: Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Raffensperger

575.720 Air Resources Modeling and Management
Topics covered in this course include an overview of atmospheric motion to give students a sense of how air pollutant transport and transformation is modeled; regulatory considerations in air pollution control related to model selection and use; system analytic approaches for developing air pollution control strategies; a brief overview of air pollution control technology; the state of air pollution in Maryland and the United States; and a detailed look at air pollution data and related information—what exists, how can data be accessed and processed, and which organizations collect and manage data. Specific air pollution problems addressed in the course include those involving tropospheric ozone, stratospheric ozone, acid rain, carbon monoxide, nitrogen oxides, and particulate matter.

Ellis, Abt

575.721 Air Quality Control Technologies
This is a multidisciplinary course that involves the applications of chemistry, thermodynamics, and fluid mechanics in the selection and design of air pollution control equipment. Topics include the estimation of potential pollutants, chemical characterization of gas streams to be controlled, theory and practice of air pollution control, and design and costing of control technologies. The course emphasizes the design of systems to reduce particulate matter emissions, volatile organic compound (VOC) emissions, nitrogen oxide emissions, and sulfur dioxide emissions.
Environmental Engineering, Science and Management

Prerequisites: Fluid Mechanics or an equivalent course in fluid flow; an undergraduate course in thermodynamics.

575.727  Environmental Monitoring and Sampling
Myers
The course examines in detail the principles and methods for monitoring and discrete sampling of environmental media, including surface water, ground water, soil, air, solid wastes, and tissues within the context of regulatory compliance. Basic health and safety issues and Data Quality Objectives will be covered initially. Sampling design covers basic statistical concepts including data variability and detection of significant differences among sample sets. Regulatory perspectives reviews requirements of the major statutes governing sampling of various media, including the Clean Water Act, Clean Air Act, CERCLA, and RCRA. Sampling methods surveys current methods for discrete sampling and automated data acquisition for each medium. Chemical and biological analysis reviews laboratory methods for analyzing samples. Data presentation and interpretation covers data management methods to support decision making. The course includes field trips and off-campus lectures and/or demonstrations at laboratories.

Stoddard

575.728  Sediment Transport and River Mechanics
This course examines the processes of sediment entrainment, transport, and deposition and the interaction of flow and transport in shaping river channels. Topics reviewed include boundary layer flow; physical properties of sediment; incipient, bed-load, and suspended-load motion; bed forms; hydraulic roughness; velocity and stress fields in open channels; scour and deposition of bed material; bank erosion; and size, shape, planform, and migration of river channels. In addition, the course develops techniques of laboratory, theoretical, and numerical modeling and applies them to problems of channel design, restoration, and maintenance.
Prerequisites: Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Wilcock

575.730  Geomorphic and Ecologic Foundations of Stream Restoration
This course presents principles from hydrology, sedimentation engineering, geomorphology, and ecology relevant to the design and evaluation of stream restoration projects. A watershed context is emphasized in developing the background needed to assess different design approaches. After developing a common foundation in stream dynamics, the course considers tradeoffs among restoration objectives, the merits of analog and predictive approaches, the role of uncertainty in restoration design, and metrics for assessing ecological recovery. The course includes field trips, design exercises, and project assessment.

Wilcock

575.731  Water Resource Planning
Myers
The course will discuss the application and interrelationships among microeconomics, ecology, hydrology and related fields to the planning and management of water systems. Topics will include flood control, navigation, hydropower, water supply, environmental restoration, multiobjective planning, and urban water resource management. The course will demonstrate the process for planning a water resource project, including identifying the problems and opportunities, inventorying and forecasting conditions, formulating alternative plans, evaluating alternative plans, comparing alternative plans and selecting a plan. Particular attention will be paid to the appropriate interdisciplinary approach to plan formulation.

Kranzer

575.733  Energy Planning and the Environment
This course examines the interconnections between the environment and the ways in which energy is produced, distributed, and used. Particular attention is paid to consequences of government intervention and regulation, as well as market and regulatory economics. The purpose is to help students understand how energy industries operate, and how public policy shapes the impact that these industries have on the environment.
Prerequisite: 575.411 Economic Foundations for Public Decision Making, or an equivalent course in microeconomic theory.

Lightner

575.741  Seminar in National Water Resources Planning
This seminar addresses the theory and practice of water resources planning at all levels of government, with particular emphasis on federal-level planning and state-federal relationships. Although this is nominally an online course, it begins with a five-day residence session, conducted at the Johns Hopkins University in Baltimore. The residence session includes a series of lectures by JHU faculty and distinguished scholars from several other universities. During this session, personnel from the U.S. Army Corps of Engineers (USACE) will present a complex case study, typically an ongoing Corps feasibility study that involves significant economic, social, and environmental issues. Where feasible, part of the presentation may take place at the project site. After the residence session, students return home and begin a six-week online session. During this time, the students are expected to complete individual assignments and to collaborate in the preparation of a comprehensive planning report (comparable to feasibility reports performed by USACE) that addresses all aspects of the case study, considers and evaluates alternatives, and makes a final recommendation. These products will be reviewed and critiqued online by a panel of experienced planners.
Prerequisites: Students are expected to have successfully undertaken introductory graduate study or have equivalent work experience in the following areas (substitutions and alterna-
Arora

Treatment.

Prerequisite
and operation of engineered and natural aquatic systems. Concepts learned in this class to better understand the design, water and wastewater treatment systems. Students will use the application of these operations to the design and operation of various chemical and physical unit operations, with direct filtration. The goal is to provide a theoretical understanding of fundamental understanding of intermolecular interactions and thermodynamic principles. Mechanisms of important thermochemical, photochemical, and biochemical transformation reactions are also investigated, leading to development of techniques (such as structure-reactivity relationships) for assessing environmental fate or human exposure potential.

Prerequisite: Introductory organic chemistry.

Jayasundera

575.744 Environmental Organic Chemistry

This course focuses on examination of processes that affect the behavior and fate of anthropogenic organic contaminants in aquatic environments. Students learn to predict chemical properties influencing transfers between hydrophobic organic chemicals, air, water, sediments, and biota, based on a fundamental understanding of intermolecular interactions and thermodynamic principles. Mechanisms of important thermochemical, photochemical, and biochemical transformation reactions are also investigated, leading to development of techniques (such as structure-reactivity relationships) for assessing environmental fate or human exposure potential.

Prerequisite: Introductory organic chemistry.

Jayasundera

575.745 Physical and Chemical Processes for Water and Wastewater Treatment

In the course, mass and momentum transport, aquatic chemistry, and chemical reaction engineering are applied to physical and chemical processes used for water and wastewater treatment. Students also learn the theory and practice of various unit processes including disinfection, oxidation, coagulation, sedimentation, filtration, adsorption, gas transfer, and membrane filtration. The goal is to provide a theoretical understanding of various chemical and physical unit operations, with direct application of these operations to the design and operation of water and wastewater treatment systems. Students will use the concepts learned in this class to better understand the design and operation of engineered and natural aquatic systems.

Prerequisite: 575.405 Principles of Water and Wastewater Treatment.

Arora

575.746 Water and Wastewater Treatment Plant Design

This course familiarizes students with appropriate design criteria and the design process for water and wastewater treatment plants. This includes design of treatment processes, cost estimates, and a working design team under project managers. Additional course requirements include oral presentations and writing engineering reports.

Prerequisites: 575.405 Principles of Water and Wastewater Treatment and one of 575.706 Biological Processes for Water and Wastewater Treatment or 575.745 Physical and Chemical Processes for Water and Wastewater Treatment.

Arora

575.747 Environmental Project Management

This course educates students on the key elements of an integrated approach to environmental project management, an endeavor which requires expertise in scientific, engineering, legal, public policy, and project management disciplines. Emphasis is placed on critical factors that are often unique to a major environmental project, such as the uncertainty surrounding scope definition for environmental cleanup projects and the evolving environmental regulatory environment. The students learn to develop environmental project plans, establish project organization and staffing, define management functions, develop time management approaches, resolve project conflicts, determine project effectiveness, implement integrated project management techniques such as the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) as they relate to environmental project management, perform pricing and cost estimating, establish cost control, set priorities, and perform tradeoff analyses. The course uses environmental project case studies to examine the integrated nature of environmental project management. Examples of topics to be covered in this case study format include environmental security projects, environmental technology deployment projects, privatization of governmental environmental projects, and pollution prevention/waste minimization projects.

Toussaint

575.759 Environmental Policy Analysis

The course explores the problem of developing appropriate public policies for the primary purpose of restoring, preserving, and protecting aspects of the physical environment. Emphasis is placed on the need to harmonize environmental science, human health, socio-political, technological, legal, financial, and economic considerations in a context of incomplete information and uncertain futures. One or more specific environmental policies are studied in the course of the semester. Students are expected to plan and execute individual research projects that demonstrate the use of quantitative and/or economic tools in designing and evaluating responses to environmental management problems.

Boland
575.801 Independent Project in Environmental Engineering, Science and Management

This course provides students with an opportunity to carry out a significant project in the field of environmental engineering, science, technology, planning or management as a part of their graduate program. The project is individually tailored and supervised under the direction of a faculty member and may involve conducting a semester-long research, an in-depth literature review, a non-laboratory study, or application of a recent development in the field. The student may be required to participate in conferences relevant to the area of study. To enroll in this course, the student must be a graduate candidate in the Environmental Engineering, Science, and Management Program within the later half of the degree requirements and must obtain the approval and support of a sponsoring faculty member in the Department of Geography and Environmental Engineering at Johns Hopkins University. The proposal description and completed required forms must be submitted prior to registration for approval by student’s adviser and the program chair. A maximum of one independent project course may be applied toward the master’s degree or post-master’s certificate.
Information Systems and Technology

Information technology permeates all aspects of modern society. The Information Systems and Technology (IS&T) program stresses the analysis, design, development, and integration of systems that enable the effective and efficient use of information. With emphasis in computer science, networking, and technical management, the discipline employs techniques and methodologies that allow practitioners to create and manage automated systems that can be used to solve real world problems.

The Master of Science in IS&T is designed to appeal to a wide range of individuals. The program balances theory with practice, offers an extensive set of traditional and state of the art courses, and provides the flexibility to accommodate students with various backgrounds. As a result, the program will appeal to engineers and scientists seeking an applied technology program designed to enhance their abilities to develop real world information systems. It will also appeal to technically oriented business people looking to acquire a deeper understanding of information technology in order to manage systems and resources more effectively. By providing a broad based education in the field, the IS&T program allows students to design effective information systems, develop efficient computer and communications networks, conduct complex systems analyses, and create sophisticated decision-support systems.

Courses are offered across a wide variety of topic areas, including decision-support systems, telecommunications and networking, software development, database and multimedia systems, human computer interaction, distributed systems, and project management. Research and development interests of the faculty span the spectrum of information systems and technology. Students may take courses at the Applied Physics Laboratory, the Montgomery County Campus, the Dorsey Center, and online. Extensive computing facilities, including a networked multiprocessor server, X-terminals, workstations, and personal computers are available and can be reached from any of the sites or from home via high speed modems. A variety of software systems, applications, development tools, and specialized lab facilities are also supported.

Program Committee
Ralph D. Semmel, Program Chair
Principal Professional Staff
Applied Physics Laboratory

John A. Piorkowski, IS&T Coordinator
Principal Professional Staff
Applied Physics Laboratory

Eleanor Boyle Chlan
Senior Lecturer in Computer Science
Whiting School of Engineering

Admission Requirements
Applicants must meet the general requirements for admission to a graduate program outlined in the Admission Requirements section of this catalog. In addition, applicants should have completed the following:

A. One year of college mathematics
B. One year of introductory computer science including a course in Java, or C++, and a course in data structures.

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing equivalent courses with grades of A or B. In particular, those students who do not satisfy the introductory computer science requirements may take the following undergraduate courses:

605.201 Introduction to Programming Using Java
605.202 Data Structures

Course Requirements
Ten courses, approved by an adviser, must be completed within five years. At least eight courses must be from the IS&T curriculum, which includes IS&T courses, applied computer science courses, and selected systems engineering and tech-
nical management courses. Three courses must be from the same concentration area and at least two courses must be 700-level.

Students may take up to two electives from other Whiting School programs. Students who take electives from other programs must meet the specific course and program requirements listed for each course.

Graduate students not pursuing a master’s degree in information systems and technology should consult with their adviser to determine what courses must be successfully completed before 400- or 700-level IS&T courses may be taken. 700-level courses are open only to students who have been admitted with graduate status.

Please refer to the course schedule each term for dates, times, locations, fees, and instructors.

**Foundation Courses**

All students working toward a master’s degree in information systems and technology must take three foundation courses before taking other graduate courses:

- 605.401 Foundations of Software Engineering
- 635.411 Foundations of Networking and Telecommunications
- 635.421 Foundations of Decision Support Systems

One or more foundation courses can be waived if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate courses, and may take these courses after all remaining foundation course requirements have been satisfied.

**IS&T Courses**

- 635.411 Foundations of Networking and Telecommunications
- 635.412 Local and Wide Area Network Technologies
- 635.413 IP Networking and Applications
- 635.414 Wireless Networking
- 635.421 Foundations of Decision Support Systems
- 635.431 Information Systems Architectures and Methodologies
- 635.476 Information Systems Security
- 635.482 Web Site Development
- 635.483 Electronic Commerce
- 635.711 Internetworking: Methods, Technologies, and Devices
- 635.721 Human-Computer Interaction
- 635.731 Distributed Architectures
- 635.781 XML: Technology and Applications
- 635.792 Management of Innovation
- 635.795 Information Systems and Technology Capstone Project
- 635.801 Independent Study in Information Systems and Technology

**Undergraduate Courses**

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures

**Concentration Areas**

The IS&T concentration areas including all applicable courses in IS&T, applied computer science, systems engineering, and technical management are as follows:

**I. Information Assurance Systems**

- 605.431 Principles of Enterprise Security and Privacy
- 605.432 Public Key Infrastructure and Managing E-Security
- 605.433 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
- 605.434 WWW Security
- 605.731 Network Security
- 605.734 Information Assurance Architectures and Technologies
- 635.476 Information Systems Security

**II. Distributed Systems**

- 605.481 Distributed Development on the World Wide Web
- 605.482 User Interface Development with the Java Foundation Classes
- 605.781 Distributed Objects
- 605.782 Web Application Development with Servlets and JavaServer Pages (JSP)
- 605.783 Reusable Software Components with JavaBeans
- 605.784 Enterprise Computing with Java
- 605.785 Web Services: Framework, Process, and Applications
- 605.786 Enterprise System Design and Implementation
- 635.482 Web Site Development
- 635.483 Electronic Commerce
- 635.731 Distributed Architectures

**III. Knowledge Management**

- 605.441 Principles of Database Systems
- 605.445 Artificial Intelligence
- 605.741 Distributed Database Systems on the World Wide Web
- 605.743 The Semantic Web
- 605.744 Information Retrieval
- 635.781 XML: Technology and Applications

**IV. Software Systems**

- 605.401 Foundations of Software Engineering
- 605.402 Software Analysis and Design
Course Descriptions

635.411  Foundations of Networking and Telecommunications
This course provides an overview of networking and telecommunications. Topics include analog and digital voice; data, imaging, and video communications fundamentals, including signaling and data transmissions; and basic terminology. The course also covers networking and telecommunication techniques, applications technology, and networking topologies and internetworking architectures. Specific areas discussed include LAN system fundamentals, such as Ethernet and token ring; and WAN system fundamentals, such as circuit-switching, packet-switching, X.25, frame relay, and Asynchronous Transfer Mode. The open systems interconnection (OSI) reference model standard is also described and compared with other network layering standards used in telecommunications.

Piorkowski, Romano, Burbank

635.412  Local and Wide Area Network Technologies
This course provides an in-depth presentation of the fundamental technology, architecture, and protocols necessary for local- and wide-area networking. It covers network topology, transmission media, media access control, interconnection devices, and fundamental communications standards such as IEEE 802. It addresses important LAN and WAN concepts such as switching, virtual LANs, DWDM, and interconnection of different LAN and WAN technologies. It also examines typical communication protocols used in LAN and WAN systems such as Ethernet, Fibre Channel, SONET, xDSL, cable modems, and ATM/ Frame Relay.

Prerequisite: 635.411 Foundations of Networking and Telecommunications.

Romano

635.413  IP Networking and Applications
This course covers the underlying networking protocols and technologies upon which the Internet and other IP-based networks are built. The TCP/IP suite, including IP, TCP, UDP, and ICMP are studied in detail. Routing protocols for IP-based networks are explored including BGP, OSPF, and IGRP; ARP, DHCP and the Domain Name Service and other important utility protocols are also discussed. A comprehensive survey is provided of the applications that are being implemented over IP-based networks, including secure electronic commerce, streaming media, Voice over IP, content distribution, and future directions. In addition to textbook assignments, students will have assigned readings and research from the web.

Prerequisite: 635.411 Foundations of Networking and Telecommunications.

Hsu, Romano

635.414  Wireless Networking
This course provides an overview of emerging and existing technologies in wireless networking from the perspectives of wireless telephony, wireless data networking, and sensor networking. The course covers cellular communications technologies as well as the IEEE 802 wireless networking technology family. Key network layer technologies will be discussed, including Mobile IP and NEtwork MObility (NEMO), layer-2 mesh routing approaches, and layer-3 Mobile Ad-hoc Network (MANET) routing approaches. Security, management, and key performance issues of wireless networks will also be presented.

Prerequisites: 635.411 Foundations of Networking, or equivalent.

Burbank

635.421  Foundations of Decision Support Systems
This course focuses on the use and application of information systems to support the decision-making process. Knowledge-based systems, neural networks, expert systems, electronic meeting systems, group systems and web-based systems are discussed as a basis for designing and developing highly effective decision support systems. Data models, interactive processes, knowledge-based approaches and integration with
database systems are also described. Theoretical concepts are applied to real-world applications.

Nag, Felikson

635.431 Information Systems Architectures and Methodologies
This course introduces the fundamental principles which govern information system architecture, data and storage structures, operating systems, data definition and manipulation languages, query structures, and systems analysis as applied to information systems. Hardware considerations for supporting the construction of complex systems are described.

Nag, Felikson

635.476 Information Systems Security
This course describes the systems security engineering process with a focus on security during the design, implementation, and operation of information systems. The course will present the processes that have been defined and published by the federal government for designing and certifying secure information systems. Examples include defense-in-depth, the Information Assurance Technical Framework and the DITSCAP. There will also be material on commercial and government security products available and the Common Criteria Project for evaluating security products.

Pearson

635.482 Web Site Development
This course covers the design and implementation of web sites. Various web standards, as developed by the World Wide Web Consortium and by browser manufacturers are studied. HTML 4.01 and XHTML 1.0 specifications are covered, including topics such as text control, images, hypertext links, tables, frames and embedded objects (e.g., video and applets). Cascading Style Sheets (CSS1 and CSS2), a web scripting language (such as Javascript), CGI programming, and their use in Dynamic HTML is also covered. Design and development topics include ease of navigation, download time, maintaining a consistent look and feel across multiple pages, making a web site work well across multiple browsers, and web server selection and configuration.

Noble

635.483 Electronic Commerce
This course covers the architecture and technologies required to build e-commerce systems. Basic concepts of e-commerce are introduced followed by coverage of the Internet backbone, including fundamental networking infrastructure. The course describes the inadequacy of current World Wide Web technology for e-commerce, which has resulted in the development of the concept of Service-Oriented Architecture (SOA) and its implementation in the form of an Enterprise Service Bus (ESB). SOA and ESB provide a robust and reliable way for service-to-service and business-to-business integration at the data, information and the application levels. Web Services provides the underlying messaging service and is built on four open standards, XML, SOAP, WSDL, and UDDI. The course also introduces the two major frameworks, J2EE and .NET, for building Web services. The critical security and governance issues in SOA implementation along with SOA design and implementation roadmaps are discussed. The second generation Web 2.0 and the AJAX technology are also covered. Finally a software architecture from Business Process Management (BPM) to Grid Computing is presented. (This course is the same as 635.483 Electronic Commerce.)

Summer

635.711 Internetworking: Methods, Technologies, and Devices
In this course, students learn the methods for interconnecting data networks and creating internetworks. This will cover the LAN internetworking processes and address the extension of LAN coverage and traffic. It will provide the basics for hubs, LAN switching, and router functions. This course will address the methods used in switching and routing as well as some of the gateway requirements used in internetworking. Advanced internetworking topics such as VLANs, MPLS, VPNs, DiffServ, and Intserv will be covered. In addition to the study of principles behind internetworking, the course includes a laboratory where students configure networks using switches and routers. Students will also be assigned a network design project.

Prerequisites: A foundations course in data communications (e.g., 635.411) and an advanced course in LANs or IP networking (e.g., 635.412 or 635.413).

Fall, Spring

635.721 Human-Computer Interaction
Well-designed human-computer interaction is critical to the success of computer and information systems. This course focuses on the HCI design process and covers the underlying scientific principles, HCI design methodology, and the user-interface technology used to implement HCI. Topics include human cognition, HCI theories, user observation and task analysis, prototyping and evaluation techniques, user interface modalities and graphical user interface components, and accessibility. Selected additional topics may include HCI in web site design, support of collaborative work, human interaction with automation, and ubiquitous computing. Student design projects are an integral part of the course. Reading the current HCI research literature is also required. (This course is the same as 605.766 Human-Computer Interaction.)

Spring

635.731 Distributed Architectures
This course explores technologies for enabling distributed systems. Performance, scalability, security, concurrency, synchronization, error handling, and open standards in the context of heterogeneous systems are discussed as a basis for making the distributed nature of systems transparent to users. Key areas covered include client-server systems, coordination and agreement, data encryption, and communications. Students will
also investigate advanced topics such as distributed artificial intelligence, mobile agents, storage area networking, distributed databases, and device discovery.

Anderson

635.781 XML: Technology and Applications

The course covers the concepts, technology, and applications of XML (Extensible Markup Language), especially to Web-based technologies. The course concentrates on XML fundamentals and associated technologies, and processing XML using Java. Topics covered include the XML Specification; XML Namespaces; Document Type Definitions (DTDs); XML Schemas; XML Transformation (XSLT); XML Links and XML Pointers; and parsing XML using the Document Object Model (DOM) and Simple API (Application Programming Interface) for XML (SAX), the Java API for XML Processing (JAXP), and the Java Document Object Model (JDOM). Additional topics may be drawn from Cascading Style Sheets (CSS); XQuery; the Simple Object-Oriented Protocol (SOAP); Web Services Description Language (WSDL); Universal Description, Discovery and Integration (UDDI); applications of XML such as RDF; and the architecture of Web Service, EAI, and B2B systems using XML. (This course is the same as 605.742 XML: Technology and Applications.)

Prerequisite: 605.481 or equivalent Java experience.

Silberberg

635.792 Management of Innovation

A critical issue for entrepreneurs and technical managers is how to translate opportunity into competitive advantage. This course explores the management of innovation, including the technical transition of applied R&D into products, the planning and launching of new products, and product management. Management of discontinuous technologies will be explored. The impact of competition by the introduction of new discontinuous technology will be addressed. Managing engineers through the creative process, as well as innovation and technological evolution, will be covered. The course includes both formal and guest lectures. Case studies will be used as an important learning vehicle.

Fall, Spring

Addison and Husick

635.795 Information Systems and Technology Capstone Project

This course is designed for students who would like to conduct a major, independent project involving a substantial enterprise information system design that builds upon elements of the IS&T curriculum. The project includes requirements analysis, IT architecture design, network design, software integration, decision support applications, and deployment planning. Interim deliverables include presentations to the course advisors. Project proposals are required and a mentor will be assigned to the student.

Prerequisites: Completion of eight courses in the IS&T curriculum, including all IS&T foundations courses.

Note: Students may not receive graduate credit for both 635.795 and 635.802 Independent Study in Information Systems and Technology II.

Staff

635.801 Independent Study in Information Systems and Technology I

This course permits graduate students in Information Systems and Technology to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper.

Prerequisites: Seven IS&T graduate courses including the foundation courses, three concentration area courses, and two courses numbered 635.7xx; or admission to the advanced certificate for post-master’s study. Students must also have permission of a faculty member.

635.802 Independent Study in Information Systems and Technology II

Students wishing to take a second independent study in information systems and technology should sign up for this course.

Prerequisites: 635.801 and permission of a faculty mentor, the student’s academic adviser, and the program.

Note: Students may not receive graduate credit for both 635.802 and 635.795 Information Systems and Technology Capstone Project.
Materials Science and Engineering

Materials science and engineering is concerned with the structure, processing, properties, and applications of materials. Materials scientists investigate how the structure and composition of materials affect their properties and performance. Materials engineering develops, modifies, and applies materials to specific technological applications.

The Department of Materials Science and Engineering offers three different graduate degrees: the Ph.D., the M.S.E. (Master of Science in Engineering), and the M.M.S.E. (Master of Materials Science and Engineering). The M.M.S.E. is offered through Engineering and Applied Science Programs for Professionals and is described in detail below. Information about the Ph.D. and M.S.E. can be obtained from the Arts and Sciences/Engineering Undergraduate and Graduate Programs Catalog.

The M.M.S.E. degree is designed specifically as a part-time degree that can be completed by taking courses in the late afternoon or evening. It is viewed as a terminal degree and is generally not considered sufficient preparation to continue toward the Ph.D. Those interested in pursuing a Ph.D. degree should consider applying to the department for the M.S.E. degree which, unlike the M.M.S.E., requires a formal thesis. Please note that the application materials for the Ph.D. or M.S.E. degrees are different from the Engineering and Applied Science Programs for Professionals application used in applying for the M.M.S.E. degree.

The Department of Materials Science and Engineering has active and well-funded research programs in biomaterials, nanomaterials and nanotechnology, electrochemistry, nondestructive evaluation, thin films, mechanics of materials, and physical metallurgy.

Program Committee
Robert C. Cammarata, Program Chair
Professor, Materials Science and Engineering
Whiting School of Engineering

James B. Spicer
Professor, Materials Science and Engineering
Whiting School of Engineering

Jennifer Sample
Senior Professional Staff
Applied Physics Laboratory

Timothy Foecke
Staff Materials Scientist
National Institute of Standards & Technology

Admission Requirements
The Master of Materials Science and Engineering (M.M.S.E.) program is best suited to students who have received undergraduate degrees in engineering or science. Applicants are expected to have completed a mathematics sequence through differential equations and courses in general physics and chemistry. Applicants must meet the general requirements for graduate study outlined in this catalog.

The program committee is willing to consider applicants who do not meet the general admission requirements only in exceptional cases. In these cases, the applicant must present convincing evidence of outstanding ability and a record of achievement. For all candidates, in addition to the application form and required transcripts, the program committee requests applicants to arrange for two letters of recommendation to support their applications.

Individuals who desire a non-degree status for taking courses may request consideration for Special Student status. Regardless of level, courses taken while a Special Student do not necessarily count toward fulfillment of degree requirements if the student is subsequently accepted as a degree candidate. This status is normally extended for one year with reapplication required for continuation.

Course Requirements
The Master of Materials Science and Engineering degree is awarded after successful completion of 10 one-term courses within five years. All students are required to take either 515.401 Structure and Properties of Materials or 510.601 Structure of Materials; in addition all students must take 515.402 Thermodynamics of Materials or 510.602 Thermodynamics of Materials and 510.603 Phase Transformations in Materials. Of the remaining seven electives at least one must be 600-level or higher. Courses offered by the Department of Materials Science and Engineering are acceptable as electives. Students interested in taking the 515.730-731 Materials Science and Engineering Project must get prior approval from the departmental coordinator and be assigned an adviser.

Below is a list of acceptable course electives offered by other departments. Students wishing to take a course not on the list to satisfy the degree requirements must get prior approval from the departmental coordinator.

525.406 Electronic Materials
525.407 Introduction to Electronic Packaging
530.753 Fatigue
535.406 Advanced Strength of Materials
535.413 Structural Engineering Applications
535.720 Analysis and Design of Composite Structures
540.426 Introduction to Biomacromolecules
540.427 Introduction to Polymer Science
540.438 Interfacial Phenomena in Nanotechnology
540.439 Polymer Nanocomposites
540.627 Microscopic and Macroscopic Analyses of Polymer Solution
585.409 Mathematical Methods for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
Nanotechnology Option

Students enrolled in the Master of Science in Materials Science and Engineering Program can elect to pursue the Nanotechnology Option. Two concentrations are offered: the Nanomaterials Concentration and the Biotechnology Concentration. A complete description of the requirements is listed under the Nanotechnology Option section of this catalog.

Course Descriptions

Courses numbered 600-level and above are open only to students who have been admitted for graduate status.

510.407  Biomaterials II
This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs.

Note: Also listed as 510.607.

510.422  Micro- and Nano-Structured Materials and Devices
Almost every materials property changes with scale. We will examine ways to make micro- and nano-structured materials and discuss their mechanical, electrical, and chemical properties. Topics include the physics and chemistry of physical vapor deposition, thin film patterning, and microstructural characterization. Particular attention will be paid to current technologies including computer chips and memory, thin film sensors, diffusion barriers, protective coatings, and microelectromechanical devices (MEMS).

Note: Also listed as 510.622.

510.601  Structure of Materials
This course introduces the structure of inorganic and polymeric materials. Topics include the atomic scale structure of metals, alloys, ceramics, and semiconductors; structure of polymers; crystal defects; elementary crystallography; tensor properties of crystals; and an introduction to the uses of diffraction techniques (including X-ray diffraction and electron microscopy) in studying the structure of materials.

Prerequisite: Undergraduate chemistry, physics, and calculus; or permission of instructor.

Cammarata

510.602  Thermodynamics of Materials
This course introduces the classical and statistical thermodynamics of materials. Topics include the zeroth law of thermodynamics; the first law (work, internal energy, heat, enthalpy, heat capacity); the second law (heat engines, Carnot cycle, Clausius inequality, entropy, absolute temperature); equilibrium of single component systems (free energy, thermodynamic potentials, virtual variations, chemical potential, phase changes); equilibrium of multicomponent systems and chemical thermodynamics; basics of statistical physics (single and multiple particle partition functions, configurational entropy, third law; statistical thermodynamics of solid solutions); and equilibrium composition-temperature phase diagrams.

Prerequisite: Undergraduate calculus, chemistry, and physics; or permission of instructor.

Hufnagel

510.603  Phase Transformations in Materials
This course presents a unified treatment of the thermodynamics and kinetics of phase transformations from phenomenological and atomistic viewpoints. Phase transformations in condensed metal and nonmetal systems are discussed. Topics include absolute reaction rate theory, thermodynamics of irreversible processes, thermodynamics of surfaces and interfaces, chemical kinetics, nucleation and growth, spinodal decomposition, order-disorder transformations, diffusional transformations, martensitic transformations, coarsening, glass transition.

Prerequisite: 510.601 and 510.602, or permission of instructor (offered at Homewood campus).

Erlebacher

510.604  Mechanical Properties of Materials
This course introduces the properties and mechanisms that control the mechanical performance of materials. Topics include mechanical testing, tensor description of stress and strain, isotropic and anisotropic elasticity, plastic behavior of crystals, dislocation theory, mechanisms of microscopic plasticity, creep, fracture, and deformation and fracture of polymers.

Prerequisite: 510.601 or permission of instructor.

Weihs

510.605  Electronic, Optical and Magnetic Properties of Materials
This course is an overview of electrical, optical and magnetic properties arising from the fundamental electronic and atomic structure of materials. Continuum materials properties are developed through examination of microscopic processes. Top-
ics to be covered include quantum mechanical structure of solids including electronic band structure; electrical, thermal and ionic conduction; response of materials to electromagnetic fields including dielectric permittivity, ferroelectric materials and piezoelectricity; magnetic behavior including paramagnetism and ferromagnetism, magnetic permeability, magnetic domains, and magnetostriction; interactions of electromagnetic radiation with materials (absorption, reflection, refraction, and scattering, electro- and magneto-optic effects); and superconductivity. Emphasis will be placed on both fundamental principles and applications in contemporary materials technologies.

**Prerequisite:** 510.601.

### 510.606 Chemical and Biological Properties of Materials

This course introduces to the chemical and biological properties of organic and inorganic materials. Topics include an introduction to polymer science, polymer synthesis, chemical synthesis and modification of inorganic materials, biomineralization, biosynthesis and properties of natural materials (proteins, DNA and polysaccharides), structure-property relationships in polymeric materials (synthetic polymers and structural proteins), and materials for biomedical applications.

**Prerequisite:** Undergraduate chemistry and biology, or permission of instructor.

**Instructor:** Yu

### 510.607 Biomaterials II

This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs.

**Instructor:** Mao

### 510.608 Electrochemistry

Thermodynamics of electrochemical interfaces, including electrochemical potential, the Nernst equation, ion-solvent interactions, and double layer theory. Charge transfer kinetics for activation and diffusion controlled processes. Analysis of kinetics at various electrodes, including redox reactions, metal-ion electrodes, and semiconductor electrodes. Electro-analytical techniques are discussed, including those related to bioelectrochemistry and semiconductor electrochemistry. Selected reactions of technological importance are evaluated, including the hydrogen evolution reaction, oxygen reduction, electrodeposition, and energy generation and storage.

**Undergraduate prerequisite:** Introductory chemistry or permission of instructor.

### 510.609 Electrochemistry Lab

A series of laboratory experiments is used to illustrate the principles of electrochemistry.

**Prerequisite:** 510.608 or permission of instructor.

**Instructor:** Searson

### 510.610 Chemistry and Physics of Semiconductor Surfaces

Basic principles of bonding, thermodynamics of crystals, surface energy, space charge effects, and potential distributions at phase boundaries are reviewed. Processes related to solid/liquid interfaces including electron transfer, photoeffects, adsorption, catalysis, etching, and oxide formation are covered. Relevant experimental methods including surface analytical techniques are reviewed. Examples of applications, including photovoltaic devices and solar cells, are discussed.

**Instructor:** Searson

### 510.611-612 Solid State Physics

An introduction to solid state physics for advanced undergraduates and graduate students in physical science and engineering. Topics include crystal structure of solids; band theory; thermal, optical, and electronic properties; transport and magnetic properties of metals, semiconductors, and insulators; and superconductivity. The concepts and applications of solid state principles in modern electronic, optical, and structural materials are discussed.

**Two-term course**

**Instructor:** Poehler

### 510.616 Applications of X-Ray Diffraction

This course introduces the student to crystal structure and what can be learned about materials by a variety of X-ray diffraction, radiographic, topographic and tomographic techniques. The techniques covered include single crystal orientation, single crystal perfection, structure of polycrystalline materials, compositional analysis, and phase identification. An overview will be presented of research efforts illustrating how rapid X-ray diffraction imaging has served to study the plastic deformation of metals, grain boundary migration during recrystallization, and the structure of explosively loaded metals. The utility of X-ray topographic imaging for qualitative assessment of single crystals will be discussed using specific examples of topographic images acquired from nickel based superalloy turbine blades, gallium-arsenide wafers, and quartz crystal resonators. Finally, the radiographic aspect of X-ray imaging will be considered with illustrations given of the application of computer assisted X-ray tomography. The course will include both classroom lectures and laboratory exercises.

**Instructor:** Hufnagel

### 510.620 Metallic Glasses

Structure, properties, and processing of metallic glasses and amorphous thin films. Particular emphasis on structural characterization of amorphous materials, including X-ray and neutron scattering, EXAFS, small-angle scattering, and
anomalous X-ray scattering. Also: phase transformations in amorphous materials, including phase separation and crystallization; mechanical and magnetic properties of metallic glasses; thermodynamics and kinetic considerations in the production of metallic glasses.

Hufnagel

510.657  Materials Science of Thin Films
The processing, structure, and properties of thin films are discussed emphasizing current areas of scientific and technological interest. Topics include elements of vacuum science and technology; chemical and physical vapor deposition processes; film growth and microstructure; chemical and microstructural characterization methods; epitaxy; mechanical properties such as internal stresses, adhesion, and strength; and technological applications such as superlattices, diffusion barriers, and protective coatings.

Wehls

510.661  Alloy Stability and Phase Diagrams
This course examines the fundamentals of alloy theory and phase diagram modeling to understand the formation, stability, and evolution of alloy phases and microstructures. Topics to be covered include structures of intermediate alloy phases such as electron phases, Laves phases, interstitial phases, valency compounds, and superlattices; stability criteria of solid solutions and intermediate alloy phases, including Hume-Rothery rules, theories of ordering, electronic theories of solid solubility and alloy stability, and elastic instability; thermodynamic and kinetic analysis of phase and microstructural instability due to different driving forces: chemical, strain, interfacial, gradient, etc.; balance of kinetic stability and thermodynamic instability: formation of highly metastable or unstable phases far from equilibrium; and calculations of the phase stability ranges in terms of equilibrium or metastable binary or multicomponent phase diagrams using CALPHAD modeling.

Ma

510.665  Advanced Topics in Thermodynamics of Materials
Selected areas of thermodynamics will be examined in depth with the aim of understanding the ideas and assumptions underlying results of importance to materials science. Attempts will be made to be as rigorous as possible without losing sight of the physical meaning. The theories and models obtained will be evaluated critically to determine their validity and limitations. Tentative list of topics to be covered: review of the traditional development of the laws of thermodynamics; alternate formulations (Carathéodory, Truesdell, single axiom approach); equilibrium thermodynamics of Gibbs; thermodynamics of solids; thermodynamics of surfaces; principles of statistical thermodynamics; critical phenomena; third law; nonequilibrium thermodynamics (“rational” thermodynamics, thermodynamics of irreversible processes, absolute reaction rates).

Cammarata

510.650  Principles of Quantum Physical Interactions
Foundational quantum-mechanical study of nanometer-scale electronic and optoelectronic materials structures. Principles of quantum physics, stationary-state eigenfunctions and eigenvalues for one-dimensional potentials, interaction with the electromagnetic field, electronic conduction in solids, surface and interface effects, tunneling microscopy and spectroscopy.

Prerequisite: 110.201 and 110.302 or equivalent, 510.311.

Spicer

510.636  Electronic Materials Science

Searson

515.401  Structure and Properties of Materials
Topics include types of materials, bonding in solids, basic crystallography, crystal structures, tensor properties of materials, diffraction methods, crystal defects, amorphous materials.

Staff

515.402  Thermodynamics and Kinetics of Materials
Topics include laws of thermodynamics, equilibrium of single and multiphase systems, chemical thermodynamics, statistical thermodynamics of solid solutions, equilibrium phase diagrams, chemical kinetics, diffusion in solids; nucleation and growth processes, coarsening, glass transition.

Staff
**515.410 Fiber Reinforced Composites**
This course acquaints students as well as practicing engineers with the issues needed to deal with composites. Included in the course are a survey of applications and the rationale for usage; an understanding of the mechanics of composites; design characteristics including strength, stability, fatigue, fracture, effects of stress concentrations, and environment; test methods; fabrication, including automation; and quality assurance. Included are several guest lecturers from industry and other universities.

*Prerequisite:* A basic materials science course or consent of instructor.

**515.414 Alloy Selection for Engineering Design**
This course examines mechanical property design requirements including code base design requirements. Alloy selection for strength, ductility, fatigue life, cost, fracture toughness, corrosion resistance, and wear are studied. The joining of materials by welding and brazing is addressed. Alloy systems, nomenclature, and physical properties are examined with attention to information sources.

*Prerequisite:* A basic materials science course or permission of instructor.

**515.416 Introduction to Nanotechnology**
Nanoscale science and nanotechnology are broad, interdisciplinary areas, encompassing not just materials science but everything from biochemistry to electrical engineering and more. This will be a survey course introducing some of the fundamental principles behind nanotechnology and nanomaterials, as well as applications of nanotechnology. The role of solid state physics and chemistry in nanotech will be emphasized. Nanoscale tools such as surface probe and atomic force microscopy, nanolithography, and special topics such as molecular electronics will also be covered.

**Sample**

**515.417 Nanomaterials**
This course will take an in-depth look at nanomaterials discussed in Introduction to Nanotechnology. However, this course stands alone with no prerequisite. Theory and concepts of nanomaterials will be covered, including the chemistry and physics of nanomaterials. The course will also focus on major classes of nanomaterials, including carbon nanotubes, nano-structured materials, nanowires, nanoparticles, nanoclays, and other nanomaterials. Applications of nanomaterials to technology areas of interest to the class will also be discussed.

**Sample, Zhang**

**515.706 Introduction to Composites**
This course covers the fundamental aspects of both continuous and discontinuously fiber-reinforced composite materials. Emphasis is placed on continuous fiber organic matrix composites. Material characteristics, fabrication aspects, and micromechanical material characteristics are discussed. Topics include the development and utilization of laminated plate theory for determination of material properties and strengths of composite laminates, flat plate design considerations, and fabrication methods and applications.

*Prerequisites:* 510.601 or consent of instructor.

**515.730-731 Materials Science and Engineering Project**
This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student’s field of interest. On completion of this course, a written essay must be submitted. Final approval of the essay will be given by the faculty adviser.

*Prerequisites:* All other course work should be completed before this project begins (or at least completed concurrently with this project). Consent of adviser is required.

**Note:** This course is available only to students in the Master of Materials Science and Engineering program.

Two-term course

**Staff**
Materials and Condensed Matter Option

Materials and condensed matter, technical areas crossing the boundaries of physics and various engineering disciplines, are of growing importance in all our technical activities ranging from sensor development to space science. Although there is a separate degree in Materials Science and Engineering, students can elect to pursue a concentration in materials and condensed matter from the Applied Physics curriculum. This concentration offers students the opportunity to become well grounded in the principles of physics and then apply this knowledge to study leading edge topics in materials and condensed matter. To do this students can complete a combination of courses from the Applied Physics, Materials Science and Engineering, Electrical and Computer Engineering, and Chemical and Biomolecular Engineering disciplines. The wide variety of courses from these four areas allows students, working with advisers to structure a program meeting their professional development needs in materials.

Admission Requirements
Applicants must meet the general requirements for admission to a graduate program outlined in this catalog. In addition, applicants must meet the specific program requirements for Applied Physics (see Graduate Admissions). The special option in Materials and Condensed Matter will be noted on the student’s transcript.

Course Requirements
A total of 10 one-term courses must be completed. Students specializing in Materials and Condensed Matter must complete three of the first six required courses listed below, plus 615.480 Materials Science.

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.451 Statistical Mechanics and Thermodynamics
- 615.453 Classical Mechanics
- 615.454 Quantum Mechanics
- 615.465 Modern Physics

Of the remaining six courses, four or more must be from the courses listed below selected from the Applied Physics, Electrical and Computer Engineering, Materials Science and Engineering, and Chemical and Biomolecular Engineering curricula.

Applied Physics offers six additional courses:
- 615.460 Sensors and Sensor Systems for Homeland Security
- 615.746 Nanoelectronics: Physics and Devices
- 615.747 Sensors and Sensor Systems
- 615.757 Solid State Physics
- 615.760 Physics of Semiconductor Devices
- 615.768 Superlattices and Heterostructure Devices

Note: 615.800 Applied Physics Project and 615.802 Directed Studies in Applied Physics also can be used to allow students to pursue specialized interests in materials and condensed matter.

Electrical and Computer Engineering offers the following courses:
- 525.406 Electronic Materials
- 525.421 Introduction to Electronics and the Solid State

Materials Science and Engineering offers the following courses:
- 510.420 Topics in Biomaterials
- 510.604 Mechanical Properties of Materials
- 510.606 Chemical and Biological Properties of Materials
- 510.622 Micro- and Nano-Structured Materials and Devices
- 510.422 Micro- and Nano-Structured Materials and Devices

In addition, the following courses from Chemical Engineering can be selected:
- 540.427 Introduction to Polymer Science
- 540.439 Polymer Nanocomposites
Mechanical Engineering

From the design of medical prostheses to the cooling of advanced computers, and from robot vision to computer-integrated manufacturing, modern technology has considerably broadened the scope and the impact of mechanical engineering.

The Master of Mechanical Engineering program at Johns Hopkins is designed for practicing engineers who wish to prepare for, and enhance their effectiveness in, a world of increasing complexity. For this reason, the program is designed not only to broaden and strengthen students’ understanding of the traditional fundamentals, but also to introduce them to contemporary applications and technologies.

Courses are offered in three basic concentrations: mechanics, manufacturing, and robotics and controls. Within each one of these, a number of electives enable students to select courses from other concentrations if they wish. In any case, students are expected to coordinate their selection of courses under the guidance of an adviser.

The degree is awarded on the basis of course work only. No thesis is required. Course offerings are structured in two-year cycles.

Program Committee

Kevin Hemker, Program Chair
Professor of Mechanical Engineering
Whiting School of Engineering

David A. Didion
Leader, Thermal Machinery Group
National Institute of Standards and Technology

Robert Ivester
Manufacturing Metrology Division
National Institute of Standards and Technology

Jack C. Roberts
Principal Professional Staff
Applied Physics Laboratory

Andrea Prosperetti
Charles A. Miller Jr. Distinguished Professor of Mechanical Engineering
Whiting School of Engineering

Louis Whitcomb
Professor
Mechanical Engineering
Whiting School of Engineering

Admission Requirements

Applicants must meet the general requirements for admission to graduate study outlined in this catalog (see Admission Requirements). Each applicant should hold a bachelor's degree in mechanical engineering or in a closely related field. Prospective students who do not meet these criteria should direct admission inquiries to the program committee. All admissions decisions are made on an individual basis by the program committee.

Course Requirements

The program offers three concentrations: mechanics, manufacturing, and robotics and controls. The following requirements are common to all concentrations. Additional requirements are listed with the course listings for each concentration.

Ten one-term courses, numbered 400-level or above, must be completed within a maximum of five years. One of these must be an advanced mathematics course such as:

Mathematical Methods for Engineers

Five courses must be chosen from one concentration. The remaining four courses can be selected from the graduate offerings of any of the full- or part-time engineering programs of the Whiting School of Engineering. In particular, students concentrating in one area can take courses offered under one of the other concentrations.

All course selections must be approved by the student’s adviser. Neither a thesis nor knowledge of a foreign language is required.

All courses have as minimum prerequisites the following: undergraduate engineering courses in differential equations, statics, dynamics, thermodynamics, and strength of materials. In addition, the specific prerequisites for each course must be fulfilled.

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

I. Mechanics

Each student must take either 535.406 and 535.423 in Solid Mechanics or 535.421 and 535.433 in Thermo-Fluid Mechanics. Three additional courses must be chosen from either sub area; not necessarily all from the same area. The only restriction is that course prerequisites must be fulfilled in all cases.

Solid Mechanics

- 515.414 Alloy Selection for Engineering Design
- 535.406* Advanced Strength of Materials
- 535.411 Friction and Wear
- 535.412 Intermediate Dynamics
- 535.423* Intermediate Vibrations
- 535.427 Computer-Aided Design
- 535.431 Introduction to Finite Element Methods
- 535.454 Theory and Applications of Structural Analysis
- 535.620 Orthopedic Biomechanics
- 535.625 Advanced CAD Modeling, Analysis, and Manufacturing
- 535.720 Analysis and Design of Composite Structures

*Students choosing the solid mechanics concentration are required to take these courses.
Thermo-Fluid Mechanics
535.421* Intermediate Fluid Dynamics
535.424 Energy Engineering
535.433* Intermediate Heat Transfer
535.434 Applied Heat Transfer
535.452 Thermal Systems Design and Analysis
535.481 Commercial Nuclear Reactors
535.636 Applied Computational Fluid Mechanics
*Students choosing the thermo-fluid mechanics concentration are required to take these courses.

II. Manufacturing
515.410 Fiber Reinforced Composites
515.414 Alloy Selection for Engineering Design
515.706 Introduction to Composites
535.411 Friction and Wear
535.423 Intermediate Vibrations
535.426 Kinematics and Dynamics of Robots
535.427 Computer-Aided Design
535.433 Intermediate Heat Transfer
535.442 Control Systems for Mechanical Engineering Applications
*Students choosing the manufacturing concentration are required to take these courses.

III. Robotics and Controls
535.412* Intermediate Dynamics
535.423 Intermediate Vibrations
535.426* Kinematics and Dynamics of Robots
535.427 Computer-Aided Design
535.442* Control Systems for Mechanical Engineering Applications
535.454 Theory and Applications of Structural Analysis
535.459 Manufacturing Systems Analysis
535.625 Advanced CAD Modeling, Analysis, and Manufacturing
*Students choosing the robotics and controls concentration are required to take these courses.

Course Descriptions
The courses listed with the prefix 535 are offered one night per week. Courses with the prefix 530 are usually offered during the day as part of the full-time graduate program in mechanical engineering.

530.753 Fatigue
High-cycle and low-cycle fatigue. Constant amplitude and spectrum loading. Phenomenological relations. Special emphasis on notches and on short cracks.

535.406 Advanced Strength of Materials
This is a practical course in advanced strength of materials that uses design techniques to solve complex difficult problems. It concentrates on newly developed experimental techniques that allow simplification of previously unsolvable problems to something that can be quickly "estimated." It concentrates on stresses in torsion, shear and bending, stress concentration effects, stability, fatigue, fracture mechanics, general design criteria, cantilever beams with different boundary conditions, variable section cantilever beams, beams with different constraints, curved bars and hooks, plates and flanges, panels and closures, flanges and brackets, weld analysis, pressure vessels (thick and thin), and combined axial and bending response of beams and cylinders.

535.411 Friction and Wear
This course provides basic concepts for understanding contact, friction, and wear. An introduction to different forms of friction and wear and to the necessary elements of continuum mechanics is followed by an examination of pressure and stress distributions and the interaction of rough surfaces. Frictional effects, including fretting, microslip, and rolling-sliding contact are also discussed. Students examine the mechanics of lubrication, including hydrodynamic and elastohydrodynamic lubrication, film thickness effects, and the friction inside a lubricant layer. The course concludes with industrial applications, including the design of ball and roller bearings, the selection of lubricants for bearings and gears, and the design of antifriction and wear resistant coatings.
Prerequisite: An undergraduate course in strength of materials.

535.412 Intermediate Dynamics
Course topics include kinematics and dynamics of systems of particles and of rigid bodies, applications of the conservation equations, orbital motion, vibration theory, Lagrangian mechanics, gyroscopic motion, and Hamilton’s principle. The course is oriented toward a balance between classical theory and practical problem solving. Matlab is introduced and used as a computational and plotting tool throughout the course.
Prerequisite: An undergraduate dynamics course.
535.413 Structural Engineering Applications
This course covers case histories of structural applications from large scale truss structures, avionics, space, electronics, biomedical, composite ship hulls, torpedoes, etc. The emphasis is placed not only on the types of solutions, i.e., hand structural analysis, finite element analysis, and statistics, but also on the problems encountered in obtaining requirements, interpreting those requirements, applying the requirements, and reporting the results.

535.414 Acoustics
An introduction to the physical principles of acoustics and their application. Fundamental topics include the generation, transmission and reception of acoustic waves. Applications covered are selected from underwater acoustics, architectural acoustics, remote sensing and nondestructive testing.

Prerequisite: Some familiarity with linear algebra, complex variables and differential equations.

Burkhardt

535.421 Intermediate Fluid Dynamics
This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier-Stokes equations. Students examine vorticity and circulation, dynamic similarity, laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. The course includes a programming project to develop a numerical solution to a practical fluid flow problem.

Prerequisite: An undergraduate fluid mechanics course.

Hess

535.422 Robot Motion Planning
This course investigates the motion planning problem in robotics. Topics include motion of rigid objects by the configurations space and retraction approaches; shortest path motion; motion of linked robot arms; compliant motion; coordinated motion of several objects; robust motion with error detection and recovery; and motion in an unknown environment.

Conn

535.423 Intermediate Vibrations
Course topics include transient and forced vibrations of one- and N-degrees of freedom systems and an introduction to vibrations of continuous systems.

Prerequisite: An undergraduate vibrations course.

Lamb

535.424 Energy Engineering
The course will focus on an analytical system performance technique known as Availability or Exergy Analysis, which is based on the 2nd law of thermodynamics. It is applicable to all types of thermodynamic systems but since the text focuses on traditional power and refrigeration systems, so will the course. However, non-traditional power generation systems will be considered by way of a special project of each student’s choice. It will include an engineering description of the state-of-the art of the selected topic (e.g., wind or solar power, fuel cell, etc.) and a second law performance analysis a prototype system will be presented to the class. In addition to the power system topics, the availability analysis will be applied to the combustion and psychrometric processes. Lectures will follow the textbook and the student will be responsible for a selected number of text problems, upon which the test(s) will be literally based.

535.425 Computer Vision
This course gives an overview of fundamental methods in computer vision from a computational perspective. Methods include computation of 3-D geometric constraints from binocular stereo, motion, texture, shape-from-shading, and photometric stereo. Edge detection and color perception are studied as well. Elements of machine vision and biological vision are also discussed.

Waters

535.426 Kinematics and Dynamics of Robots
This course introduces the basic concepts and tools used to analyze the kinematics and dynamics of robot manipulators. Topics include kinematic representations and transformations, positional and differential kinematics, singularity and workspace analysis, inverse and forward dynamics techniques, and trajectory planning and control.

Lovell

535.427 Computer-Aided Design
This course explores many aspects of the design and development process, introducing Computer-Aided Design (CAD) as the unifying element of the process. Solid and assembly modeling, as well as structural and kinematic analysis techniques using IDEAS software (Structural Dynamics Research Corporation) are used within the framework of the design process to complete assigned projects. (IDEAS will be run on the workstations on the Homewood campus.) Topics covered include design theory, design for manufacturing and assembly (DFMA), geometric dimensioning and tolerance (GD&T), quality, and electromechanical packaging.

Prerequisites: An undergraduate machine design course and some familiarity with the UNIX operating system.

Rothman

535.428 Computer-Integrated Design and Manufacturing
This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, infor-
information management, process control, quality control, etc. The current capabilities, applications, limitations, trends, and economic consideration are stressed.

535.429 Robotic Control

This course focuses on the theory and methods used for the control of robotic manipulators. Topics include review of basic systems theory, robot position control, model-based trajectory tracking and force control. Stability properties for each control strategy will be analyzed. Practical implementation issues will also be addressed. Students will simulate different control methods using Matlab.

Prerequisite: Kinematics and Dynamics of Robots, Ordinary Differential Equations, Linear Algebra.

Kramer, Lee

535.431 Introduction to Finite Element Methods

This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties.

Lear

Patriciu

535.433 Intermediate Heat Transfer

This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties.

Prerequisite: An undergraduate heat transfer course.

Oguz

535.441 Mathematical Methods for Engineers

This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include ordinary differential equations, complex variables, integral transforms, vectors and matrices, special functions, and partial differential equations. Application of these topics to the solutions of physics and engineering problems is stressed.

Prerequisites: Vector analysis and ordinary differential equations. This course may be substituted for 615.441 Mathematical Methods for Physics and Engineering in the electrical engineering program.

Nakos

535.442 Control Systems for Mechanical Engineering Applications

This course presents an overview of the current control elements and processes for mechanical and electromechanical systems used in standard engineering practice. Various systems, including thermal and fluid models, are described with particular emphasis placed on computer control applications. Analysis is performed on commonly used servomechanisms, and design and stability criteria are investigated.

Konopacki

535.443 Computational Heat Transfer

This course presents various methods used in modeling and simulating heat transfer processes associated with complex, realistic physical systems. Coupled conduction, convection, and radiation effects are analyzed. Finite difference concepts are also examined along with the stability and convergence criteria of the models. Several of the commercial large scale heat transfer codes are introduced. Matlab is used for course assignments.

Prerequisites: An undergraduate course in heat transfer.

Konopacki

535.450 Combustion

This is a multidisciplinary course involving applications of thermodynamics, fluid mechanics, heat transfer, and chemistry. Course contents include a review of chemical thermodynamics, chemical kinetics, transport theory, and conservation equations; laminar flow in premixed and non-premixed gases; combustion waves; ignition; combustion aerodynamics; multiphase combustion; and turbulent combustion. Selected applications are discussed including gas turbines, spark ignition and diesel engines, jet engines, industrial furnaces, pollutant formation, and control in combustion.


Staff
535.452  **Thermal Systems Design and Analysis**  
Thermodynamics and heat transfer principles are applied to power and refrigeration systems with emphasis on economic and performance trade-offs. Where it has practical value, the use of second law analysis (i.e., an entropy inventory) is introduced. The mathematical modeling of thermal elements and complex systems is developed to minimize primary energy consumption while meeting variable load patterns. This leads to the use of an advanced PC-based equation solver software package for simulation and numerical solution. The necessary software is provided to the students.  
*Prerequisites:* Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.  
*Didion*

535.453  **Fundamentals of Applied Thermal Systems**  
This course deals with the engineering science behind the vapor compression and absorption cycles, psychrometrics, and heat exchange through the use of extended surfaces and direct contact between liquid and vapor. The processes that go on in positive displacement and centrifugal compressors, condensers, evaporators, expansion devices, absorbers and rectifiers, cooling towers, air washers and spray dehumidifiers will be studied. While the course emphasis is primarily on traditional thermal science processes, at least one lecture will be on their environmental impact since the energy resources, ozone and climate change problems have become new criteria for thermal machine design.  
*Prerequisites:* 535.433 Intermediate Heat Transfer or permission of instructor.  
*Didion*

535.454  **Theory and Applications of Structural Analysis**  
Course topics include classical shell structures; twisting and bending of single cell open section structures; twisting and bending of closed section structures; pure twisting of multi-celled structures; bending of multi-celled structures; classical plate theory; applications of bending and buckling of plates in multi-celled structures; and finite element analysis of structures.  
*Roberts*

535.458  **Design for Manufacturability**  
The key principles for designing a quality, cost efficient product are related to competitiveness in manufacturing environments in this course. Topics include design for manufacturing, design for assembly, process selection, inspection planning, concurrent engineering, product re-engineering, quality management, and agile manufacturing. The focus is on engineering designs and system approaches which affect the cost, quality, cycle time, and maintainability.  
*Staff*

535.459  **Manufacturing Systems Analysis**  
This course is a review of the fundamentals of modern manufacturing processes, computer-aided design/manufacturing tools, flexible manufacturing systems, and robots. The course addresses relationships between process machinery, process conditions, and material properties. Examples of high-tech industries illustrate how mechanical and electronic components are manufactured from metals, polymers, ceramics, composites, and silicon.  
*Staff*

535.472  **Advanced Manufacturing Systems**  
This course examines the effect that new technology, engineering, and business strategies have on transforming U.S. industry into a world-class, competitive force. An emphasis is placed on the state of the art of factory automation and computer-integrated manufacturing. Topics include advanced manufacturing processes, rapid prototyping, intelligent manufacturing controls, and information technology in manufacturing. Technical principles related to advanced manufacturing are presented. Examples of actual production systems (including video presentations and plant visits) illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.  
*Staff*

535.474  **Quality Assurance Engineering**  
This course addresses quality assurance topics that are suitable in applications for various engineering disciplines. Course discussions include the latest in quality and business management, strategic planning, productivity improvement tools, techniques, and the implementation of quality initiatives. Advanced topics related to the principles and application of total quality methodologies are presented. Students discuss implementing quality assurance tools and systems, including benchmarking, process control, quality measurement, concurrent engineering, Taguchi methods, Supplier Quality Management (SQM), and auditing. Current applications and strategies are introduced such as Lean Manufacturing philosophy, Demings P-D-S-A cycle, Kaizen continuous improvement process, strategic planning, total employee participation, business process re-engineering, and the views of various quality "gurus." The course covers the Malcolm Baldrige Award criteria, and a comprehensive practical understanding of the ISO 9000 standards are discussed.  
*Ali*

535.481  **Commercial Nuclear Reactors**  
This is an introductory course to commercial nuclear power plant operation from a heat transfer and thermal-hydraulics perspective. You will gain a working knowledge of criticality theory and reactivity management, the two basic domestic light water reactor designs (Pressurized Water Reactors and Boiling Water Reactors), and the practical problems resulting from large-scale one- and two-phase flow heat transfer. While the course will involve some problem solving, the main thrust...
is to provide a conceptual understanding of the design and theory of operation of light water reactor fluid systems.

Merschoff

535.620 Orthopedic Biomechanics
This course is an introduction to the field of orthopedic biomechanics for the engineer. The course will cover the structure and function of the musculoskeletal system, including detailed discussions on the material properties of bone, ligament, tendon, cartilage, and muscle. Other topics of discussion will include viscoelasticity, bone remodeling, and injury mechanisms. Journal articles from the biomechanics literature will be used to explore current areas of active research.

Prerequisite: Statics required and dynamics recommended.

Kleinberger

535.625 Advanced CAD Modeling, Analysis, and Manufacturing
The course presents advanced mechanical design techniques using the Pro/ENGINEER (PTC, Inc.) CAD/CAM software. The course gives advanced methods and techniques about assembly management and mechanism design, kinematic and dynamic analyses, structural analyses (FEA), and CNC manufacturing. The material is presented based on extensive hands-on examples. The CAM sections include practical examples with 3-5 axes Vertical Machining Centers (HAAS FV-1&2) and a Turning CNC center (HAAS SL-20).

Prerequisites: include knowledge and experience with basic ProE parts and assembly management.

Stoianovici

535.636 Applied Computational Fluid Mechanics
This course explores engineering applications of computational fluid dynamics with background information on the most common numerical methods: two-dimensional inviscid and viscous flows; boundary layer flows; and an introduction to three-dimensional flows. Applications are illustrated utilizing commercially available codes.

Prerequisites: 535.421 Intermediate Fluid Dynamics and 535.441 Mathematical Methods for Engineers. Students should have a least one basic course in fluid dynamics, one course in ordinary differential equations and some familiarity with partial differential equations.

Janajreh

535.720 Analysis and Design of Composite Structures
Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

Roberts

535.726 Robot Control
This course focuses on the theory and methods used for the control of robotic manipulators. Topics include review of basic systems theory, robot position control, model-based trajectory tracking and force control. Stability properties for each control strategy will be analyzed. Practical implementation issues will also be addressed. Students will simulate different control methods using Matlab.

Prerequisites: 535.426 Kinematics and Dynamics of Robots, Ordinary Differential Equations, Linear Algebra.

Patriciu
Nanotechnology Option

Nanotechnology involves science and engineering on the nanometer scale, generally less than or of order 100nm. It involves the design, synthesis, and processing of nanoscale structures for engineering applications. In some cases this can involve the assembly of materials one molecule or even one atom at a time. At these small length scales, materials often display novel behavior that can be exploited technologically. For example, in the area of nanoelectronics, there has been an intense effort toward continued miniaturization of semiconductor devices in order to increase the density of transistors in integrated circuits or to exploit quantum mechanical effects that occur only when the length scale is reduced to the nanoscale range. Nanomaterials also display enhanced mechanical, optical, magnetic, and chemical properties that offer a wide variety of technological uses. Recently nanotechnology has also become extremely important in the area of biotechnology, allowing for the study of the science and engineering of biological materials for a variety of medical applications.

Admission Requirements

Applicants must meet the requirements for admissions into the Master of Materials Science and Engineering (M.M.S.E.) program. The program is best suited for students who have received undergraduate degrees in engineering or science. Applicants are expected to have completed a mathematics sequence through differential equations and courses in general physics and chemistry. Applicants must also meet the general requirements for study outlined in this catalog.

The program committee is willing to consider applicants who do not meet the general admission requirements only in exceptional cases. In these cases, the applicant must present convincing evidence of outstanding ability and a record of achievement. For all candidates, in addition to the application form and required transcripts, the program committee requests applicants to arrange for two letters of recommendation to support their applications.

Course Requirements

Students enrolled in the Master of Science in Materials Science and Engineering program can elect to pursue the Nanotechnology Option. Two concentrations are offered: the nanomaterials concentration and the biotechnology concentration. For either concentration, the student must successfully complete the core courses and then at least three courses selected from the corresponding concentration course list. The student, in consultation with the departmental coordinator, will select the other courses (for a total of 10) from the part-time or full-time graduate courses offered by the Whiting School of Engineering. The set of 10 courses must represent a coherent educational program and be approved by the departmental coordinator. At least one of the non-core courses must be 600-level or higher.

Required Core Courses

510.601 Structure of Materials  or
515.401 Structure and Properties of Materials
510.602 Thermodynamics of Materials  and
510.603 Phase Transformations in Materials  or
515.402 Thermodynamics and Kinetics of Materials
515.416 Introduction to Nanotechnology
525.417 Nanomaterials

Nanomaterials Concentration

Materials Science and Engineering Courses

510.422 Micro- and Nano-Structured Materials and Devices
510.620 Metallic Glasses
510.650 Principles of Quantum Physical Interactions
510.657 Materials Science of Thin Films
515.730-731 Materials Science and Engineering Project

Applied Physics Courses

615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.768 Superlattices and Heterostructure Devices

Mechanical Engineering Courses

530.487 Introduction to Micro-Electromechanical Systems (MEMS)
530.652 Bridging Length Scales in Materials Behavior

Chemical and Biomolecular Engineering Courses

540.438 Interfacial Phenomena in Nanotechnology
540.439 Polymer Nanocomposites

Geography and Environmental Engineering Course

570.429 Surface Effects of Technological Processes and Materials

Any course from the Biotechnology Concentration list. (See below)

Biotechnology Concentration

Materials Science and Engineering Courses

510.606 Chemical and Biological Properties of Materials
515.730-731 Materials Science and Engineering Project

Chemical and Biomolecular Engineering Course

540.438 Interfacial Phenomena in Nanotechnology
Applied Biomedical Engineering Courses

580.637 Cellular and Tissue Engineering
585.405-406 Physiology for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.614 Applications of Physics and Technology to Biomedicine

Course Descriptions

Please refer to the section in the catalog concerning each degree program for the description of the courses given by that program. Some courses are not offered every year. Dates, times, locations, fees, and instructors are given in the course schedule published each term.
Photonics Option

Photonics, a technical area crossing the boundaries of Physics and Electrical Engineering, continues to be of considerable importance in our technical activities. Although there is no separate degree curriculum in photonics, students can elect to pursue a concentration in photonics from either the Applied Physics or Electrical and Computer Engineering curricula. To do this students can complete a combination of courses selected from both the Applied Physics and Electrical and Computer Engineering disciplines. The wide variety of courses from both areas allows students, working with advisers, to structure a program meeting their professional development needs.

Admission Requirements
Applicants must meet the general requirements for admission to graduate programs outlined in this catalog. In addition, applicants must meet the specific program requirements for either Applied Physics or Electrical and Computer Engineering. The special option in photonics will be noted on the student’s transcript.

Course Requirements
A total of 10 one-term courses must be completed.

Applied Physics students specializing in photonics must complete three required courses:

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.454 Quantum Mechanics

The seven additional courses must include five or more from the courses listed below.

Electrical and Computer Engineering students specializing in photonics must complete the following three required courses:

- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.491 Fundamentals of Photonics

Three additional courses must be selected from the lists below. The four additional courses needed to complete the degree may be any courses approved by the advisor, selected so as to fulfill the general requirements for the M.S.

Applied Physics courses:

- 615.471 Principles of Optics
- 615.472 Optical Remote Sensing
- 615.751 Modern Optics
- 615.752 Statistical Optics
- 615.778 Computer Optical Design
- 615.780 Optical Detectors and Applications
- 615.781 Quantum Information Processing
- 615.782 Optics and Matlab

Note: 615.800 Applied Physics Project and 615.802 Directed Studies can also be used to allow the student to pursue specialized interests in optics.

Electrical Engineering courses:

- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
- 525.753 Laser Systems and Applications
- 525.756 Optical Propagation, Sensing, and Backgrounds
- 525.772 Fiber-Optic Communication Systems
- 525.792 Electro-Optical Systems
- 525.796 Introduction to High-Speed Electronics and Optoelectronics
- 525.797 Advanced Optics and Photonics Laboratory

Note: 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.

Course Descriptions
Courses numbered 600-level and above are open only to students who have been admitted for graduate study. Some courses may not be offered every year. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.
Systems Engineering

Systems engineering is that part of the technical management process that coordinates and oversees the translation of an operational need into a system designed to meet that need. It integrates the inputs of all the required technical disciplines into a coordinated effort that meets established performance, cost, and schedule goals. Systems engineers provide the leadership and coordination of the planning, development, and engineering of technical systems, including hardware and software components. Systems engineering currently enjoys growing importance and recognition as a distinct discipline, widely sought by both industry and government.

The Master of Science in Systems Engineering program is designed to address the specific needs of engineers and scientists engaged in all aspects of analysis, design, integration, production, and operation of modern systems. Since systems engineering is essentially an experience-based rather than a knowledge-based subject, the program makes use of practicing professional systems engineers as instructors. The methodology employs a combination of lectures and readings on theory and practice, together with realistic problem situations in which students, either individually or as members of small teams, learn to apply the principles, tools, and skills they learn. The educational objective is to provide students with both theoretical and practical knowledge, skills, and tools; a systematic approach to problem solving; and the confidence to solve complex system problems.

Students are encouraged to pursue the entire master's degree, but in special approved cases may apply for a Graduate Certificate in Systems Engineering. The requirements for admission are the same as for the master's degree and the student must complete six courses, as approved by the program chair/vice chair, with a grade of A or B (see Admission Requirements).

Program Committee
Kenneth A. Potocki, Chair
Principal Professional Staff
Applied Physics Laboratory

Samuel J. Seymour, Vice Chair
Principal Professional Staff
Applied Physics Laboratory

Conrad J. Grant
Principal Professional Staff
Applied Physics Laboratory

Ben F. Hobbs
Professor and Chair
Geography and Environmental Engineering
Whiting School of Engineering

Jerry A. Krill
Principal Professional Staff
Applied Physics Laboratory

Nicholas J. Langhauer
Principal Professional Staff
Applied Physics Laboratory

Ronald R. Laman
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements
Applicants must meet the general requirements for admission to a graduate program outlined in this catalog (see Admission Requirements under General Information). In addition, the applicant should have a degree in a technical field and have a minimum of two years of appropriate full-time work experience in that field. A resume must be submitted with the application form.

Course Requirements
Prior or concurrent completion of 645.467 Management of Systems Projects and 645.462 Introduction to Systems Engineering (taken in either order) is generally a prerequisite to more advanced courses in the systems engineering curriculum. Specific prerequisites for each course are shown under the individual course descriptions. An approved program plan is required for preferential placement in registering.

Neither a thesis nor knowledge of a foreign language is required in this program. Academic standards governing graduate study, as specified in this catalog, must be maintained.

All students must satisfactorily complete 10 one-term courses. The core curriculum of eight required courses includes:

- 595.763 Software Engineering Management
- 645.462 Introduction to Systems Engineering
- 645.467 Management of Systems Projects
- 645.767 System Conceptual Design
- 645.768 System Design and Integration
- 645.769 System Test and Evaluation
- 645.770 Systems Engineering Project

Select one of the following:

- 645.771 Systems of Systems Engineering or
- 645.753 Enterprise Systems Engineering or
- 645.761 Systems Architecture or
- 645.742 Management of Complex Systems

The latter student selected course can only be taken after completion of 645.770. The course descriptions for the latter courses can be found in the Systems Engineering Advanced Certificate for Post-Master's Study catalog section.
Electives
Two relevant electives may be selected from the technical management, applied biomedical engineering, applied physics, computer science, electrical engineering, environmental engineering and science, and information systems and technology programs. Individual courses (595 series) are described in the current catalog under the technical management program section.

Course Descriptions
Systems Engineering courses are primarily for those students who have been accepted as candidates for the master’s degree. Courses numbered 600-level and above are open only to students who have been admitted to graduate status.

Courses are offered at the APL Education Center, the Montgomery County Campus, the Dorsey Center, and the Southern Maryland Higher Education Center. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

645.462 Introduction to Systems Engineering
This course introduces students to the fundamental principles of systems engineering and their application to the development of complex systems. It describes how the systems engineering viewpoint differs from that of the engineering specialist, and the essential role that systems engineering plays as an integral component of program management. Topics include requirements analysis, concept definition, system synthesis, design tradeoffs, risk assessment, interface definition, engineering design, system integration, and related systems engineering activities. The course defines the breadth and depth of the knowledge that the systems engineer must acquire concerning the characteristics of the diverse components that constitute the total system. Special topics such as simulation and models and test and evaluation are discussed in relation to the systems engineering viewpoint. Students address typical systems engineering problems that highlight important issues and methods of technical problem resolution.

Prerequisites: An engineering, science, or mathematics degree and two years of experience in science or engineering.

Biemer, Bender, Crossett, Montoya, Pardoe, Reichert, Reitz, Smith, Tuck

645.467 Management of Systems Projects
The course addresses the management of a technical project from concept to operational use, with emphasis on the functions, roles and responsibilities of the project manager. From the development of a proposal to the delivery of a product to a customer, the efforts to conceive, plan, budget, schedule, monitor, control/direct and report the progress of the project are discussed. Throughout the project life cycle, the need for good communications, interface and configuration management, and conflict resolution are emphasized. Students assume the role of project managers who must use management tools and who must address typical problems that arise in the conduct of a high-technology systems project.

Prerequisite: Admission into the Systems Engineering Program (not available for Technical Management students).

645.767 System Conceptual Design
This course addresses in detail the systems engineer’s responsibilities and activities during the conceptual phases of a system development program. Systems engineering tools commonly employed at this stage of a program are presented along with selected problems which illustrate both the applicability and limitations of commonly employed tools and procedures. The course steps through conceptual design beginning with analysis of needs and objectives and proceeding to the exploration of alternative concepts and the selection of a concept that best meets goals of performance, timeliness, and affordability. Topics include definition of operational scenarios, functional analysis, risk assessment, system trade-offs, measures of effectiveness, and requirements formulation. Emphasis is on the application of these systems engineering techniques in a team environment to a class project. Students apply systems engineering methods learned from reading and lectures to the development of a realistic system in an ongoing project in a team format.

Prerequisites: 595.460 Introduction to Project Management and 645.462 Introduction to Systems Engineering, or permission of the student’s adviser and the course instructor.

Biemer, Britcher, Carpenter, Gealy, Ryder, Smith, Smyth, Utara, Wilmot

645.768 System Design and Integration
This course addresses the systems engineering objectives, responsibilities, and activities during the demonstration and validation and the engineering and manufacturing development phases of a system development program. Systems engineering procedures and tools employed during these phases are identified and their use illustrated. Topics include the relationship between a system specification and the system design, systems engineering management plan, risk management, system development models, customer integration into the design process, and design disciplines and practices. The course uses a system problem scenario extensively to illustrate systems engineering principles and specific product design issues.
Prerequisites: 595.763 Software Engineering Management and 645.767 System Conceptual Design or permission of the student’s adviser and the instructor.

Britcher, Happel, McLoughlin, Schulmeyer, Utara

645.769 System Test and Evaluation
This course focuses on the application of systems engineering principles to the test and evaluation of system elements and, ultimately, of the total system. Test requirements, selection of critical test parameters, analysis of test results, and determination of remedial action in the event of discrepancies are all systems engineering functions. Topics include validation and verification, similarities and differences in the nature of hardware and software testing, test tools and test procedures, testing during hardware-software integration, quality assurance test, environmental test, and operational test and evaluation. Student problems include scenario case studies using examples developed in the several previous courses.

Prerequisite: 645.768 System Design and Integration or permission of the student's adviser and the instructor.

Pardoe, Reichert, Schulmeyer, Sprigg, Wynne, VanderVliet, Tuck

645.770 Systems Engineering Project
This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical project, which is suggested by the student and is presented in a formal proposal. The product of the system project is a final report, as well as interim reports and oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the system engineering faculty. The program chair, vice chair, and mentor review proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

Prerequisite: 645.769 System Test and Evaluation or permission of the program chair or vice chair.

Seymour
Systems Engineering Advanced Certificate for Post-Master’s Study

The challenges in developing products and in solving systems problems are complex and multidisciplinary, requiring engineers who understand and execute programs that require enterprise systems-of-systems engineering discipline. A structured, balanced, comprehensive approach is needed to develop sophisticated architectures, employ innovative enterprise management processes, and deploy global high technology products, often comprised of multiple systems. This graduate program is designed to provide senior engineers and managers who already have a master’s degree in systems engineering, advanced state-of-the-art tools and knowledge that goes beyond the traditional systems engineering program.

The objective of the Johns Hopkins University Advanced Certificate for Post-Master’s Study in Systems Engineering is to provide students with skills and habits of thought employing advanced principles of systems engineering and to contribute to the development of new knowledge through directed research and publication. It is expected that students will participate, possibly in collaboration with their employers, in developing and evolving the body of knowledge in this modern discipline and in improving the systems engineering practices in complex technology-based programs. Current definitions, methodologies, tools, and technologies used in academia, government, and industry will be explored.

The program builds upon the existing JHU EPP MS Program in Systems Engineering that provides an integrated foundation course series based on the acquisition project life cycle. The hundreds of JHU MS SE graduates over the last 15 years and the SE graduates of other institutions are now engaged in leading their organizations in programs of increasing value and complexity.

This certificate program will provide the opportunity to expand the student’s experience and knowledge horizons to encompass the enterprise and integrated systems environments. An emphasis on commercial and government challenges will be explored. The courses are taught by current advanced systems engineering practitioners who are intimately familiar with the current challenges facing government and industry. Students should continue to expect relevant, applied, meaningful hands-on learning experiences coupled with sound research into the latest problems facing systems engineering.

Admissions Requirements
Applicants must have completed a Master of Science degree in Systems Engineering; or a Master of Science in a technical field such as EE, ME, CS, etc., plus a minimum of 10 years of professional experience as a practicing systems engineer; or a Master of Science in a technical field such as EE, ME, CS, etc., plus a minimum of five years of professional work experience as a practicing systems engineer, plus the completion of the Introduction to Systems Engineering course, 645.462. Eligibility will be determined by a current resume and verification in an employer recommendation letter. Graduates of the Johns Hopkins University must supply evidence of their Systems Engineering degree through a copy of their transcript. Systems Engineering MS graduates of other institutions must request official transcripts be sent to JHU.

Course Requirements
The Systems Engineering Advanced Certificate for Post-Master’s Study is awarded after completion of six courses beyond the Master of Science in Systems Engineering. It is intended to add depth and breadth to the discipline. The program consists of four required courses and two advanced electives. The student’s program will be planned in consultation with an advisor. The two electives can both be an independent systems engineering research project leading to a paper suitable for submission for publication in a refereed journal.

Required Courses
- 645.742 Management of Complex Systems
- 645.753 Enterprise Systems Engineering
- 645.761 Systems Architecting
- 645.771 Systems of Systems Engineering

Elective Courses
- 645.775 Advanced Systems Engineering Research Project (2 semesters)
  or Two approved 700 level courses in the EPP offering

Course Descriptions

645.742 Management of Complex Systems
Traditional systems engineering is usually applied to closed, precise and recursive systems with the assertion that the methodologies used can be scaled up to more elaborate systems of systems. This course addresses the more realistic and emerging field of the management of complex systems, where multiple current development efforts with disparate and non-linear attributes characterize the system components. Engineering complex systems must account for the likelihood of multiple disciplines, differing scales, often unpredictable future states, irreducible uncertainty and non-linear behavior. Multi-customer, -corporations, -governments, -technologies, and -systems now must be considered on a global scale with a mix of new and legacy systems. The student will be encouraged to think...
645.753 Enterprise Systems Engineering

Enterprise Systems Engineering is a multidisciplinary approach combining system engineering and strategic management to address methods and approaches for aligning system architectures with enterprise business rules and the underlying IT architecture; development and implementation consistent with enterprise strategic objectives; and the total enterprise system and capabilities, with diverse complex subsystems. This course uses the system engineering life cycle as a framework for linking outcome-based engineering analysis and decision making with enterprise strategic objectives, addressing methods and tools for managing complexity, determining measures of effectiveness, and assessing ROI from an engineering perspective. The complex nature of enterprises will be discussed, including the multiplicity of technical and business components involved in delivering enterprise capability, as well as methods for modeling and analysis of their interdependence. Business and technical interdependencies between infrastructure, computing, applications, services, and end-user environments will be discussed. Particular attention will be paid to outcome-based management, understanding total cost of ownership for delivered capabilities, and end-to-end systems engineering.

Prerequisite: MS in Systems Engineering.

645.761 Systems Architecting

As the systems that systems engineers face become more complex, it is no longer sufficient to use “good engineering practices.” The complex systems of today need to be architected before design work can begin. This course examines the principles and art of systems architecting as a subset of broad systems engineering when developing individual systems and systems which are components of a systems of systems or federation of systems. The objective is to provide students with the principles, techniques, and hands-on experience of architecting modern, complex systems. Students will learn the latest architecture development techniques using DoD and commercial architectural frameworks, extending those frameworks to specific problems involving unique systems development environments. Topics include the management of underlying system and data models and the special architecting requirements of command, control and communications systems. Special attention will be placed on visualizing architecture artifacts, qualitatively and quantitatively evaluating architectures and the systems model they represent, and utilizing system architectures for investment decisions. Case studies from actual experiences will be presented.

Prerequisite: MS in Systems Engineering.
Graduate Certificate in Technical Innovation and New Ventures

Joint offering of Engineering and Applied Science Programs for Professionals and the Carey Business School

The Graduate Certificate Program in Technical Innovation and New Ventures provides engineers and technical professionals with the knowledge and skills needed to start their own business or bring innovation to an established company. Courses are offered primarily at the university’s Montgomery County Campus, and scheduled evenings and Saturdays to accommodate working professionals. For additional flexibility, some courses are offered online.

Admission Requirements
Applicants must meet the general requirements for admission to graduate study in Johns Hopkins University’s Engineering Programs for Professionals (EPP) and the Carey Business School. Each applicant should hold a bachelor’s degree in engineering or another technical field with a 3.0 on a scale of 4.0 GPA, and have a minimum of three years of appropriate full-time work experience. A resume must be submitted with the application form.

Program Profile
Technical Innovation and New Ventures consists of five integrated courses, to be completed within three years in the sequence recommended below. In exceptional circumstances, students may be able to obtain a waiver from one of these required courses to substitute an appropriate elective chosen in consultation with a program adviser. The preferred elective is:

761.762 Legal Fundamentals for Technical Start-ups

Courses
The recommended sequence of courses for the certificate is:

605.791 New Technical Ventures
771.731 Marketing for Engineers and Technical Professionals
771.753 Finance for Technical Start-ups
635.792 Management of Innovation
505.770 Capstone Business Plan
761.762 Legal Fundamentals for Technical Start-ups (if taken)

Course Descriptions

505.770 Capstone Business Plan
This course challenges students to integrate course work from the program’s other certificate courses and apply their knowledge to the production of a business plan for a technology-driven venture. The exercise reinforces students’ understanding of business plan components and uses, such as attracting investment, inciting strategic thinking and focus, and providing benchmarks for tactical and operating decisions. Students break into small groups to produce a business plan for a specific opportunity, while learning how to develop a plan for a variety of technology driven ventures. Students also gain experience presenting a plan to potential funding sources.

Elective (substituting for a required course that has been waived).

605.791 New Technical Ventures
This course is intended for those who are considering forming their own high tech or Internet venture or developing new technical ventures within their existing organizations. The purpose of the course is to provide a basic understanding of the success factors of a new venture including personal, technical, and market factors. In addition, the course seeks to prepare potential entrepreneurs to plan a venture, write a business plan, assemble a team, and secure financing. Course topics include the traits of an entrepreneur, market analysis, product positioning, competitive advantage, securing venture capital and funding, corporate partners and joint ventures, building organizations, and managing growth. The course will draw heavily on case studies of technology-based businesses. Students will work individually or in small groups to develop a product concept and a business plan around a new innovation in their concentration area.

Prerequisite: Students should be in the second half of their MS degree, or enrolled in the Certificate for Technical Innovation and New Ventures, and have two years of work experience.

Summer, Fall, Spring  Addison

635.792 Management of Innovation
A critical issue for entrepreneurs and technical managers is how to translate opportunity into competitive advantage. This course explores the management of innovation, including the technical transition of applied R&D into products, the planning and launching of new products, and product management. Management of discontinuous technologies will be explored. The impact of competition by the introduction of new discontinuous technology will be addressed. Managing engineers through the creative process, as well as innovation and technological evolution will be covered. The course includes both formal and guest lectures. Case studies will be used as an important learning vehicle.

Fall, Spring  Addison and Husick
761.762 Legal Fundamentals for Technical Start-ups
This course gives students an understanding of selected fundamental legal issues faced by technology-driven start-ups, legal traps to avoid, and situations warranting legal counsel. Students also learn about fundamental legal issues concerning ownership and protection of intellectual property, choice of business entity, structuring the ownership of the new venture, employment law, contracts, and securities law.

771.731 Marketing for Engineers and Technical Professionals
This course teaches basic marketing principles and techniques, including market analysis, market segmentation, pricing across the life cycle of technology offerings, and marketing channels. The course helps students understand specific marketing issues faced by technology-driven and start-up companies, such as determining market needs for innovative offerings, problems of marketing embedded technologies, marketing technological intellectual property, marketing use of technology standards, difficulties of selling a technical product as a start-up, and market cycles.

771.753 Finance for Technical Start-ups
This course gives students a basic understanding of financial structures and instruments, as well as fundamental financial principles such as risk and return, cost of capital, and the time value of money. It covers financial statements, types of capital typically available to technically-driven start-ups, sources of start-up capital, criteria that funding sources use in selecting companies, financial and non-financial terms of funding, and methods used by funding sources to evaluate prospects.
Technical Management

Supervisory and management positions in scientific and engineering organizations are usually awarded to staff members who have earned the respect of management and coworkers by excelling in their areas of technical expertise. They then act as “lead scientists” or “lead engineers,” directing the work of other scientists or engineers. Although they have proved that they have good judgment in strictly technical matters, nothing in their past education and little in their work experience has prepared them for supervisory and management responsibilities.

The overall objective of this program is to prepare individuals trained and experienced in science or engineering in the elements of managing technical projects and organizing and supervising technical personnel. The program is organized along three parallel tracks: Project Management—the organization and direction of specific technical projects; Organization Management—the organization and supervision of people to accomplish technical objectives; and Project/Organization Management—a combination of the previous two tracks.

Instructional methodology employs a mixture of lectures on theory and practice by experienced technical managers and realistic problem situations in which students play a management role, dealing with problems and making decisions that are typically required of technical managers. Management theories and tools are presented in the context of problem situations.

Appropriate emphasis is given to that blend of technical, administrative, business, and interpersonal skills required for the successful management of continuously changing high-technology organizations and projects.

Students are encouraged to pursue the entire master’s degree, but in special approved cases may apply for a Graduate Certificate in Technical Management. The requirements for admission are the same as for the master’s degree and the student must complete six courses, as approved by the program chair/vice chair, with a grade of A or B (see Admission Requirements).

Program Committee

Kenneth A. Potocki, Chair
Principal Professional Staff
Applied Physics Laboratory

Samuel J. Seymour, Vice Chair
Principal Professional Staff
Applied Physics Laboratory

Conrad J. Grant
Principal Professional Staff
Applied Physics Laboratory

Ben F. Hobbs
Professor and Chair
Geography and Environmental Engineering of Engineering
Whiting School of Engineering

Jerry A. Krill
Principal Professional Staff
Applied Physics Laboratory

Nicholas J. Langhauser
Principal Professional Staff
Applied Physics Laboratory

Ronald R. Laman
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog (see Admission Requirements). In addition, the applicant must have a degree in a science or engineering field and must have a minimum of five years of appropriate fulltime work experience in that field. A resume must be submitted with the application form.

Course Requirements

All students complete 10 one-term courses within five years. Students may elect to pursue a concentration in Project Management, Organization Management, or Project/Organization Management.

Neither a thesis nor knowledge of a foreign language is required in this program. Academic standards governing graduate study, as specified in this catalog, must be maintained.

I. Required Courses for Project Management Candidates (7 courses)

- 595.460 Introduction to Project Management
- 595.461 Technical Group Management
- 595.464 Project Planning and Control
- 595.465 Communications in Technical Organizations
- 595.466 Financial and Contract Management
- 595.763 Software Engineering Management
- 645.462 Introduction to Systems Engineering

II. Required Courses for Organization Management Candidates (7 courses)

- 595.460 Introduction to Project Management
- 595.461 Technical Group Management
- 595.463 Technical Personnel Management
- 595.464 Project Planning and Control
- 595.465 Communications in Technical Organizations
- 595.466 Financial and Contract Management
- 595.762 Management of Technical Organizations

III. Elective Courses (for all options)

- 595.760 Total Quality Management
- 595.766 Advanced Technology
Electives
Students in the Project Management concentration may also take Systems Engineering courses as electives. (Systems Engineering course, 645.467, Management of Systems Projects, may not be taken as an elective.) Permission may also be granted by the chair/vice chair to take certain relevant courses in other EPP programs as electives.

Course Descriptions

Technical Management courses are primarily for those students who have been accepted as candidates for the master's degree. Degree candidates are given preference in registering. Special students, including students from other degree programs, may be admitted on a space-available basis, providing they meet the same admission criteria as technical management degree candidates.

Prior or concurrent completion of 595.460 Introduction to Project Management and 595.461 Technical Group Management (taken in either order) is generally prerequisite to more advanced courses. Specific prerequisites for each course are shown under the individual course descriptions. An approved program plan is required for preferential placement in registering.

Courses numbered 600-level and above are open only to students who have been admitted to graduate status.

Courses are offered at the APL Education Center, the Montgomery County Campus, the Dorsey Center, and the Southern Maryland Higher Education Center in St. Mary's County. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

595.460 Introduction to Project Management
This course concentrates on the general methodology of managing a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. Topics include career aspects of project management; business factors affecting the project and the manager; project organization, planning, execution, and communications; the project life cycle; risk analysis; interface management; design review; design control assessment; reporting; and reaction to critical problems. Students are formed into groups, presented with a scenario that simulates the development of a high technology system, and are assigned to make decisions required of the project manager in the execution of the project. The project manager's decisions must then be effectively communicated (and perhaps defended) to a variety of audiences (represented by other students and faculty) that include top management, the customer, functional management, and members of the project team.

Prerequisites: An engineering, science, or mathematics degree and five years' work experience in science or engineering.

Bates, Buchanan, Dabbah, Seymour, Teems, Tuck, Walker, Wheeler

595.461 Technical Group Management
This course covers the general functions and responsibilities of a technical group supervisor. Topics include functions of a technical group in an R&D or engineering organization; primary responsibilities of group supervisor; interactions with management, support organization, and project organization; organization of projects in group structure; development of work costs and schedules; progress monitoring and reporting; introduction to personnel management—leadership, motivation, evaluation, and professional growth; reaction to critical problems; technical leadership; and planning for the future. Students assume the roles of technical group supervisors in a high-technology organization. They address typical problems in the delegation of responsibilities, staffing new projects, dealing with project managers, and handling conflicts and priorities.

Prerequisites: An engineering, science, or mathematics degree and five years' work experience in science or engineering or permission of the program chair/vice chair.

Bjerkaas, Buckman, Fletcher, Horne, Keane, Terry

595.463 Technical Personnel Management
This course reviews the problems of personnel management in a technical organization. Topics include environmental requirements for effective and innovative technical efforts, direction and motivation, leadership behavior, recruitment of technical staff, orientation and training programs, personnel placement and reassignment, assignment of work, salary administration, personnel evaluation and counseling, professional growth and promotion, technical obsolescence and retraining, equal opportunity programs, employee grievances, and handling of conflict situations. Students explore typical personnel management situations that arise in a technical organization.

Prerequisite: 595.461 Technical Group Management or permission of the student's adviser or the course instructor.

Buckman, Burnett, Dickson, Lasky

595.464 Project Planning and Control
This course concentrates on the exploration of the Planning and Control decisions required when developing a new high technology product. Students are formed into groups, and presented with a scenario that requires the development of a plan that will guide their organization through entry into a new business area. When developing the new product-offering plan, students must consider a wide variety of questions
that their top management will need to have answered prior to making a decision to either accept or reject the plan. Other topics include the role of planning and control in project management; processes for responding to a Request for Proposal (RFP); assignments to prepare a Statement of Work (SOW), a Work Breakdown Structure (WBS), and a Critical Path Network (CPN) for the new product development plan; value earned performance measurement; analysis of project performance measures; integrated project planning; new product development considerations; and enterprise information systems applications.

Prerequisite: 595.460 Introduction to Project Management or the permission of the student's adviser or the course instructor.

Chism, McLoughlin, Terry, Utara, Wheeler

595.465 Communications in Technical Organizations

This course covers problems and instruction in human communications within a technical organization. Topics include the nature of difficulties in human communications (perception and cognition, semantics, individual differences in processing information, and listening), techniques for effective oral and written communications and presentations, problems in communication between supervisors and subordinates, assignment of work, and reporting to management and sponsors. Students assume roles in various interpersonal situations, meetings, discussions, and conflicts calling for a supervisor to write letters and memoranda; they also deliver oral presentations and participate in group and one-on-one discussions.

Prerequisite: 595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.

Moazami, Terry, Wheeler, Williamson

595.466 Financial and Contract Management

This course is an introduction to financial and contract management for technical managers. Topics include financial and management accounting (including elementary accounting principles, assets, liabilities, and stockholders' equity); direct and indirect costs, revenues, and profits; indices to financial position; use of financial reports; return on investment, net present value; internal rate of return; and financial management (including cash and funds flow statements). An introduction to the principles of contract formation, highlighting the distinctive characteristics of contracting with the federal government is presented, as well as emphasis on a team concept for effective contracting and the role of the program manager as a key team member. Subcontract management, competitive negotiation techniques, contract financing, and cost reimbursement are also included. Case studies supplement theoretical discussions.

Prerequisite: 595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.

Langhauser, Williamson, Wyant

595.760 Total Quality Management

Quality management is developed as an integrated system of management for organizational improvement. Topics covered include the quality management guiding principles of leadership commitment, customer focus, employee involvement/teambuck, continuous process improvement, and the systematic use of measurement data. Case studies of technical organizations and government agency experiences describe adapting quality management in diverse organizations to improve the performance of products and services in satisfying customer needs. Students draw upon theory and practice, recent journal articles, multimedia presentations, and their own work experiences in tailoring applications of the material to their workplace. Guest speakers discuss real-world examples of the various aspects of quality management. Students participate in highly interactive classroom discussions based upon these materials and assignments. This course requires a final applied research paper.

Prerequisite: 595.460 Introduction to Project Management, 595.461 Technical Group Management, or permission of the student’s adviser and the instructor.

Cormier

595.762 Management of Technical Organizations

This course reviews problems in the management of high-technology organizations at the senior technical management level. Topics include management of change and managing managers; establishing organization, technical, and business objectives and strategies; market analysis, technology, and product development, planning, and costing; organizing, staffing, and training to meet new needs; managing independent research and development; organizational conflicts; technical, financial, and personnel problems; and interaction with top management, staff executives, peers, and subordinates. Students assume the roles of senior technical managers dealing with typical problems in a department, including applied research, product development, and engineering support in an environment of rapidly changing technology.

Prerequisites: 595.463 Technical Personnel Management, 595.464 Project Planning and Control, or permission of the student’s adviser and the instructor.

Fountain, Hagler, Potocki, Terry

595.763 Software Engineering Management

This course covers software engineering principles and software tools and techniques as applied to the development of software systems. Topics include differences between software engineering and conventional programming; understanding the important issues in managing software engineering; understanding the basic concepts of software development using software engineering principles; software-unique aspects of project management; software development facilities and discussing some of the technologies and management trends in software engineering today. Students may examine case studies from their own environment as well as develop a plan for a notional project.
Prerequisites: 645.462 Introduction to Systems Engineering or permission of the student’s adviser or the course instructor. Completion of 595.460 Introduction to Project Management is helpful.

Britcher, Carpenter, Haser, Houle-Caruso, Miklos, Mosley, Saunders, Zitzman

595.766 Advanced Technology

This course emphasizes the impact of recent technological advances on new products, processes, and needs, as well as the role of the technical manager in rapidly evolving technologies. Subject areas and lecture content track current topics of interest, such as trends and developments in microelectronics, communications, computers, intelligent machines, and expert systems. Advanced technologies in application areas such as transportation, space, manufacturing, and biomedicine are also discussed. Students are encouraged to explore new technology areas and share information with each other. The seminar format encourages student participation that culminates in a term paper on a new or emerging technology area.

Prerequisites: 595.460 Introduction to Project Management and/or 645.462 Introduction to Systems Engineering or permission of the student’s adviser and the instructor.

Seymour, Strawser, Terry, Utara
Telecommunications and Networking Option

The field of telecommunications and networking is one of great importance to our society. As a technical discipline, it draws from the more traditional fields of computer science and electrical engineering. Although the Engineering and Applied Science Programs for Professionals do not offer a separate master’s degree in telecommunications and networking, students may pursue an option in this area as degree candidates in either computer science or electrical and computer engineering. The wide variety of courses from both areas allows students, working with advisers, to structure programs that meet their professional development needs.

Admission Requirements
Applicants must meet the general requirements for admission to graduate programs outlined in this catalog in the general Admission Requirements section. In addition, applicants must meet the specific program requirements for either computer science or electrical and computer engineering (see those programs for specific admission information).

Course Requirements
Each degree candidate is assigned an adviser. Attainment of the degree requires completion of 10 one-term courses specifically approved by the adviser. Seven of the 10 courses must be in the telecommunications and networking subject area as defined by the course lists below. The requirements for computer science degree candidates and those for electrical and computer engineering candidates can be found in the program descriptions in the respective sections of the catalog. Students who select the telecommunications and networking option through the computer science program may take a maximum of three telecommunications and networking courses from electrical and computer engineering courses listed below. Electrical and computer engineering students who select the telecommunications and networking option are required to take either two or three computer science telecommunications and networking courses as electives. All of these electives must be selected from the computer science courses listed below.

Computer Science
605.434 WWW Security
605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.475 Protocol Design
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.481 Distributed Development on the World Wide Web
605.731 Network Security
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network Management
605.773 High-Speed Networking Technologies
605.774 Network Programming
605.775 Optical Networking Technology
605.777 Internetworking with TCP/IP II
605.778 Voice over IP

Electrical and Computer Engineering
525.408 Digital Telephony
525.414 Probability and Stochastic Processes for Engineers
525.416 Communication Systems Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.437 Telecommunications Signal Processing
525.438 Introduction to Wireless Technology
525.439 Introduction to High-Speed Networks
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.444 Introduction to ATM Networks and Video Applications
525.707 Error Control Coding
525.722 Wireless Control Coding
525.723 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.747 Speech Processing
525.754 Wireless Communication Circuits I
525.755 Wireless Communication Circuits II
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread Spectrum Communications
525.789 Digital Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems
525.795 Advanced Communication Laboratory

Applied and Computational Mathematics
(Undergraduate transition course for students who lack electrical and computer engineering course prerequisites.)
625.260 Introduction to Linear Systems

Course Descriptions
Descriptions of the computer science courses can be found on pages 66-82 and electrical and computer engineering courses on pages 86-98.
Policy Statements

Equal Opportunity/Nondiscrimination Policy as to Students
Johns Hopkins University is committed to recruiting, supporting, and fostering a diverse community of outstanding faculty, staff, and students. As such, Johns Hopkins does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment. Defense Department discrimination in ROTC programs on the basis of sexual orientation conflicts with this university policy. The university continues its ROTC program, but encourages a change in the Defense Department Policy.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, 130 Garland Hall, Telephone: 410-516-8075, TTY: 410-516-6225.

Policy on the Reserve Officer Training Corps
Present Department of Defense policy governing participation in University-based ROTC programs discriminates on the basis of sexual orientation. Such discrimination is inconsistent with the Johns Hopkins University nondiscrimination policy. Because ROTC is a valuable component of the University that provides an opportunity for many students to afford a Hopkins education, to train for a career, and to become positive forces in the military, the University, after careful study, has decided to continue the ROTC program and to encourage a change in federal policy that brings it into conformity with the University’s policy.

Admissions Policy
Johns Hopkins University admits as regular students only persons who have a high school diploma or its recognized equivalent, or persons who are beyond the age of compulsory school attendance in Maryland.

To be eligible for federal student aid, students who are beyond the age of compulsory attendance but who do not have a high school diploma or its recognized equivalent must meet ability-to-benefit criteria or meet the student eligibility requirements for a student who is home schooled.

Statement Regarding the Privacy Rights of Students
Notice is hereby given that the Johns Hopkins Engineering Programs for Professionals complies with the provisions of the Family Educational Rights to Privacy Act of 1974 (P.L. 93-380), as amended, and regulations promulgated thereunder. The Family Educational Rights and Privacy Act (FERPA) affords eligible students, with certain rights with respect to their education records. They are (1) The right to inspect and review the student’s education records within 45 days of the day the university receives a request for access. Students should submit to the Registrar written requests that identify the record(s) they wish to inspect. The Registrar will make arrangements for access and notify the student of the time and place where the records may be inspected. If the records are not maintained by the Registrar, the student will be advised of the correct official to whom the request should be addressed; (2) The right to request the amendment of the student’s education records that the student believes are inaccurate or misleading. Students should write the university official responsible for the record they want changed and specify why it is inaccurate or misleading. If the university decides not to amend the records as requested by the student, the student will be notified of the decision and advised of his or her right to a hearing regarding the request for amendment. Additional information regarding the hearing procedures will be provided to the student when notified of the right to a hearing; (3) The right to consent to disclosures of personally identifiable information contained in the student’s education records, except to the extent that FERPA authorizes disclosures without consent. Disclosure without consent is granted to school officials with legitimate educational interests. A school official is a person employed by the university in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person serving on the Board of Trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks. A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibility; (4) The right to file a complaint with the U.S. Government of Education concerning alleged failures by the university to comply with the requirements of FERPA.

The name and address of the office that administers FERPA is:

Family Policy Compliance Office
U.S. Department of Education
400 Maryland Avenue S.W.
Washington, DC 20202-4605

Americans With Disabilities Act Policy (ADA)
The Johns Hopkins University does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, veteran status or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment.

A person with a disability is defined by the Rehabilitation Act of 1973 and by the Americans With Disabilities Act of 1990 as an individual who has a physical or mental impairment that substantially limits one or more major life activities,
Policy Statements

has a record of such an impairment, or is regarded as having such an impairment. For faculty, staff and students with disabilities, it is important to provide to the university a comprehensive evaluation of a specific disability from an appropriate qualified diagnostician that identifies the disability, describes the current level of functioning in an academic or employment setting and lists recommended accommodations. The university provides appropriate, necessary and reasonable accommodations in programs and facilities for those individuals who are qualified.

The policy is available on the JHU Disability Support Services Web site at www.jhu.edu/disabilityservices. Questions regarding compliance with the provisions of the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973 should be referred to Peggy Hayeslip, associate director for disability services, Office of Institutional Equity, Garland Hall, Suite 130, 410-516-8949 or (TTY) 410-516-6225.

Sexual Harassment Prevention and Resolution Policy

Preamble

The Johns Hopkins University is committed to providing its staff, faculty and students the opportunity to pursue excellence in their academic and professional endeavors. This can only exist when each member of our community is assured an atmosphere of mutual respect, one in which they are judged solely on criteria related to academic or job performance. The university is committed to providing such an environment, free from all forms of harassment and discrimination. Each member of the community is responsible for fostering mutual respect, for being familiar with this policy and for refraining from conduct that violates this policy.

Sexual harassment, whether between people of different sexes or the same sex, is defined to include, but is not limited to, unwelcome sexual advances, requests for sexual favors, and other behavior of a sexual nature when:

1. submission to such conduct is made implicitly or explicitly a term or condition of an individual’s employment or participation in an educational program;
2. submission to or rejection of such conduct by an individual is used as the basis for personnel decisions or for academic evaluation or advancement;
3. such conduct has the purpose or effect of unreasonably interfering with an individual’s work or academic performance or creates an intimidating, hostile, or offensive working or educational environment.

Fundamental to the University’s purpose is the free and open exchange of ideas. It is not, therefore, the University’s purpose, in promulgating this policy, to inhibit free speech or the free communication of ideas by members of the academic community.

Policy

The University will not tolerate sexual harassment, a form of discrimination, a violation of federal and state law, and a serious violation of University policy. In accordance with its educational mission, the University works to educate its community regarding sexual harassment. The University encourages individuals to report incidents of sexual harassment and provides a network of confidential consultants by which individuals can report complaints of sexual harassment. The means by which complaints are resolved can range from informal to formal.

The University encourages reporting of all perceived incidents of sexual harassment, regardless of who the alleged offender may be. Individuals who either believe they have become the victim of sexual harassment or have witnessed sexual harassment should discuss their concerns with any member of the Sexual Harassment Prevention and Resolution System. Complainants are assured that problems of this nature will be treated in a confidential manner, subject to the University’s legal obligation to respond appropriately to any and all allegations of sexual harassment.

The University prohibits acts of reprisal against anyone involved in lodging a complaint of sexual harassment. Conversely, the University considers filing intentionally false reports of sexual harassment a violation of this policy.

The University will promptly respond to all complaints of sexual harassment. When necessary, the University will institute disciplinary proceedings against the offending individual, which may result in a range of sanctions, up to and including termination of University affiliation.

Complaints of sexual harassment may be brought to Susan Boswell, dean of students, Levering Hall, telephone 410-516-8208; Ray Gillian, associate provost for Institutional Equity; or Caroline Laguerre-Brown, associate director for compliance and conflict resolution, 130 Garland Hall, telephone 410-516-8075, TTY 410-516-6225.

University Alcohol and Drug Policy for Students

In keeping with its basic mission, the University recognizes that its primary response to issues of alcohol and drug abuse must be through educational programs, as well as through intervention and treatment efforts. To that end, the University provides appropriate programs and efforts throughout the year. The brochure “Maintaining a Drug-Free Environment: The Hopkins Commitment” is distributed annually to all faculty, students, and staff of the Johns Hopkins University, and copies are available on request from the offices of the Faculty and Staff Assistance Program, 4 East 33rd Street, Baltimore, Maryland 21218; telephone 410-516-3800; or at the Counseling and Student Development Center located on the Homewood campus; telephone 410-516-8270.
**Policy on Possession of Firearms on University Premises**
The possession, wearing, carrying, transporting, or use of a firearm or pellet weapon is strictly forbidden on University premises. This prohibition also extends to any person who may have acquired a government-issued permit or license. Violation of this regulation will result in disciplinary action and sanctions up to and including expulsion, in the case of students, or termination of employment, in the case of employees. Disciplinary action for violations of this regulation will be the responsibility of the divisional student affairs officer, dean or director, or the vice president for human resources, as may be appropriate, in accordance with applicable procedures. Any questions regarding this policy, including the granting of exceptions for law enforcement officers and for persons acting under the supervision of authorized University personnel, should be addressed to the appropriate chief campus security officer.

**Campus Security Act Notice**
In accordance with the Crime Awareness and Campus Security Act of 1990 (PL 102-26), as amended, and the regulations promulgated thereunder, the University issues its Annual Security Report that describes the security services at each of the University’s divisions and reports crime statistics for each of the campuses. The report is published online at www.jhu.edu/~security/annual-report.html. Copies of the report are available from the University’s Security Department, 14 Shriver Hall, 3400 North Charles Street, Baltimore, Maryland 21218-2689; telephone 410-516-4600.

**Photography and Film Rights Policy**
The Johns Hopkins University reserves the right from time to time to film or take photographs of faculty, staff, and students engaged in teaching, research, clinical practices, and other activities, as well as casual and portrait photography or film. These photographs and films will be used in such publications as catalogs, posters, advertisements, recruitment and development materials, as well as on the university's Web site, for various videos, or for distribution to local, state, or national media for promotional purposes. Classes will be photographed only with the permission of the faculty member.

Such photographs and film—including digital media—which will be kept in the files and archive of The Johns Hopkins University, will remain available for use by the university without time limitations or restrictions. Faculty, students, and staff are made aware by virtue of this policy that the university reserves the right to alter photography and film for creative purposes. Faculty, students, and staff who do not want their photographs used in the manner(s) described in this policy statement should contact the Office of Communications and Public Affairs.

Faculty and students are advised that persons in public places are deemed by law to have no expectation of privacy and are subject to being photographed by third parties. The Johns Hopkins University has no control over the use of photographs or film taken by third parties, including without limitation the news media covering University activities.

**Return of Title IV Funds Policy**
The Financial Aid Office is required by federal statute to recalculate federal financial aid eligibility for students who withdraw, drop out, are dismissed, or take a leave of absence prior to completing 60% of a payment period or term. The federal Title IV financial aid programs must be recalculated in these situations.

If a student leaves the institution prior to completing 60% of a payment period or term, the financial aid office recalculates eligibility for Title IV funds. Recalculation is based on the percentage of earned aid using the following Federal Return of Title IV funds formula:

\[
\text{Percentage of payment period or term completed} = \frac{\text{number of days completed up to the withdrawal date}}{\text{total days in the payment period or term}} \times 100%
\]

This percentage is also the percentage of earned aid.

Funds are returned to the appropriate federal program based on the percentage of unearned aid using the following formula:

\[
\text{Aid to be returned} = (100\% - \text{percentage of earned aid}) \times \text{total amount of aid that could have been disbursed during the payment period or term.}
\]

Funds are returned to the appropriate federal program based on the percentage of unearned aid using the following formula:

\[
\text{Aid to be returned} = (100\% - \text{percentage of earned aid}) \times \text{total amount of aid that could have been disbursed during the payment period or term.}
\]

If a student earned less aid than was disbursed, the institution would be required to return a portion of the funds and the student would be required to return a portion of the funds. Keep in mind that when Title IV funds are returned, the student borrower may owe a debit balance to the institution.

If a student earned more aid than was disbursed to him/her, the institution would owe the student a post-withdrawal disbursement which must be paid within 120 days of the student’s withdrawal.

The institution must return the amount of Title IV funds for which it is responsible no later than 30 days after the date of the determination of the date of the student’s withdrawal.

Refunds are allocated in the following order:

- Unsubsidized Federal Stafford Loans
- Subsidized Federal Stafford Loans
- Unsubsidized Direct Stafford Loans (other than PLUS loans)
- Subsidized Direct Stafford Loans
- Federal Perkins Loans
- Federal Parent (PLUS) Loans
- Direct PLUS Loans
- Federal Pell Grants for which a Return of funds is required
- Federal Supplemental Opportunity Grants for which a Return of funds is required (e.g., LEAP)
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Directions and Maps

Applied Physics Laboratory
Education Center
From Baltimore and I-95 (southbound): Take I-95 South from the Baltimore Beltway (I-695) intersection. Go 13 miles and take Columbia exit (MD Route 32 West). Go 2.5 miles and take Washington DC exit (US Route 29 South). Go 1.5 miles and take Johns Hopkins Road exit. APL is on the right about 0.5 mile. Turn right onto Pond Road, and follow signs to the Kossiakoff Center parking on the lower lot.

From Washington and I-95 (northbound): Take I-95 North from the Capital Beltway (I-495) toward Baltimore. Go 8 miles and take MD Route 216 West (toward Clarksburg). Go 1.2 miles, turn right onto Leeshear Road. Go 0.8 mile, turn left onto Gorman Road. Go 0.7 mile, cross traffic circle and bridge over US Route 29. Road name changes to Johns Hopkins Road. APL is on the right about 0.5 mile. Turn right onto Pond Road, and follow signs to the Kossiakoff Center parking on the lower lot.

From US Route 29: Proceed on US 29 to the Johns Hopkins Road exits. APL is about 0.5 mile west. Turn right on Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

Montgomery County Campus
From Baltimore (via major arteries): Take Beltway (I-695) to I-95 south. Continue toward Washington on 95 to the Capital Beltway (I-495). Take 495 west to I-270. From 270 north, take the Shady Grove exit (Exit 8). Once on the exit ramp, stay in the left lane. At the light make a left onto Shady Grove Road. Proceed approximately .6 miles to Key West Avenue. Turn right at Key West Avenue and follow to first intersection. Make a left on Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

From Interstate 70 (I-70): Take I-70 west to Md. Route 97 (Georgia Avenue). Turn left on Md. Route 97. Go south on Md. Route 97 to Norbeck Road (Md. Route 28). Turn right onto Norbeck Road. Continue west on Norbeck Road about 3.3 miles to East Gude Drive. Turn right onto East Gude Drive and proceed 4.3 miles across Rockville Pike (Md. Route 355) and Piccard Drive to Key West Avenue. Turn right on Key West Avenue. Cross Shady Grove Road and make a left at the first light onto Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

From Washington, D.C. and Northern Virginia: Take the Beltway (I-495) to I-270 north, and take the Shady Grove exit (Exit 8). Once on the exit ramp, stay in the left lane. At the light make a left onto Shady Grove Road. Proceed approximately .6 miles to Key West Avenue. Turn right at Key West Avenue and follow to first intersection. Make a left on Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

Dorsey Student Services Center
From I-95 North or South: Exit I-95 towards Route 100 East. Exit Route 100 towards Route 1 South. On Route 1, move to the inside lane. At the first light, turn left onto Dorsey Road (Route 103). After about one-third mile on Dorsey Road, turn left onto Douglas Legum Drive. Once on Douglas Legum Drive, the JHU/Dorsey Center is on the second floor of the five-story high white building with blue windows.

From I-295 (Baltimore Washington Parkway) North or South: Exit I-295 towards Route 100 West. Exit Route 100 using the Coca-Cola Drive exit. Turn left onto Coca-Cola Drive towards Dorsey Road. At the end of Coca-Cola Drive, turn right onto Dorsey Road. After about 1 mile on Dorsey Road, turn right onto Douglas Legum Drive. Once on Douglas Legum Drive, the JHU/Dorsey Center is on the second floor of the five-story high white building with blue windows.

Homewood Campus
From I-95 (southbound) or from I-695 (the Baltimore Beltway): Take the beltway toward Towson to exit 25. Take Charles Street south for about 7 miles (when Charles Street splits a block after Loyola College and Cold Spring Lane, take the right fork). As you approach the university and cross University Parkway, continue southbound but be sure to jog right onto the service road. After you pass the university on the right, turn right onto Art Museum Drive. Just after the Baltimore Museum of Art, bear right at the traffic island onto Wyman Park Drive. Take an almost immediate right through the University gates.

From I-95 (northbound): Exit at I-395, then take the exit to Martin Luther King Jr. Blvd. and follow the directions below.

From Maryland 295 (the Baltimore-Washington Parkway): Entering Baltimore, the parkway becomes Russell Street. Stay on Russell Street until (with Oriole Park at Camden Yards looming before you) you reach the right-hand exit marked Martin Luther King Jr. Boulevard (look carefully for this; the signs are small). Take King Boulevard until it ends at Howard Street (remain in one of the middle lanes of King Boulevard to avoid a premature forced right or left turn). Turn left at Howard Street and proceed about 2 miles. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the University gates.

From the Jones Falls Expressway (I-83) southbound: Take the 28th Street exit to 28th Street east. Turn left on Howard Street. One
block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the University gates.

**HEAT Center**

*From Baltimore and Washington, D.C. area:* Take I-95 North to exit 85 Route 22 towards Aberdeen/Churchville. Keep left at the fork in the ramp. Turn left onto Churchville Road (Route 22). Turn left onto Technology Drive. The Center is on the left-hand side.

**Southern Maryland Higher Education Center, St. Mary’s County**

*From Lexington Park:* Take Maryland Route 235 north approximately six miles to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

*From Calvert County:* Take Maryland Route 4 south. At Solomons, cross the Thomas Johnson Bridge, and continue four miles to the stoplight at Maryland Route 235. Turn right on Route 235, and go north past the Wildwood Shopping Center to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

*From Charles County:* Take Maryland Route 5 south to St. Mary’s County. About 20 miles south of Waldorf, Route 5 branches to the right toward Leonardtown, and the main four-lane road continues straight and becomes Maryland Route 235. Continue on Route 235 approximately 12 miles to Airport Road. Turn right on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

**Washington D.C. Center**

*From points north of the District of Columbia:* Take I-95 to 495 (Capital Beltway) to exit 30, Route 29 south toward Silver Spring. Follow Route 29 through downtown Silver Spring and cross Georgia Avenue until you reach the circle at the intersection of 16th Street, N.W. Turn left onto 16th Street. Take 16th Street to Scott Circle bearing to the right to avoid the underpass. Turn right onto Massachusetts Avenue. The center is on the corner of Massachusetts Avenue and 17th Street.

*From points south of the District of Columbia:* From Vienna, Falls Church, Tyson’s, and Route 66: Take Route 66 into Washington. Go over the Roosevelt Bridge and follow the signs to Constitution Avenue. Make a left turn onto 18th Street, N.W. (there is a left turn arrow). Follow 18th Street through the city and across Connecticut Avenue (you will need to be in the middle lane in order to cross Connecticut Avenue and stay on 18th Street rather than veer left onto Connecticut). Go one more block on 18th Street and you will come to Massachusetts Avenue. Turn right onto Massachusetts Avenue, go one block to 17th Street, and the center is located on the corner of Massachusetts Avenue and 17th Street.

*From Alexandria, South Arlington, 495, 95, 395, and Route 1:* Take I-495 or 95 to 395. Take 395 (or Route 1) over the 14th Street Bridge and follow the signs for 14th Street, N.W. Take 14th Street to Thomas Circle at M Street. Get in the far right lane and take the outer circle 3/4 of the way around until you reach the turn-off for Massachusetts Avenue (it is just one lane at first, alongside green railing over a tunnel—you will merge with Massachusetts Avenue traffic). Take Massachusetts Avenue to Scott Circle at 16th Street and follow Massachusetts Avenue around the circle to 17th Street. The center is located on the corner of Massachusetts Avenue and 17th Street. An optional route would be to take 14th Street through Thomas Circle to P Street. Turn left onto P Street and take P Street to 17th Street where you would turn left. The center is on the corner of 17th Street and Massachusetts Avenue. This route would allow for more street parking options and would avoid traffic backed up on Massachusetts Avenue.

**Parking**

Garage parking is available in two locations. Parking is available at the Central parking garage located on N Street between 17th and 18th streets, N.W. This garage is open from 6 a.m. until 10:30 p.m. weekdays only. The JHU discounted parking rate is $4 if you enter the garage after 4:30 p.m. You must stamp your parking ticket at the front desk of the center. Parking is also available in a Colonial parking garage underneath the center. The garage is open from 7 a.m. until 7 p.m. weekdays only. While you cannot enter the garage after 7 p.m., you can exit the garage anytime before 9:45 p.m. The parking rate is $5 after 5 p.m. Otherwise, it is $5 per hour or $11 all day. Enter this garage from Massachusetts Avenue or 17th Street. Parking in the evenings and on the weekends is also available along Massachusetts Avenue and 17th Street and surrounding side streets.

**Metro**

Many Washington Center students travel to and from class on the Metro. The center is conveniently located near two Metro stops: Dupont Circle (south exit) on the red line (two blocks away) and Farragut West on the blue and orange lines (five blocks away).
The Johns Hopkins University
APPLIED PHYSICS LABORATORY
APL EDUCATION CENTER
11100 Johns Hopkins Road
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443-778-6510 (Baltimore)
240-228-6510 (Washington, D.C.)
The Johns Hopkins University
WHITING SCHOOL OF ENGINEERING
DORSEY STUDENT SERVICES CENTER
Dorsey Business Park
6810 Deerpath Road, Suite 100
Elkridge, MD 21075
410-540-2960
The Johns Hopkins University
HOMEWOOD CAMPUS
3400 N. Charles Street
Baltimore, MD 21218
410-516-8000
The Johns Hopkins University
SOUTHERN MARYLAND HIGHER EDUCATION CENTER
44219 Airport Road
Wildewood Technology Park
California, MD 20619
301-737-2500
The Johns Hopkins University
HIGHER EDUCATION APPLIED TECHNOLOGY CENTER (HEAT)
1201 Technology Drive
Aberdeen, MD 21001
800-548-3647
Index

Academic and Registration Calendar, ii
Academic Ethics, 9
Academic Integrity, 16
Academic Standing, 7, 9
Academic Regulations, 6-9
Accreditation, 2
Adding Courses, 6
Administrative Staff, iv
Admission Requirements, 3, 4
Admission to Other Divisions of the University, 4
Advisers, 6
Advisory Council, 148
Application Fee, 18
Application Procedures, 4
Applied Analysis Concentration, 18
Applied Biomedical Engineering, 25-30
Applied and Computational Mathematics, 17-24
Applied Physics, 31-39
Applied Physics Laboratory Education
  Center, 14
  Bookstore, 14
  Computers, 14
  Directions/Maps, 164, 166-167
  Library, 14
  Parking, 14
Attendance, 9
Audits, 6
Biochemical Engineering Concentration, 52
Bioinformatics, 40-50
Bioinformatics Concentration, 64, 65
Calendar, ii
Career Services, 12
Certificates
  Graduate, 3
  Post-Master's Study Candidate, 3
Change of Program or Concentration, 5
Chemical and Biomolecular Engineering, 51-57
Civil Engineering, 58-62
Computational Biology Concentration, 41
Computer Engineering, 134
Computing Policy, 9
Computer Science, 63-82
Copyright Violations, 9
Course Credit, 5
Course Descriptions (see individual degree listings)
Course Enrollment Limits, 6
Course Numbering System, 5
Course Load, 6
Course Requirements (see individual degree listings)
Course Schedule, 5
Data Communications and Networking
  Concentration, 65
Database and Knowledge Management, 65-66
Degrees, 3
  Master of Science, 3
  Master of Engineering, 3
Directions and Maps to Campuses, 164
  Applied Physics Laboratory, 164, 166, 167
  Dorsey Student Services Center, 164, 166, 169
  Homewood, 164-165, 166, 170-171
  Montgomery County Campus, 164, 166, 168
  Washington DC Center, 165, 166, 174
Southern Maryland Higher
  Education Center, 165, 166, 172
HEAT, 165, 166, 173
Disability Services, 12
Dismissal, 7
Distributed Computing Concentration, 65, 109
Dorsey Student Services Center, 15
  Directions/Maps, 164
Dropping Courses, 6
Electrical and Computer Engineering, 83-99
Electronics and the Solid State Concentration, 85
Environmental Engineering, 100
Environmental Engineering Advisory Board, 149
Environmental Engineering, Science
  and Management, 99
Environmental Planning and Management, 100-103
Environment Conscious Processing Concentration, 52
Ethics, Academic, 9
Facilities, 12-16
Faculty, 150-163
Fees, 10
  Application, 4, 10
  Graduation, 10
  Late Registration, 5, 10
  Removal of Incomplete, 10
  Transfer Credit, 10
Financial Aid, 10-11
Genomics and Sequencing Concentration, 41
Geophysics and Space Science, 41
Geotechnical Engineering, 59
Grade Appeals, 8
Grade Reports, 8
Grading System, 8
Graduation, 7, 8
Graduate Programs, 2
Graduation Fee, 10
Higher Educational Applied
  Technology Center, 15, 165, 166, 173
Index

Homewood Campus, 13, 14
  Book Center, 13
  Computers, 13
  Directions/Maps, 164, 165, 166, 170
  Hopkins Student Union, 13
  Libraries, 13
  Parking, 14
  Security Services, 13-14
Honors, 8
Incomplete Fee, 8
Incompletes, 8
Information Assurance, 62, 109
Information Systems and Technology, 111-115
Information Technology and
  Computation Concentration, 18
Information Systems Management Concentration, 111
International Student Services, 12
International Credential Evaluation, 4
Inter-Site Links, 16

JCards, 12

Knowledge Management Concentration, 112

Late Registration Fee, 5, 10
Leave of Absence, 7

Manufacturing Concentration, 123
Master of Engineering, 3
Master of Science, 3
Master’s Degree Candidate, 3
Materials Science and Engineering, 116-120
Materials and Condensed Matter Option, 32, 121
Mechanics Concentration, 122-123
Mechanical Engineering, 122-127
Montgomery County Campus, 14
  Bookstore, 15
  Cafe, 15
  Computers, 14
  Directions/Maps, 164
  Library, 14
  Parking, 15
Nanotechnology Option, 117, 128-129
Networking Concentration, 113
Non-Degree Students, 3

Online Courses, 15
  Registration Deadlines, 15
  Online Orientation, 16
  Books, 16
Ocean Engineering, 59
Organization Management Concentration, 138
Operations Research Concentration, 18
Photonics, 32
Photonics Option, 32, 130
Photonics Concentration, 85
Policy Statements, 143-145
  Alcohol and Drug, 144
  Americans With Disabilities Act, 143-144
  Campus Security Act, 145
  Firearms, 145
  Nondiscrimination Policy, 143
  Photography and Film Rights, 145
  Privacy Rights, 143
  ROTC, 143
  Sexual Harassment, 144
Polymer Engineering Concentration, 52
Probability and Statistics Concentration, 18
Probation and Dismissal, 7
Program Plans, 6
Programs by Location Chart, 2
Project Management Concentration, 138
Protein Bioinformatics Concentration, 41
Readmission, 4
Refund Policy, 10
Refund Schedule, 10
Registration, 5-15
  Interdivisional, 6
  Late, 5
  New Applicants, 4, 6
  Online Courses, 5
  Web, 5
Removal of Incomplete, 10
RF and Microwave Engineering Concentration, 85
Robotics and Controls Concentration, 123
Second Degree, 7
Signal Processing Concentration, 85
Simulation and Modeling Concentration, 18-19
Software Engineering Concentration, 64
Software Systems Concentration, 112-113
Southern Maryland Higher Education Center, 15
  Directions/Maps, 164-165, 172
Special Students, 4
Special Topics, 66
Structural Engineering, 58
Student Services, 12
Systems and Control Concentration, 85
Systems Biology Concentration, 41
Systems Concentration, 65
Systems Engineering, 131-133
Systems Engineering Advanced Certificate for
  Post Masters Study, 134-135
Technical Innovation and New Ventures, 136-137
Technical Management, 138-141
Telecommunications Option, 84
Telecommunications and Networking
  Option, 142
Textbooks, 6
Theory Concentration, 65
Time Limitation, 7
Transcripts, 12
Transfer Credits, 12
Transfer Credit Fee, 10
Trustees/Administration, 146-148
Tuition and Fees, 10
Veterans Benefits, 11
Violations of Academic Integrity, 9
Visa Status, 5
Visualization and Human-Computer Interaction Concentration, 65
Washington DC Center, 15, 165-166, 174
Weather, 13
APPLICATION FOR ADMISSION

Please complete all sections of this form and return it to Engineering and Applied Science Programs for Professionals, Johns Hopkins University, 6810 Deerpath Road, Suite 100, Elkridge, MD 21075, along with your $75 application fee.

PERSONAL INFORMATION

SSN ___________________________ Date of Birth _______________________ Gender: □ Male □ Female
Name: Last ____________________ First ______________________ Middle ________________ Maiden ________________
List any other names used on previous academic records ______________________________________________________
Address: Street __________________________________________________________________________________________
City __________________________________ State ____________ County (if in MD) ________________ Zip ____________
Employer ____________________________________________________ Location _____________________________________________
Work Phone: ________________________ Home Phone: __________________ E-mail Address: ____________________________

CITIZENSHIP AND ETHNICITY

Are you a U.S. citizen? □ Yes □ No If yes, choose ethnic group (optional): □ Native American
□ African American □ Asian American □ Hispanic □ Caucasian
If you are not a U.S. citizen, state country of citizenship ______________________________________________________
• Specify visa type: ____________________________ • Permanent Resident number: _________________________

ACADEMIC INTENT

□ Master’s Degree
□ Graduate Certificate
□ Advanced Certificate for Post-Master’s Study
□ Special Student (choose only if you do not wish to seek a degree or certificate)

Program:
□ Applied Biomedical Engineering
□ Applied & Computational Mathematics
□ Applied Physics  __ Photonics Option  __Materials and Condensed Matter Option
□ Chemical and Biomolecular Engineering
□ Civil Engineering
□ Computer Science  __ Telecommunications and Networking Option
□ Electrical and Computer Engineering  __ Photonics Option  __ Telecommunications Option
□ Environmental Engineering
□ Environmental Engineering and Science
□ Environmental Planning and Management
□ Information Systems and Technology
□ Materials Science and Engineering  __ Nanotechnology Option
□ Mechanical Engineering
□ Systems Engineering
□ Technical Innovation and New Ventures (Graduate Certificate)
□ Technical Management

dee back to complete form
Note: Some programs require supporting documents (i.e., resume, letters of recommendation). Please submit these items as soon as possible. For graduates of foreign institutions, we may require course by course evaluations of your credentials. For more information, visit the World Education Services website (www.wes.org).

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Student Agreement

I understand that my application will be considered only if the proper fee is enclosed. I recognize the right of the University to exclude at any time a student whose academic conduct or academic standing renders undesirable his or her presence in the institution.

Signature ______________________________________________________ Date _________________________________________

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Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, 130 Garland Hall, Telephone: 410-516-8075, TTY: 410-516-6225

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