Chemical and Biomolecular Engineering

Chemical and Biomolecular Engineering (ChemBE) is dedicated to the study and exploitation of chemical, biological, and physical processes and phenomena for chemical and biological applications. As a result of the scope and breadth of this rigorous undergraduate program, our students commonly secure employment in industries such as Chemical and Pharmaceutical Production, Biomedicine, Biotechnology, Material Design, Food, and Energy. Graduates may embark on a career to explore new products such as:

<table>
<thead>
<tr>
<th>Novel polymers and materials</th>
<th>Biopharmaceuticals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels</td>
<td>Drugs and Vaccines</td>
</tr>
<tr>
<td>Gene Therapy Products</td>
<td>Drug Delivery Devices</td>
</tr>
<tr>
<td>Cells and Tissues</td>
<td>Semiconductors</td>
</tr>
<tr>
<td>Nanodevices</td>
<td>Food, Beverage, and Health Care Products</td>
</tr>
</tbody>
</table>

The demands on the modern engineer are high, and graduates must possess a wide range of skills in order to be competitive in a global market. The ChemBE program successfully satisfies these demands. Students take advanced courses in chemistry, physics, mathematics, and biology. Additionally, students are trained in transport, kinetics, and thermodynamics, which are essential to solving real-world engineering problems. Students also hone their professional and communication skills (report writing, oral presentations, and teamwork) in courses involving experimental projects, process design and product design.

Depending on their interests and future career goals, students can choose electives from exciting areas including green engineering, nanotechnology, and bioengineering. These courses, along with undergraduate research opportunities offered by our faculty, are designed to prepare graduates for careers in the chemical industry, biotechnology, pharmaceuticals or microelectronics. The curriculum also offers an outstanding foundation for advanced graduate studies in Chemical and Biomolecular Engineering, Biomedical Engineering, Materials Engineering, or for medical, law, or business school.

Students also have the opportunity to develop more in-depth specialty in one or two areas within chemical and biomolecular engineering. Our two tracks are Interfaces and Nanotechnology (IN) and Molecular and Cellular Bioengineering (MCB).

Interfaces and Nanotechnology (IN) Track

Interesting and new physics exist at nanometer length scales, as the surface area of an object begins to approach and exceed its volume. In this focus area, students are trained in the fundamental sciences used to solve problems in nanotechnology and interfacial science. Students take a chemistry course in Materials and Surface Characterization, an advanced physical chemistry laboratory course, and two electives such as Colloids and Nanoparticles, Supramolecular Materials and Nanomedicine and Micro/Nanotechnology: the Science and Engineering of Small Structures.

Molecular and Cellular Bioengineering (MCB) Track

Fields in Biotechnology and Biomedicine often involve processes at biological, cellular and molecular levels. Common areas utilizing skills in the MCB focus area include the genetic manipulation of cells for protein and vaccine production, and the study and treatment of diseases such as arteriosclerosis and cancer. Students in this focus area must take a laboratory course in Biochemistry, and two electives such as Metabolic Systems Biotechnology, Bioengineering in Regenerative Medicine, and Computational Protein Structure Prediction. In addition, students will take the Biomolecular Engineering Laboratory to learn the hands-on skills required for future careers in biological systems at the molecular and cellular level.

Our mission is to define and educate a new archetype of innovative and fundamentally-grounded engineer at the undergraduate and graduate levels through the fusion of fundamental chemical engineering principles and emerging disciplines. We will nurture our passion for technological innovation, scientific discovery, and leadership in existing and newly created fields that transcend traditional boundaries. We will be known for developing leaders in our increasingly technological society who are unafraid to explore uncharted engineering, scientific, and medical frontiers that will benefit humanity. Recent graduates of the Chemical and Biomolecular Engineering program will attain within a few years of graduation:

- careers in industrial, academic, or government organizations related to chemical, physical, and life sciences and engineering, and/or pursue graduate or professional education.
- positions in which they apply their chemical and biomolecular engineering skills to solve diverse traditional and emerging problems in the workplace.

The department also offers graduate programs leading to the Master of Science and Ph.D. degrees. These programs emphasize research leading to a written thesis.

Undergraduate students strongly involved in research may be interested in our B.S./M.S.E. program in Chemical and Biomolecular Engineering that allows students to obtain a master’s of science in engineering immediately after completion of their bachelors.

Facilities

The offices and state-of-the-art laboratories of Chemical and Biomolecular Engineering are located in Croft Hall and Maryland Hall on the Homewood campus. The research laboratories are well-equipped for studies in the areas of biochemical engineering, cell and tissue engineering, phase equilibria, membrane science, polymer science, interfacial phenomena, separation processes, fluid mechanics, and nucleation phenomena. The Milton S. Eisenhower Library on the Homewood campus contains over two million volumes and access to more than 325 electronic journals. The university’s other libraries located at the School of Medicine and at the Applied Physics Laboratory are also available to students. Through close collaborations with scientists at the National Institutes of Health, and the National Institute of Standards and Technology, The Institute for Genomic Research, Human Genome Sciences, Inc., and the Food and Drug Administration, students and faculty also have access to a variety of world-class facilities and other resources for research.
Financial Aid

Undergraduate scholarships and financial assistance are described in the catalog (see page 25). Part-time work is available in the Chemical and Biomolecular Engineering research laboratories on research projects supported by grants and contracts. There is also a federally sponsored work-study program for qualified students.

Financial assistance to graduate students is available in the forms of research assistantships, teaching assistantships, fellowships, and partial or full tuition remission. The financial aid package is specified following acceptance into the graduate program.

Graduates receive a Bachelor of Science degree in Chemical and Biomolecular Engineering accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. As permitted under the ABET guidelines, we are continually updating our undergraduate programs to include the latest advances in chemical and biomolecular engineering. Such modifications will enable us to offer the best possible education experience to our undergraduates. For the latest chemical engineering educational programs, potential applicants are referred to our website at http://www.jhu.edu/chembe/

Requirements for the B.S. Degree

(See also General Requirements for Departmental Majors (http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree))

The Bachelor of Science degree requires a minimum of 128 credits. Additional details are given in the Chemical and Biomolecular Engineering Undergraduate Advising Manual available from the department or online.

The 128 credits must include:

## Chemical and Biomolecular Engineering Core Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.101</td>
<td>Chemical Engineering Today</td>
<td>1</td>
</tr>
<tr>
<td>EN.540.202</td>
<td>Introduction to Chemical &amp; Biological Process</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.203</td>
<td>Engr Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.301</td>
<td>Kinetic Processes</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.303</td>
<td>Transport Phenomena I</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.304</td>
<td>Transport Phenomena II</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.305</td>
<td>Modeling and Statistical Analysis of Data for</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Chemical and Biomolecular Engineers</td>
<td></td>
</tr>
<tr>
<td>EN.540.306</td>
<td>Chemical &amp; Biomolecular Separation</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.311</td>
<td>Chemical Engineering Lab I</td>
<td>6</td>
</tr>
<tr>
<td>or EN.540.313</td>
<td>Chemical and Biomolecular Engineering Lab</td>
<td></td>
</tr>
<tr>
<td>EN.540.314</td>
<td>ChemBE Product Design</td>
<td>2</td>
</tr>
<tr>
<td>EN.540.315</td>
<td>Process Design with Aspen</td>
<td>2</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.490</td>
<td>Chemical Laboratory Safety</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Engineering electives</td>
<td>9</td>
</tr>
</tbody>
</table>

## Physics Courses and Laboratories

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics:Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
</tbody>
</table>

or AS.171.108 General Physics for Physical Science Majors (AL)

## Basic Chemistry Courses and Laboratories

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.105</td>
<td>Introductory Chemistry Lab I</td>
<td>1</td>
</tr>
<tr>
<td>AS.030.102</td>
<td>Introductory Chemistry II</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.106</td>
<td>Introductory Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>

## Advanced Chemistry and Biology Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.020.305</td>
<td>Biochemistry</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.307</td>
<td>Cell Biology for Engineers (Optional; students must take this or EN.540.204)</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.315</td>
<td>Biochemistry Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>or AS.030.307</td>
<td>Physical Chemistry Instrumentation Laboratory III</td>
<td></td>
</tr>
</tbody>
</table>

## Mathematics Requirement

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
<td></td>
</tr>
<tr>
<td>AS.110.302</td>
<td>Diff Equations/Applic</td>
<td>4</td>
</tr>
</tbody>
</table>

Total Credits 90

- **Humanities and Social Sciences Courses.** Eighteen credits designated as Humanities or Social and Behavioral Sciences are required. Students are required to take these courses in at least two subject areas other than writing. At least one of these courses must be an advanced course at the 300-level or higher. See the Chemical and Biomolecular Engineering Undergraduate Advising Manual for more details.

- **Writing Courses.** Two writing intensive courses are required. One of the courses must be EN.661.315 Culture of the Engineering Profession. The courses that are taken to satisfy the university writing requirement must be passed with a grade of C- or better.

- **Undesignated Electives.** A minimum of 128 credits is required for the degree. Therefore, in addition to all the credits taken to fulfill the requirements mentioned in the various sections above (e.g., chemical engineering core courses, engineering electives, basic science, advanced chemistry electives, mathematics requirement, and Humanities and Social and Behavioral Sciences courses) additional credits (called undesignated credits) are required.

* Students also must have a grade point average of at least 2.00 in the chemical and biomolecular engineering core courses to graduate. The core courses for GPA calculation comprise all of the above courses except for EN.540.101 Chemical Engineering Today and EN.540.490 Chemical Laboratory Safety.

** Students need additional courses beyond these courses. Requirements include additional courses in Chemistry and Biology. Students who are pursuing tracks in Molecular and Cellular Bioengineering or Interfaces and Nanotechnology have additional and/or alternate requirements.

*** Calculus is so essential to Chemical Engineering that a grade of C- or better in both Calculus I and Calculus II is required.
## Sample Program for Chemical and Biomolecular Engineering Degree

### Freshman

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
<td>AS.030.102 Introductory Chemistry II</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.105 Introductory Chemistry Lab I</td>
<td>1</td>
<td>AS.030.106 Introductory Chemistry Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.101 General Physics: Physical Science Major I</td>
<td>4</td>
<td>AS.171.102 General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.111 General Physics Laboratory I</td>
<td>1</td>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.101 Chemical Engineering Today</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanities/Social and Behavioral Sciences Elective</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17</strong></td>
<td><strong>Total</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

### Sophomore

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.202 Introduction to Chemical &amp; Biological Process Analysis</td>
<td>4</td>
<td>EN.540.203 Engr Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.490 Chemical Laboratory Safety</td>
<td>1</td>
<td>EN.540.303 Transport Phenomena I</td>
<td>3</td>
</tr>
<tr>
<td>AS.110.202  Calculus III</td>
<td>4</td>
<td>AS.110.302 Diff Equations/Applic</td>
<td>4</td>
</tr>
<tr>
<td>AS.020.305  Biochemistry</td>
<td>4</td>
<td>EN.540.307 Cell Biology for Engineers</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.205  Organic Chemistry I</td>
<td>4</td>
<td>Undesignated Elective</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17</strong></td>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
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</tbody>
</table>

### Senior

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.301 Kinetic Processes</td>
<td>3</td>
<td>EN.540.304 Transport Phenomena II</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.307 Physical Chemistry Instrumentation Laboratory III</td>
<td>2-3</td>
<td>EN.540.306 Chemical &amp; Biomolecular Separation</td>
<td>3</td>
</tr>
<tr>
<td>Humanitites/Social and Behavioral Sciences Elective</td>
<td>3</td>
<td>Engineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Elective</td>
<td>3</td>
<td>Advanced Chem/Bio Elective</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>15-16</strong></td>
<td><strong>Total</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

### Tracks

**Molecular and Cellular Bioengineering (MCB) Track**

Students must fulfill the following requirements:
- Students take either AS.020.306 Cell Biology or EN.540.307 Cell Biology for Engineers.
- The Advanced Chemistry and Biology laboratory requirement is fulfilled with AS.020.315 Biochemistry Laboratory or AS.250.253 Protein Engineering and Biochemistry Lab.
- Six credits of bioengineering electives are required. See department for a list of approved electives.
- Students take EN.540.313 Chemical and Biomolecular Engineering Lab instead of EN.540.311 Chemical Engineering Lab I.

**Molecular and Cellular Bioengineering (IN) Focus Area**

Students must fulfill the following requirements
- Students take EN.540.204 Applied Physical Chemistry.
- The Advanced Chemistry and Biology laboratory requirement is fulfilled with AS.030.307 Physical Chemistry Instrumentation Laboratory III.
- AS.030.452 Materials & Surface is required and satisfied three credits of the advanced chemistry electives.
- Six credits of interfaces and nanotechnology electives are required. See department for a list of approved electives.

### Sample Program: Molecular and Cellular Bioengineering Track

#### Freshman

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
</tr>
<tr>
<td>AS.030.105</td>
<td>Introductory Chemistry II</td>
</tr>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
</tr>
<tr>
<td>AS.171.101</td>
<td>General Physics: Physical Science Major I</td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
</tr>
<tr>
<td>EN.540.101</td>
<td>Chemical Engineering Today</td>
</tr>
</tbody>
</table>

#### Sophomore

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.202</td>
<td>Introduction to Chemical &amp; Biological Process Analysis</td>
</tr>
<tr>
<td>EN.540.490</td>
<td>Chemical Laboratory Safety</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
</tr>
<tr>
<td>AS.020.305</td>
<td>Biochemistry</td>
</tr>
<tr>
<td>AS.030.205</td>
<td>Organic Chemistry I</td>
</tr>
</tbody>
</table>

#### Senior

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.313</td>
<td>Chemical and Biomolecular Engineering Lab</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
</tr>
<tr>
<td>EN.540.305</td>
<td>Chemical and Biomolecular Engineering Lab</td>
</tr>
<tr>
<td>EN.540.314</td>
<td>ChemBE Product Design</td>
</tr>
<tr>
<td>EN.540.306</td>
<td>Process Design with Aspen</td>
</tr>
</tbody>
</table>

#### Total Credits: 128

### B.S./M.S.E. Program in Chemical and Biomolecular Engineering

The B.S./M.S.E. program in Chemical and Biomolecular Engineering allows students to obtain a master of science in engineering immediately after the bachelor of science degree by adding at least one year of study. For students who qualify academically, the Whiting School of Engineering allows a 50 percent waiver after the completion of eight semesters or having received the Bachelor of Science degree.

### Master of Science in Engineering

Students have two options in pursuing an M.S.E. in Chemical and Biomolecular Engineering.

1. Master of Science in Engineering (requiring an essay)
   - The student must complete six graduate (600-799) level courses approved by the student’s research advisor. The student and advisor select these courses to design a curriculum appropriate for the student’s research interest and educational goals.
   - These six courses cannot include seminars, independent study, graduate research, or special studies.
   - At least four of the six courses must be in the Department of Chemical and Biomolecular Engineering.
   - Students are allowed to count 400-level courses toward their M.S.E. degree if (1) the course is not offered at the 600-level, and (2) if the department offering the course considers it to be a graduate-level course in their program. Courses offered at both the 400- and 600-level must be taken at the 600-level to fulfill M.S.E. course requirements. All ChemBE coursework must be taken at the 600-level.
• The student must also enroll in at least one semester of graduate seminars EN.540.600 Chemical and Biomolecular Engineering Seminar and EN.540.601 Chemical and Biomolecular Engineering Seminar throughout his or her tenure in the Department of Chemical and Biomolecular Engineering at Johns Hopkins University.

• Students must have a B average in coursework to complete this degree.

• No D grade in ChemBE courses can be counted towards the requirements. In a given semester, one D grade, one F grade, or two C grades will result in probation. Once on probation, an additional grade of C or below will result in termination from the program.

• Students must remain in good research standing with his or her research advisor. Failure to do so will result in probation and transfer to the coursework M.S. program.

• The student must write an essay based on original research and literature review and present his or her results at an open seminar attended by the faculty and students. The essay must be approved by the departmental graduate committee which consists of the graduate research advisor and at least one more faculty member from the Department of Chemical and Biomolecular Engineering.

2. Master of Science in Engineering (course work only)

• The student must complete ten graduate (600-799) level courses approved by the Director of Graduate Studies. The student and Director of Graduate Studies select these courses to design a curriculum appropriate for the student’s interest and educational goals.

• These ten courses cannot include seminars, independent study, graduate research or special studies.

• At least six of the ten courses must be in the Department of Chemical and Biomolecular Engineering.

• Students are allowed to count 400-level courses toward their M.S.E. degree if (1) the course is not offered at the 600-level, and (2) if the department offering the course considers it to be a graduate-level course in their program. Courses offered at both the 400- and 600-level must be taken at the 600-level to fulfill M.S.E. course requirements. All ChemBE coursework must be taken at the 600-level.

• The student must also enroll in at least one semester of graduate seminars (EN.540.600 Chemical and Biomolecular Engineering Seminar/EN.540.601 Chemical and Biomolecular Engineering Seminar) throughout his or her tenure in the Department of Chemical and Biomolecular Engineering at Johns Hopkins University.

• Students must have a B average in coursework to complete this degree.

• No D grade in ChemBE courses can be counted towards the requirements. In a given semester, one D grade, one F grade, or two C grades will result in probation. Once on probation, an additional grade of C or below will result in termination from the program.

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Recommended courses for all M.S.E. students

Completion of two of the four core courses of the Ph.D. program is recommended (but not required) for M.S.E. students. The four core Ph.D. courses are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.630</td>
<td>Thermodynamics, Statistical Mechanics, and Kinetics</td>
</tr>
<tr>
<td>EN.540.652</td>
<td>Advanced Transport Phenomena</td>
</tr>
<tr>
<td>EN.540.602</td>
<td>Metabolic Systems Biotechnology</td>
</tr>
<tr>
<td>EN.540.615</td>
<td>Interfacial Science with Applications to Nanoscale Systems</td>
</tr>
</tbody>
</table>

Additional information and requirements can be found in the department Graduate Handbook.

Doctor of Philosophy

The Ph.D. degree is awarded for original research performed under the guidance of a thesis advisor. The formal requirements for this degree are:

1. Successful completion of six graduate-level courses including the four required core courses.
2. Successful completion of the Preliminary Research Exam during the student’s first year.
3. Successfully serve as a teaching assistant for at least two required undergraduate courses.
4. Completion of an original research project, documented in a dissertation that is defended by the candidate in a public presentation.
5. Successful completion of the Graduate Board Oral Exam.

Course Work

Student must successfully complete six graduate-level courses including the four required core courses listed below:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.630</td>
<td>Thermodynamics, Statistical Mechanics, and Kinetics</td>
</tr>
<tr>
<td>EN.540.652</td>
<td>Advanced Transport Phenomena</td>
</tr>
<tr>
<td>EN.540.602</td>
<td>Metabolic Systems Biotechnology</td>
</tr>
<tr>
<td>EN.540.615</td>
<td>Interfacial Science with Applications to Nanoscale Systems</td>
</tr>
</tbody>
</table>

Students are strongly encouraged to take the four required courses in the first fall semester. However, students who do not have an undergraduate degree in Chemical Engineering or a closely related field may need additional courses and should discuss an appropriate course plan with the director of the graduate program.

The remaining two engineering or science courses are chosen with the help of the student’s advisor to design a curriculum appropriate for the student’s research interest. These two courses cannot include seminars, independent study, graduate research or special studies.

Each of the six courses must be passed with a letter grade of B- or higher. In addition, the student must maintain an overall grade point average (GPA) of 3.0 or better. If the student’s GPA falls below 3.0, the student must re-take one or more of the courses and earn a higher grade, upon which the prior grade in those courses are not counted toward the GPA. If a student receives a grade of C+ or lower in a
required core course, the student will be allowed to re-take the course once to achieve a grade of B- or higher. Failure to receive a B- or better the second time will be cause for dismissal from the program. Receipt of grades of C+ or lower in two or more required courses will ordinarily be cause for dismissal from the program without the opportunity to re-take those courses.

In addition:
• all first year students must enroll in EN.500.401 Research Laboratory Safety during their first semester.
• students must enroll in graduate seminars (EN.540.600 Chemical and Biomolecular Engineering Seminar/EN.540.601 Chemical and Biomolecular Engineering Seminar) every semester. Students are expected to attend department seminars throughout their tenure in the department.

Ph.D. Thesis Criteria and Graduate Board Oral Exam
Candidates must write a dissertation conforming to university requirements that describes the students work and results in detail. A public defense of the dissertation is required, and will be followed by a closed examination session. Because the closed examination session fulfills the university Graduate Board Oral (GBO) examination requirement, all procedures pertaining to GBOs as established by the University Graduate Board must be followed.

Additional information can be found in the department Graduate Handbook.

For current faculty and contact information go to http://www.jhu.edu/chembe/faculty-staff/

Faculty
Chair
Konstantinos Konstantopoulos
Professor: cell and molecular engineering; cell signaling, adhesion and migration; microfluidics; nanobioengineering; cancer metastasis.

Professors
Michael J. Betenbaugh
Professor: genomics, recombinant DNA biotechnology, biopharmaceuticals, metabolic engineering, insect and mammalian cell culture, glycosylation engineering, and cell death processes.

Michael A. Bevan
Professor and Director of Graduate Studies: colloidal interactions, dynamics, assembly, nanoparticle materials and devices, biomacromolecular interactions

Marc D. Donohue
Professor: phase equilibria, statistical thermodynamics, kinetics of diffusion and phase transitions, adsorption.

David Gracias
Professor: micro and nanotechnology, surface science, metamaterials, complex systems, nanoelectronics, nanomedicine, regenerative medicine, drug delivery and microfluidics.

Professor and Director of Graduate Admissions: biomolecular modeling, protein-protein docking, therapeutic antibodies, allostery, protein-surface interactions and design.

Marc A. Ostermeier
Professor: biomolecular engineering, molecular evolution, protein engineering, combinatorial methods, biosensors, protein therapeutics.

Denis Wirtz
Professor and Vice Provost for Research: cell adhesion and migration, cell mechanics, cytoskeleton, receptor-ligand interactions, cancer, particle tracking, new proteomics tools.

Associate Professors
Sharon Gerecht
Associate Professor: embryonic and adult stem cells, vascular regeneration, micro/nano fabrication, biomaterials, tissue engineering.

Joelle Frechette
Associate Professor and Director of Master's Studies: properties of surfaces, thin films; fluid interfaces and confined fluids; measurements of surface forces and adhesion; micro and nanotechnology; microfluidics; nanoparticles.

Assistant Professors
Honggang Cui
Assistant Professor: nanoscience and nanotechnology, biomolecular engineering, peptide synthesis and assembly, drug delivery, supramolecular polymers, nanoparticle imaging, diagnosis, and cancer therapeutics.

Zachary Gagnon
Assistant Professor: electrokinetic phenomena in micro/nanofluidic environments, cell signaling, cell migration, micro/nano fabrication, dielectrophoresis, biological separation, manipulation and characterization in microdevices.

Rebecca Schulman
Assistant Professor: nanotechnology, self-assembly, theory and experiment, nucleation, bionanotechnology, DNA, nanoelectronics, biomolecular engineering, single-molecular analysis.

Chao Wang
Assistant Professor: heterogenous catalysis, renewable energy technologies e.g., photoelectrochemical solar cells and lithium batteries, and green chemical engineering.

Senior Lecturer
Lise Dahuron
Senior Lecturer and Director of Undergraduate Studies: separations, distillation, membrane technology, new product development, process design.

An Goffin
Senior Lecturer: fluid and bioactive interfaces, kinetic processes, principles in chemical engineering, product design.

Professor Emeritus
Joseph L. Katz
Professor Emeritus: nucleation processes (e.g., condensation of supersaturated vapors, boiling of superheated liquids and its applications, e.g., the Ouzo effect, parts per quad-rillion detection)
formation of nanosized ceramic oxide powders in flames, new proteomics tools.

**Research Professor**
Gregory Aranovich
Research Professor: molecular thermodynamics, phase equilibria, adsorption phenomena, separation processes, and diffusion.

**Assistant Research Professor**
Daniele Gilkes
Eva Lai
Assistant Research Professor: biomedical sciences, biomonitoring technologies, regenerative medicine, tissue engineering.

**Adjunct Professor**
Joseph Shiloach
Senior Investigator, National Institute of Diabetes and Digestive and Kidney Diseases

**Adjunct Assistant Professor**
Jerry S. H. Lee
Program Director, National Cancer Institute and National Institute of Health

**Associate Research Professor**
George Oyler

**Adjunct Assistant Research Scientist**
Sai Prakash

**Joint, Part-Time and Visiting Appointments**
Steven An
Associate Professor, Johns Hopkins University Bloomberg School of Public Health

Patrick Brysse
Professor, Johns Hopkins University School of Medicine, Division of Environmental Health Engineering

Jennifer Elissseff
Professor, Johns Hopkins University School of Medicine, Department of Ophthamology Director of the Translational Tissue Engineering Center

Jonah Erlebacher
Professor & Chair, Johns Hopkins University Whiting School of Engineering, Materials Science and Engineering

Justin Hanes
Lewis J. Ort Professor of Ophthamology, Johns Hopkins University School of Medicine, Ophthamology

John Isaacs
Professor, Johns Hopkins University, School of Medicine

Rong Li
Bloomberg Distinguished Professor, Cell Biology & Chemical and Biomolecular Engineering

Kenneth Pienta
Professor, Johns Hopkins University School of Medicine, Urology Research

Martin Pomper
Professor, Johns Hopkins University School of Medicine, Radiology

Kannan Rangaramanujam
Professor, Johns Hopkins University School of Medicine, Opthamology

Doug Robinson
Professor, Johns Hopkins University School of Medicine, Cell Biology

Peter Searson
Professor, Johns Hopkins University Whiting School of Engineering, Materials Science and Engineering

Jin Zhang
Professor, Johns Hopkins University School of Medicine, Pharmacology

For current course information and registration go to https://isis.jhu.edu/classes/

**Courses**

**EN.540.101. Chemical Engineering Today.**
A series of weekly lectures to introduce students to chemical and biomolecular engineering and its role as a profession in addressing contemporary technological, social, ethical, and economic issues in today’s world. The lectures will include examples of how chemical and biomolecular engineers apply the principles of physics and chemistry to develop new products, improve process efficiencies, and alleviate the strain on the ecosystem through the design of novel environmentally conscious processes. In addition, the lectures will highlight exciting new areas now being advanced by chemical and biomolecular engineers, such as biochemical engineering, tissue engineering, nanoparticle fabrication, and processing smart polymers for applications in computer technology and as sensors. Freshmen Only.

Instructor(s): L. Dahuron
Area: Engineering.

**EN.540.111. Introduction to Programming for ChemBEs: Matlab Made Easy.**
Computer programming is as crucial a tool for modern engineering as calculus. Engineers use computers for almost everything: from design and manufacturing in industry to data collection and analysis in research. In this course, students will use a piece of popular engineering software, Matlab, to learn the fundamentals of programming. We will start simple, exploring such questions as: What is a program? How can we use loops and branches to accomplish a task? What exactly is Matlab doing when it’s running a script? Finally, we will build upon the fundamentals of programming to tackle relevant engineering problems. This course will help ChemBE students excel in subsequent engineering courses, such as Modeling and Statistics for ChemBEs, Separations, and Chemical Kinetics, by giving students’ knowledge of the tool that helps solve complex engineering problems.

Instructor(s): D. Scalise; J. Zenk
Area: Engineering.
Introduction to chemical and biomolecular 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, multi-unit processes will be emphasized. Introduction to the basic concepts of thermodynamics as well as chemical and biochemical reactions.
Prerequisites: Prereqs: ( AS.030.101 OR AS.030.103 ) AND ( AS.171.101 OR AS.171.107 ) AND ( AS.030.102 OR AS.030.103 OR AS.110.109 OR AS.171.102 )
Instructor(s): J. Gray; L. Dahuron
Area: Engineering.

EN.540.203. Engr 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 and biomolecular process-related systems. Extensive use is made of classical thermodynamic relationships and constitutive equations for one and two component systems. Applications include the analysis and design of engines, refrigerators, heat pumps, compressors, and turbines.
Prerequisites: EN.540.202
Instructor(s): C. Wang
Area: Engineering.

EN.540.204. Applied Physical Chemistry.
The topics in this course include thermodynamic models for multicomponent phase equilibrium including vapor liquid equilibrium, phase diagrams, activity models and colligative properties in both non-electrolyte and electrolyte solutions. A link between average thermodynamic properties and microstates and molecular interactions is made via a discussion of intermolecular forces and the partition function. Also covered are thermodynamic relationships to describe chemical equilibria, and basic concepts in quantum mechanics and statistical mechanics.
Prerequisites: EN.540.203.
Instructor(s): D. Gracias
Area: Engineering.

This course will engage students with a variety of physical and biological phenomena as they relate to fictional creatures such as dragons. This course seeks to serve as an exercise on applying engineering knowledge of transport phenomena, genetic modification and expression, metabolic networks, and biochemical reactions into a cohesive, refreshing look at creatures of myth and literature. Course is designed to be accessible for students of all backgrounds.
Area: Natural Sciences.

The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfills societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

The courses 540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfills societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.301. Kinetic Processes.
Review of numerical methods applied to kinetic phenomena and reactor design in chemical and biological processes. Homogeneous kinetics and interpretation of reaction rate data. Batch, plug flow, and stirred tank reactor analyses, including reactors in parallel and in series. Selectivity and optimization considerations in multiple reaction systems. Non isothermal reactors. Elements of heterogeneous kinetics, including adsorption isotherms and heterogeneous catalysis. Coupled transport and chemical/biological reaction rates.
Prerequisites: EN.540.203 AND EN.540.303
Instructor(s): A. Goffin
Area: Engineering.

EN.540.303. Transport Phenomena I.
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 non isothermal and multi component equations 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. Recommended Corequisite: AS.110.302, Introduction to the field of transport phenomena.
Instructor(s): K. Konstantopoulos
Area: Engineering.
EN.540.304. Transport Phenomena II.
Prerequisites: EN.540.303.
Instructor(s): Z. Gagnon
Area: Engineering.

EN.540.305. Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers.
This course seeks to build the student’s strength in Chemical Engineering computing and data analysis. To this end, in the first part of the course, we will become familiar with the Matlab/Octave computing environment and solve problems in Chemical Engineering that involve concepts from Process Analysis, Thermodynamics, Transport Phenomena, and Kinetics. In the subsequent part, we will build on the skills learnt earlier and tackle problems in Data Analysis and Hypothesis testing. Recommended Corequisites: EN.540.203 and EN.540.303 and EN.540.304.
Prerequisites: EN.540.202 OR AS.110.302
Instructor(s): R. Schulman
Area: Engineering.

This course covers staged and continuous-contacting separations processes critical to the chemical and biochemical industries. Separations technologies studied include distillation, liquid-liquid extraction, gas absorption, membrane ultrafiltration, reverse osmosis, dialysis, adsorption, and chromatography. Particular emphasis is placed on the biochemical uses of these processes and consequently on how the treatment of these processes differs from the more traditional approach.
Prerequisites: EN.540.303 AND EN.540.202 AND EN.540.203; Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): M. Betenbaugh
Area: Engineering.

This course explores fundamental structural details and molecular functions of different parts of the cell. Considerable emphasis is placed on experimental/quantitative approaches to answering these questions. Topics include Central dogma and the nucleus; protein trafficking; ion transporters; cytoskeleton; molecular motors; cell cycle and cell division; signal transduction, cell growth and cancer; cell death, the extracellular matrix; cell adhesion, cell junctions and epithelium; and muscle contraction, cell motility and morphogenesis.
Prerequisites: Cell Biology restriction: students who have completed AS.020.306 may not enroll.
Instructor(s): J. Yang; X. Chan
Area: Natural Sciences.

This course guides the student through the steps of product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill the needs. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the primary objectives of the course. Students report several times both orally and in writing on their accomplishments. This course is the first part of a two-semester sequence that optionally can be taken instead of EN.540.314 Chemical and Biomolecular Engineering Product Design. The material covered is the same as in EN.540.314, but more time is allowed so that laboratory tests can be performed and/or prototypes can be made. Note that students must take 540.310 to complete this sequence and before receiving credits for 540.309. Recommended Course Background: EN.540.301, EN.540.304, EN.540.311 or EN.540.313 or permission of instructor.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): M. Donohue
Area: Engineering.

This course is one part of a two semester sequence that optionally can be taken instead of This course is the second part of a two semester sequence (with EN.540.309) that optionally can be taken instead of EN.540.314 Chemical and Biomolecular Engineering Product Design. Students continue to work with their team on their product design project. Students report several times both orally and in writing on their accomplishments. The material covered is the same as in EN.540.314, but more time is allowed so that laboratory tests can be performed and/or prototypes can be made. Note that both courses, EN.540.309 and EN.540.310 must be taken to satisfy the Undergraduate degree requirement of the Chemical and Biomolecular Engineering program. The two courses can be started in any term. Recommended Course Background: EN.540.301, EN.540.304, EN.540.311 or EN.540.313 or permission of instructor.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.540.311. Chemical Engineering Lab I.
This course guides students with laboratory projects that are not well-defined. Students work in groups to develop an effective approach to experiments. They identify the important operating variables, decide how best to obtain them using measured or calculated values. Based on their results they predict, carryout, analyze and improve experiments. Each student analyzes three of the following projects: distillation, gas absorption, and one of the projects in EN.540.313. In addition to technical objectives, this course stresses oral and written communication. Students will have additional meeting times with the instructors and some writing professors outside of class.
Prerequisites: EN.540.301, EN.540.304, EN.540.306, EN.540.490 and EN.661.315
Instructor(s): A. Goffin; L. Dahuron
Area: Engineering.
EN.540.312. Chemical and Biomolecular Engineering Lab: Part 2.
Students who, as a part of an exchange program, participated in a laboratory course at the Technical University of Denmark at Copenhagen during the summer are required to register for this course to complete their equivalency requirement for the Chemical and Biomolecular Engineering Laboratory course offered in fall at JHU. The final grade for this course will incorporate the DTU grade. In addition, students perform one experimental project and submit a full professional report along with the current Senior Lab students. Students make a 15-min presentation to the junior class about their projects and of their experience in Denmark. Recommended Course Background: EN.540.301, EN.540.304, EN.540.306, EN.540.490, EN.661.315
Instructor(s): L. Dahuron
Area: Engineering.

EN.540.313. Chemical and Biomolecular Engineering Lab.
This course challenges students with laboratory projects that are not well-defined. Students work in groups to develop an effective approach to experiments. They identify the important operating variables, decide how best to obtain them using measured or calculated values. Based on their results they predict, carryout, analyze and improve experiments. Each student analyzes at least two of the following biomolecular projects: bioreactor, biocatalysis and membrane separation and one of the projects in EN.540.311. In addition to technical objectives, this course stresses oral and written communication. Students will have additional meeting times with the instructors and some writing professors outside of class.
Instructor(s): A. Goffin; L. Dahuron; M. Ostermeier; S. Gerecht
Area: Engineering.

This course guides the student through the contrasting aspects of product design and of process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill the needs. Process design concerns the quantitative description of processes, which serve to produce many commodity chemicals, the estimation of process profitability, and the potential for profitability improvement through incremental changes in the process. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the primary objectives of the course. Students report several times both orally and in writing on their accomplishments.
Prerequisites: (EN.540.311 OR EN.540.312 OR EN.540.313) AND EN.540.301 AND EN.540.306
Instructor(s): A. Goffin; L. Dahuron
Area: Engineering.

Prerequisites: (EN.540.311 OR EN.540.312 OR EN.540.313) AND EN.540.301 AND EN.540.306
Instructor(s): A. Goffin; L. Dahuron
Area: Engineering.

The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

The courses EN.540.290, 291, 390, and 391 guide the students through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.400. Project in Design: Pharmacokinetics.
This design project will be to develop a chemical process model of the human body that can be used to understand the temporal distribution, spatial distribution and bioavailability of pharmaceutical drugs. The course (and software to be developed) will cover the spectrum of factors affecting pharmaceutical bioavailability including drug formulation, mode of dosing and dosing rate, metabolism and metabolic cascades, storage in fatty tissues, and diffusional limitations (such as in crossing the blood-brain barrier or diffusional differences between normal and cancerous cells). The goal is to develop a process model of the human body that will predict pharmaceutical bioavailability as a function of time and organ (or cell) type that will work for a wide variety of pharmaceuticals including small molecules, biologics, and chemotherapy agents.
Instructor(s): M. Donohue
Area: Engineering.
This course is a group design project (i.e. not a lecture course) to use chemical processing simulation tools (Aspen) to model a real-world process of interest to Chemical and Biomolecular Engineers. The goal of the project will be to develop a process model that is sufficiently complete and robust that it can be used to understand the important factors in the process design and/or operation. This design project is focused on the role alternative energy will play in our country’s future. About a third of the course will be devoted to understanding the role of energy and alternative energy in the US and world economies. The remainder of the course will be devoted to a technical and economic analysis of the feasibility of making biofuel from algae.
Instructor(s): M. Donohue
Area: Engineering.

The aim of this course is to provide a fundamental understanding of the quantitative principles and methodologies of systems biology and biochemical engineering of metabolism. This includes concepts of cellular growth, cellular stoichiometric models, metabolic networks, metabolite fluxes, and genome-scale metabolic models. Quantitative methods and systems biology approaches for metabolic flux analysis and metabolic control theory will be included as well as an analysis of biochemical systems and bioreactors including a consideration of mass transport processes.
Prerequisites: AS.020.306 OR ( EN.580.440 OR EN.580.441 ) OR EN.540.307
Instructor(s): M. Betenbaugh
Area: Engineering.

EN.540.403. Colloids and Nanoparticles.
Fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nano-science and technology will be discussed throughout the course with frequent references to recent literature.
Meets with EN.540.603
Instructor(s): M. Bevan
Area: Engineering.

EN.540.405. The Design of Biomolecular Systems.
This course covers new topics in the design of systems of biomolecules, both in vitro and in vivo, for decision making and control. The course will begin with an overview of how logical decision making and control with biomolecules as is achieved in biology and then proceed to consider various strategies of engineering similar systems. The focus of the course will be on systems level principles rather than the biochemistry of molecule design. Topics will include engineering of transcriptional networks and genetic control for logically programming of cells, the design of in vitro mimics of genetic controls, molecular computing and systems aspects of metabolic engineering. The course will also cover quantitative and computational techniques for the simulation and analysis of biomolecular systems. Co-listed with EN.540.605
Instructor(s): R. Schulman.

This course describes the most recent progress in molecular self-assembly, with a focus on the application aspects of self-assembling materials in medical and energy-related areas. Specifically, the course consists of about twelve lectures covering a broad range of topics, including: principles of static and dynamic molecular assembly, nanomaterials and phase/morphology diagrams of small molecular and macromolecular amphiphiles, self-assembly in biological systems, supramolecular polymers for energy and medicine, key challenges in the fabrication of organic solar cells, and self-healing materials. The class will be taught in a seminar format, with discussions led by graduate students or postdocs. Instructor permission required. Juniors and Seniors only.
Instructor(s): H. Cui
Area: Engineering, Quantitative and Mathematical Sciences.

Introduction to modeling, dynamics, and control. Unsteady state analysis of biomolecular and chemical process control systems. State space and Laplace transform techniques, block diagram algebra, and transfer functions. Feedback and feedforward control. Frequency response and stability analysis. Model construction for biomolecular and cellular systems including pharmacokinetic modeling, biomolecular modeling using the central dogma of biology/control of gene expression, large scale biosimulation. Introduction to nonlinear dynamics.
Recommended Corequisites: AS.110.302, EN.540.203, EN.540.301, EN.540.303, AS.020.305 and AS.020.306 or equivalent.
Instructor(s): A. Goffin
Area: Engineering, Quantitative and Mathematical Sciences.

EN.540.414. Computational Protein Structure Prediction and Design.
This class will introduce the fundamental concepts in protein structure, biophysics, optimization and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, design of protein interfaces. Class will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project. Programming experience is recommended.
Instructor(s): J. Gray
Area: Engineering.

EN.540.415. Interfacial Science with Applications to Nanoscale Systems.
Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid-fluid interfaces with solid-fluid and solid-solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.
Instructor(s): J. Frechette
Area: Engineering.
This course will consist of student-led discussions of current literature in protein structure prediction, protein-protein docking, and computational protein design. Related advanced computational approaches of the Rosetta3 protein structural modeling platform will be discussed and object-oriented software design concepts dissected. Students will present and critique C++ and Python code and scripts corresponding to related research projects. Permission of Instructor Required
Instructor(s): J. Gray.

EN.540.418. Projects in the Design of a Chemical Car.
Ready to put those concepts from class into practice? Members work over the course of the semester to design and construct a chemically powered vehicle that will compete with other college teams at the American Institute of Chemical Engineers (AIChE) Regional Conference. In this course, the students work in small groups to design and construct the chassis along with chemically powered propulsion and break mechanisms within the constraints of the competition. In addition, students will give oral presentation, write reports, and do thorough safety analysis of their prototypes. Both semesters must be completed with passing grades to receive credit. Instructor Approval Only.
Instructor(s): L. Dahuron
Area: Engineering.

EN.540.419. Projects in the Design of a Chemical Car.
Ready to put those concepts from class into practice? Members work over the course of the semester to design and build a chemically powered vehicle that will compete with other college teams at the American Institute of Chemical Engineers (AIChE) Regional Conference. In this course, the students work in small groups to design and construct the chassis along with chemically powered propulsion and break mechanisms within the constraints of the competition. In addition, students will give oral presentation, write reports, and do thorough safety analysis of their prototypes.
Instructor(s): L. Dahuron.

EN.540.421. Project in Design: Pharmacodynamics.
This course covers pharmacodynamics, i.e. how pharmaceuticals affect biological processes. The course will use MatLab to aid in the design of new drug formulations.
Instructor(s): M. Donohue
Area: Engineering.

EN.540.422. Introduction to Polymeric Materials.
Polymeric materials are ubiquitous in our society from Nature-made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumable to high performance materials used in critically demanding areas, such as aviation, aerospace and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (“green polymer chemistry”) will also be covered. Lectures on functional polymers will be focused on their unique properties that are enabled by rational molecular design, controlled synthesis and processing (e.g. supramolecular assembly, and microfabrication). This class of specialty materials can find their use in high performance photovoltaics, batteries, membranes, and composites, and can also serve as “smart” materials for use in coatings, sensors, medical devices, and biomimicry.
Prerequisites: AS.030.205 or by instructor permission.
Instructor(s): H. Cui; K. Qi
Area: Engineering.

EN.540.426. Biomacromolecules at the Nanoscale.
This course introduces modern concepts of polymer physics at the nanoscale to describe the conformation and dynamics of biological macromolecules such as filamentous actin, microtubule, and nucleic acids. We will introduce scattering techniques, nano-manipulation techniques, as well as nano-rheology applied to the study of polymers for tissue engineering, nanoparticles, and drug delivery applications.
Instructor(s): D. Wirtz
Area: Engineering.

EN.540.428. Supramolecular Materials and Nanomedicine.
Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering.
Three major topics will be discussed, including 1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides), 2) inorganic nanostructures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes), and 3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should gain a deeper understanding of current challenges in translating nanoscience and nanotechnology.
Instructor(s): H. Cui
Area: Engineering, Natural Sciences.
One semester overview of year long course, students that want a comprehensive understanding of pharmacokinetics and pharmacodynamics should take the 2 courses EN.540.400 and EN.540.421. This course covers the principles of pharmacokinetics and pharmacodynamics. Computer models ofpharmacokinetic and pharmacodynamics behavior will be developed and then used to design better drug delivery regimens and to analyze drug chemotherapy modifications.
Instructor(s): M. Donohue
Area: Engineering, Natural Sciences.

EN.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 implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biopolymers (i.e. protein engineering, RNA/DNA engineering), genetic circuits and complex biological systems including cells. Meets with EN.540.637
Instructor(s): M. Ostermeier
Area: Engineering, Natural Sciences.

The field of micro / nanotechnology has been gaining tremendous momentum as evidenced by an explosive rise in the number of publications, patents and commercial activities. This is an introductory course intended to expose students to the field as well as real world applications. Lectures will include an overview of scaling of material properties at the nanoscale, micro and nanofabrication methods and essential analytical tools of relevance to the field. All through the course, we will go over electronic, optical and biological applications of emerging micro and nanoscale devices and materials. Co-listed with EN.540.640.
Instructor(s): D. Gracias
Area: Engineering.

EN.540.443. Topics in Vascular Engineering.
In-depth discussion and hands-on course focused on engineering approaches for vascular regeneration. The course will focus on engineering principles of the vasculature including induction of differentiation and administration of cell therapies. Seminal papers and approaches to analyze vascular tissues and cultures will be examined and discussed. Students will perform hands on experiments focused on vascular differentiation and regeneration. In addition, the course will be integrated with students’ presentations throughout the semester on selected topics in vascular engineering.
Instructor(s): S. Gerecht
Area: Engineering.

A selection of problems in fluid mechanics at low and moderate Reynolds numbers. This is a highly interactive class in which students are expected to choose topics and prepare a presentation at least twice a semester. Therefore, the list of problems will vary depending on student selection. Typically Tuesdays will be an introductory class and Thursdays will be seminars on a specific topic or paper. Meets with 540.647
Instructor(s): G. Drazer
Area: Engineering, Natural Sciences.

EN.540.449. Logic and Decision-making in Biomolecular Systems.
From the smallest change in gene expression to life and death and reproduction, biomolecular decision-making processes govern cellular fate. In this course we explore the design principles by which biomolecules make decisions and orchestrate complex processes such as signal transduction, homeostasis or apoptosis. We will also explore how we can in turn design complex biomolecular networks that can control biological systems and biomolecular materials.
Topics will include the design and analysis of molecular logic circuits, transcriptional and translational control, signal transduction cascades, biomolecular oscillators and cycles, DNA nanotechnology and nanobiotechnology, and molecular computing. The course will introduce principles from electrical circuit theory, computing and control theory and show how these tools can be applied to these systems. Students should be familiar with programming and chemical engineering principles.
Instructor(s): R. Schulman
Area: Engineering, Natural Sciences.

This course involves integrated lecture/discussion and laboratory components to review and participate in current and emerging topics involving eukaryotic biotechnology. Lectures and discussions review how fundamentals of biochemical kinetics and biomolecular engineering are connected to emerging problems in mammalian, algal, and stem cell biotechnology. Laboratory activities are connected to diverse scientific and technological fundamental topics on these same themes. Journal article and research presentations provide a context for laboratory activities with respect to emerging industrial applications for eukaryotic cell types. Research design and strategy is discussed in terms of its ultimate implementation in laboratory, pilot plant, and eventually manufacturing facilities. Methodologies implemented include cell and metabolic engineering for improving yields and production rates of proteins, cells, and tissues. Example topics include expansion of mammalian, stem cells, and algae for the production of membrane proteins, biologics, biofuels, and complex metabolites.
Instructor(s): M. Betenbaugh.

Introduction and in-depth discussion course focused on tissue and stem cell engineering. The course will focus on principles in tissue engineering, mechanisms of regeneration, and stem cell therapies.
Topics will include introduction to regenerative medicine, bioreactors and scaffolds in tissue engineering, adult and pluripotent stem cells, engineering the niche, and two sessions will focus on legal and ethical issues. Selected approaches to analyze tissues and stem cell culture will also be discussed. In addition, the course will be integrated with graduate students’ presentations on selected topics in stem cell engineering. Co-listed with EN.540.659 Recommended Course Background: AS.020.306 or EN.580.221.
Instructor(s): S. Gerecht
Area: Engineering.
EN.540.460. Computational and Experimental Design of Biomolecules.
This course reviews current research problems in biomolecular design both from computational and experimental approaches. Current methods in structure prediction (folding, docking and design) will illustrate fundamental concepts in protein structure, biophysics, and optimization. Current research problems in evolution-based biomolecular engineering will illustrate principles in the design of biomolecules (i.e. protein engineering, RNA/DNA engineering), metabolic pathways, signaling pathways, genetic circuits and complex biological systems including cells. Recommended Course Background: AS.020.305
Area: Engineering.

*Attendance to this course is limited to ChemBE students who are working in the instructors lab. This course focuses on the application of engineering fundamentals to cancer metastasis. Class lectures will include an overview of molecular biology fundamentals, an extensive review on extracellular matrix and basics of receptors, followed by topics on tumor cell-host cell and tumor cell-matrix interactions at both theoretical and experimental levels. Lectures will also cover the effects of physical (e.g. shear stress, strain) and chemical (e.g. cytokines, growth factors) stimuli on tumor cell function.
Instructor(s): K. Konstantopoulos
Area: Engineering.

This course will introduce students involved in cancer engineering research the fundamental elements of statistical mechanics relevant to tumor growth and progression to metastatic disease. Topics include: Fokker-Planck equation for collective cancer migration, tumor growth as a phase transition, and cancer cell motility in nth-dimension space.
Instructor(s): D. Wirtz.

This course involves integrated lecture/discussion and laboratory components to review and participate in current and emerging topics involving fluid mechanics and interfacial science. The lectures and discussions review how fundamentals of transport and interfacial science are connected to emerging problems in micro- and nanotechnologies. The focus area of the class is Electrokinetic Phenomena. The mandatory laboratory component is aimed at connecting the topics covered in the class to scientific problems. Student participation will involve presentation of laboratory results and research papers.
Instructor(s): G. Drazer; J. Frechette; Z. Gagnon.

This course involves integrated lecture/discussion and laboratory components to review and participate in current and emerging topics involving eukaryotic biotechnology. Lectures and discussions review how fundamentals of biochemical kinetics and biomolecular engineering are connected to emerging problems in mammalian, algal, and stem cell biotechnology. Laboratory activities are connected to diverse scientific and technological fundamental topics on these same themes. Journal article and research presentations provide a context for laboratory activities with respect to emerging industrial applications for eukaryotic cell types. Research design and strategy is discussed in terms of its ultimate implementation in laboratory, pilot plant, and eventually manufacturing facilities. Methodologies implemented include cell and metabolic engineering for improving yields and production rates of proteins, cells, and tissues. Example topics include expansion of mammalian, stem cells, and algae for the production of membrane proteins, biologics, biofuels, and complex metabolites.
Instructor(s): M. Betenbaugh
Area: Engineering.

EN.540.480. Current Topics in Eukaryotic Cell Biotechnology Part II.
This course involves integrated lecture/discussion and laboratory components to review and participate in current and emerging topics involving eukaryotic biotechnology. Lectures and discussions review how fundamentals of biochemical kinetics and biomolecular engineering are connected to emerging problems in mammalian, algal, and stem cell biotechnology. Laboratory activities are connected to diverse scientific and technological fundamental topics on these same themes. Journal article and research presentations provide a context for laboratory activities with respect to emerging industrial applications for eukaryotic cell types. Research design and strategy is discussed in terms of its ultimate implementation in laboratory, pilot plant, and eventually manufacturing facilities. Methodologies implemented include genomics, metabolic flux analysis, and cell and metabolic engineering for improving yields and production rates of proteins, cells, and tissues. Example topics include expansion of mammalian cells and algae for the production of membrane proteins, biologics, biofuels, and complex metabolites.
Instructor(s): M. Betenbaugh.

EN.540.490. Chemical Laboratory Safety.
This course is meant to provide the student with a basic knowledge of laboratory safety; hazards, regulations, personal protective equipment, good laboratory practice, elementary toxicology, and engineering controls. It has been developed by the Department of Chemical and Biomolecular Engineering to assist with regulatory compliance, minimize hazards, and reduce the severity of any incidents that may occur in the department’s laboratories. The course is a prerequisite of EN.540.311/EN.540.313. It is required of all Chemical and Biomolecular Engineering undergraduates. In addition once per year a three-hour refresher seminar must be taken by all students involved in laboratory research.
Instructor(s): D. Kuespert; L. Dahuron
Area: Engineering.

Instructor(s): J. Hanes.

Instructor(s): J. Frechette; K. Konstantopoulos; M. Donohue; M. Ostermeier; S. Gerecht.

EN.540.509. Undergraduate Internship.
Internship unpaid and approved by ChemBE faculty. Area: Engineering.
Instructor(s): Staff.

Instructor(s): Staff.

EN.540.574. Research-Intersession.  
Instructor(s): Staff.

EN.540.596. Summer Internship.  
Summer internship paid and approved by ChemBE faculty.  
Instructor(s): L. Dahuron; M. Betenbaugh.

EN.540.597. Research.  
Instructor(s): Staff.

EN.540.598. Summer Internship.  
Summer internship unpaid and approved by ChemBE faculty.  
Instructor(s): G. Drazier; H. Cui; Staff  
Area: Engineering, Natural Sciences.

EN.540.599. Independent Study - Summer.  
Instructor(s): J. Frechette; J. Hanes; M. Betenbaugh; M. Donohue.

EN.540.600. Chemical and Biomolecular Engineering Seminar.  
Lectures are presented on current subjects relevant to chemical engineering.  
Instructor(s): C. Wang.

EN.540.601. Chemical and Biomolecular Engineering Seminar.  
Instructor(s): C. Wang.

The aim of this course is to provide a fundamental understanding of the quantitative principles and methodologies of systems biology and biochemical engineering of metabolism. This includes concepts of cellular growth, cellular stoichiometric models, metabolic networks, metabolite fluxes, and genome-scale metabolic models. Quantitative methods and systems biology approaches for metabolic flux analysis and metabolic control theory will be included as well as an analysis of biochemical systems and bioreactors including a consideration of mass transport processes.  
Instructor(s): M. Betenbaugh.

EN.540.603. Colloids and Nanoparticles.  
Fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nano-science and technology will be discussed throughout the course with frequent references to recent literature.  
Meets with EN.540.403  
Instructor(s): M. Bevan  
Area: Engineering.

EN.540.604. Systems and Synthetic Chemical and Biomolecular Engineering.  
This course is intended for students in the ChemBE master's program. This course guides the student through the complex process of new product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill needs. Students work in small teams to develop a new product idea, design the product and then iterate on prototype development. Students report several times both orally and in writing on their accomplishments. Time is allowed so that laboratory tests can be performed and/or prototypes can be built. Note that generally both courses, 540.609 and 540.610 must be taken to complete the prototype development. The two courses can be started in any term.  
Instructor(s): M. Donohue  
Area: Engineering.

EN.540.605. The Design of Biomolecular Systems.  
This course covers new topics in the design of systems of biomolecules, both in vitro and in vivo, for decision making and control. The course will begin with an overview of how logical decision making and control with biomolecules as is achieved in biology and then proceed to consider various strategies of engineering similar systems. The focus of the course will be on systems level principles rather than the biochemistry of molecule design. Topics will include engineering of transcriptional networks and genetic control for logically programming of cells, the design of in vitro mimics of genetic controls, molecular computing and systems aspects of metabolic engineering. The course will also cover quantitative and computational techniques for the simulation and analysis of biomolecular systems. Co-listed with EN.540.405  
Instructor(s): R. Schulman.

Supervised Graduate Study  
Instructor(s): M. Donohue  
Area: Engineering.

EN.540.607. Chemical and Biomolecular Engineering Design: Spring.  
This course is one part of a two semester sequence in Chemical and Biomolecular Engineering Product Design. It is intended for students in the ChemBE master's program. This course guides the student through the complex process of new product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill needs. Students work in small teams to develop a new product idea, design the product and then iterate on prototype development. Students report several times both orally and in writing on their accomplishments. Time is allowed so that laboratory tests can be performed and/or prototypes can be built. Note that generally both courses, 540.609 and 540.610 must be taken to complete the prototype development. The two courses can be started in any term.  
Instructor(s): M. Donohue  
Area: Engineering.

EN.540.608. Chemical and Biomolecular Engineering Design: Fall.  
This course is one part of a two semester sequence in Chemical and Biomolecular Engineering Product Design. It is intended for students in the ChemBE master's program. This course guides the student through the complex process of new product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill needs. Students work in small teams to develop a new product idea, design the product and then iterate on prototype development. Students report several times both orally and in writing on their accomplishments. Time is allowed so that laboratory tests can be performed and/or prototypes can be built. Note that generally both courses, 540.609 and 540.610 must be taken to complete the prototype development. The two courses can be started in any term.  
Instructor(s): M. Donohue  
Area: Engineering.
EN.540.614. Computational Protein Structure Prediction and Design.
This class will introduce the fundamental concepts in protein structure, biophysics, optimization and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, design of protein interfaces. Class will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project. Programming experience is recommended.
Instructor(s): J. Gray
Area: Engineering.

EN.540.615. Interfacial Science with Applications to Nanoscale Systems.
Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid-fluid interfaces with solid-fluid and solid-solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.
Instructor(s): J. Frechette
Area: Engineering.

EN.540.616. Current Topics in Protein Structure Prediction.
Permission of instructor required.
Instructor(s): J. Gray.

This design project is focused on the role alternative energy will play in our country’s future. About a third of the course will be devoted to understanding the role of energy and alternative energy in the US and world economies. The remainder of the course will be devoted to a technical and economic analysis of the feasibility of making biofuel from algae. Graduate level. Meets with EN.540.401
Instructor(s): M. Donohue.

EN.540.621. Project in Design: Pharmacodynamics.
This course covers pharmacodynamics, i.e. how pharmaceuticals affect biological processes. The course will use MatLab to aid in the design of new drug formulations.
Instructor(s): M. Donohue.

EN.540.622. Introduction to Polymeric Materials.
Polymeric materials are ubiquitous in our society from Nature-made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumables to high performance materials used in critically demanding areas, such as aviation, aerospace and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (“green polymer chemistry”) will also be covered. Lectures on functional polymers will be focused on their unique properties that are enabled by rational molecular design, controlled synthesis and processing (e.g. supramolecular assembly, and microfabrication). This class of specialty materials can find their use in high performance photovoltaics, batteries, membranes, and composites, and can also serve as “smart” materials for use in coatings, sensors, medical devices, and biomimicry.
Instructor(s): H. Cui; K. Qi
Area: Engineering.

EN.540.626. Biomacromolecules at the Nanoscale.
This course introduces modern concepts of polymer physics at the nanoscale to describe the conformation and dynamics of biological macromolecules such as filamentous actin, microtubule, and nucleic acids. We will introduce scattering techniques, nano-manipulation techniques, as well as nano-rheology applied to the study of polymers for tissue engineering, nanoparticles, and drug delivery applications.
Instructor(s): D. Wirtz.

EN.540.628. Supramolecular Materials and Nanomedicine.
Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering. Three major topics will be discussed, including 1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides), 2) inorganic nanostructures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes), and 3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should gain a deeper understanding of current challenges in translating nanoscience and nanotechnology into medical therapies.
Instructor(s): H. Cui
Area: Engineering, Natural Sciences.
In this course we will aim for understanding the thermodynamics of chemical and bio-molecular systems. We will first review classical, macroscopic thermodynamics covering concepts such as equilibrium, stability and the role of thermodynamic potentials. Our goal will be to gain a feel for the generality of thermodynamics. Statistical mechanics provides a link between the mechanics of atoms and macroscopic thermodynamics. We will introduce this branch in two distinct ways: 1) following standard methods of developing concepts such as ensembles and partition functions, and 2) where we will treat the basis of statistical mechanics as a problem in inference. With this foundation, we will consider concepts relevant to understanding the liquid state. Chemical transformations in a liquid are of importance in much of chemistry and biology; quasi-chemical generalizations of the potential distribution theorem will be introduced to present these ideas. We hope to give an overview of modern developments relating equilibrium work to non-equilibrium work, as these are of increasing importance in studies on single molecule systems. Registration by instructor permission only. Instructor(s): C. Wang
Area: Engineering.

One semester overview of year long course, students that want a comprehensive understanding of pharmacokinetics and pharmacodynamics should take the 2 all 540.632 Projects in Design: Pharmacokinetics Spring 540.621 Projects in Design: Pharmacodynamics. This course covers the principles of pharmacokinetics and pharmacodynamics. Computer models ofpharmacokinetic and pharmacodynamics behavior will be developed and then used to design better drug delivery regimens and to analyze drug chemistry modifications. Instructor(s): M. Donohue
Area: Engineering.

EN.540.637. 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 implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biomolecules (i.e. protein engineering, RNA/DNA engineering), genetic circuits and complex biological systems including cells. Will meet with EN.540.437. Recommended Course Background: AS.020.305
Instructor(s): M. Ostermeier
Area: Engineering, Natural Sciences.

The field of micro / nanotechnology has been gaining tremendous momentum as evidenced by an explosive rise in the number of publications, patents and commercial activities. This is an introductory course intended to expose students to the field as well as real world applications. Lectures will include an overview of scaling of material properties at the nanoscale, micro and nanofabrication methods and essential analytical tools of relevance to the field. All through the course, we will go over electronic, optical and biological applications of emerging micro and nanoscale devices and materials. Co-listed with EN.540.440.
Instructor(s): D. Gracias.

This course will (1) focus on transport processes that are different or more prominent in microfabricated systems, (2) present practical aspects of experimental and theoretical work in microscale and nanoscale transport processes and (3) develop a working knowledge of the relevant literature. Some topics include Maxwell and Navier-Stokes equations, Couette/Poiseuille flow, Stokes flow, fluid circuits, microfluidic mixing, mass and charge transport, electrodynamics, electrophoresis, electro-osmosis, dielectrophoresis, induced-charge electrokinetics, DNA transport, and zeta potential.
Prerequisites: Prereq: EN.540.304 Transport II OR the equivalent. Instructor permission required.
Instructor(s): Z. Gagnon
Area: Engineering, Natural Sciences.

EN.540.645. Intro to Research in Micro and Nanotechnology.
A class room based learning of all aspects of conducting research in Micro and Nanotechnology including review of state-of-the-art in the field and original research descriptions. In the course, you will learn the state of the art in Micro and Nanotechnology, critical analysis of research including Design of Experiments, research ethics and strategies to deliver effective research presentations. Instructor Approval.
Instructor(s): D. Gracias.

A selection of problems in fluid mechanics at low and moderate Reynolds numbers. This is a highly interactive class in which students are expected to choose topics and prepare a presentation at least twice a semester. Therefore, the list of problems will vary depending on student selection. Typically Tuesdays will be an introductory class and Thursdays will be seminars on a specific topic or paper. Meets with 540.447
Instructor(s): G. Drazer
Area: Engineering, Natural Sciences.
EN.540.649. Logic and Decision-making in Biomolecular Systems.
From the smallest change in gene expression to life and death and reproduction, biomolecular decision-making processes govern cellular fate. In this course we explore the design principles by which biomolecules make decisions and orchestrate complex processes such as signal transduction, homeostasis or apoptosis. We will also explore how we can in turn design complex biomolecular networks that can control biological systems and biomolecular materials. Topics will include the design and analysis of molecular logic circuits, transcriptional and translational control, signal transduction cascades, biomolecular oscillators and cycles, DNA nanotechnology and nanobiotechnology, and molecular computing. The course will introduce principles from electrical circuit theory, computing and control theory and show how these tools can be applied to these systems. Students should be familiar with programming and chemical engineering principles.
Instructor(s): R. Schulman.

It is the goal of this course to move the graduate student (and advanced undergraduate student) from the introductory level of transport phenomena (undergraduate) to a level that will allow them to be effective in researching transport-related topics in a variety of biomedical, chemical and biochemical engineering areas. The basic equations that govern mass, momentum, and energy transport will be derived and used to solve problems that demonstrate the physical insight necessary to apply these equations to original situations. Some topics include solution techniques utilizing expansions of harmonic functions, singularity solutions, lubrication theory for flow in confined geometries, boundary layer theory, Stokes flow, forced convection, buoyancy-driven flow, Taylor-Aris dispersion, and reaction-diffusion.
Instructor(s): Z. Gagnon
Area: Engineering.

EN.540.659. Bioengineering in Regenerative Medicine.
Introduction and in-depth discussion course focused on tissue and stem cell engineering. The course will focus on principles in tissue engineering, mechanisms of regeneration, and stem cell therapies. Topics will include introduction to regenerative medicine, bioreactors and scaffolds in tissue engineering, adult and pluripotent stem cells, engineering the niche, and two sessions will focus on practical and ethical issues. Selected approaches to analyze tissues and stem cell culture will also be discussed. In addition, the course will be integrated with graduate students’ presentations on selected topics in stem cell engineering. Recommended Course Background: AS.020.306 or EN.580.221 or EN.580.440 Co-listed with EN.540.459
Instructor(s): S. Gerecht
Area: Engineering.

EN.540.661. Nanobioengineering Laboratory.
Students explore different experimental methodologies in Nanobioengineering. Students work in small teams to complete one or more major projects expanding their understanding and applying their theoretical knowledge to practical problems. The course will employ a variety of experimental methods, from material synthesis to biological applications. Students report several times either orally and in writing on their accomplishments. Project meetings may be held outside of the appointed class time. Graduate students only
Instructor(s): A. Goffin; J. Frechette.

In this graduate level course, we will cover important principles in thermodynamics and kinetics along with examples relevant to engineering practice. After a short review of the first and second law of thermodynamics, we will move on to their application in engines and refrigeration. We will discuss the thermodynamic properties of systems consisting of pure species and mixtures, and address phase equilibria. With the key thermodynamic concepts in place, we will discuss topics in kinetics, including the fundamentals of reaction rates, rate laws, multiple reactions and non-elementary reaction kinetics. Finally, we will address how reactor type and properties, transport limitations, and phase equilibria influence reaction rate.
Instructor(s): A. Goffin; C. Pereira.

EN.540.673. Advanced Chemical Reaction Engineering in Practice.
Chemical reaction engineering deals with the analysis on data and the design of equipment in which reactions occur. Reactors may contain one or more phases and be used to conduct chemical or biochemical transformations. The course will cover the fundamental aspects of kinetics, data acquisition, data interpretation, heterogeneous catalysis and heat and mass transfer for each type of reactor. Special emphasis will be placed on the practical application of reaction engineering in the petrochemical, chemical, biochemical and materials industries. The course will make student aware of the needs and opportunities for chemical reaction engineering in industry.
Instructor(s): C. Pereira.

EN.540.801. Graduate Research.
Instructor(s): Staff.

Instructor(s): M. Donohue.

EN.540.811. Graduate Independent Study.
Instructor(s): M. Donohue.

EN.540.871. Research - Intersession.

Cross Listed Courses
Institute for NanoBio Technology
This course will cover the physics and chemistry relevant to the design, synthesis, and characterization of nanoparticles. Topics include nanoparticle synthesis, functionalization, surface engineering, and applications in diagnostics and therapeutics. The properties of semiconductor quantum dots and magnetic nanoparticles will be reviewed along with techniques for nanoparticle manipulation, particle tracking, and bio-microscopy. Patterning tools including soft lithography, optical lithography, and electron microscopy will be discussed. Electron and scanning probe microscopy will be reviewed. Cross-listed with Materials Science & Engineering and Chemical & Biomolecular Engineering.
Instructor(s): Staff.