# PHYSICS

## Overview and Contact Information

Consulting with a departmental advisor, the student may design their major curriculum for various purposes. They may take the courses necessary to prepare for graduate study in physics or closely related fields (including engineering), or they may plan a program that, together with courses from other disciplines, prepares them for advanced work in medicine, environmental engineering, or other physical sciences or branches of engineering, as well as for secondary school teaching, technical writing, or technical positions in industry. Students interested in geophysics, astrophysics, materials science, biophysics, physical chemistry, and other similar programs can work out special majors in consultation with faculty in the appropriate departments.

## See Also

- Engineering (http://catalog.mtholyoke.edu/areas-study/engineering/)
- Dual-Degree in Engineering (http://catalog.mtholyoke.edu/other-programs/other-degree-certificate-programs/)

### Contact Information

**Kerstin Nordstrom, Chair**
**Loryn Engelbrecht, Academic Department Coordinator**

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413-538-2238
https://www.mtholyoke.edu/academics/find-your-program/physics (https://www.mtholyoke.edu/academics/find-your-program/physics/)

## Learning Goals

Graduating physics majors will be prepared for graduate work in the sciences and engineering, or a wide variety of careers in teaching, industry, or public service. Students will be prepared to:

- Apply their physical reasoning and analytic skills to tackle complex problems in a variety of academic, research, and innovative work environments; and alternative careers.
- Synthesize and apply sophisticated mathematical and physical models to complex, real-world problems.
- Apply knowledge and skills gained in the physics major toward broader goals, including social issues, environmental concerns, and daily problems.
- Engage in self-directed learning by consulting the necessary resources and building knowledge of their own strengths and weaknesses.
- Know when and how to quickly address challenging questions.
- Be a strong, confident physics major who embarks in the world and can apply their analytical skills to quickly address questions when appropriate and think deeply and at length when needed.

Physics majors will develop strong problem solving skills. Students will:

- Be able to plan an effective approach to challenging problems.
- Use proportional, conceptual, analytical, numerical, computational, and qualitative reasoning, distinguishing when each is appropriate.
- Learn to critically evaluate their assumptions, methodology and results, and to revise their approach as needed.
- Develop cooperative group problem solving skills, engaging in effective communication, planning and evaluation.
- Develop confidence and skills to independently solve complex problems.
- Develop the metacognitive skills required to engage in self-assessment of their own strategies and approaches.

Physics majors will develop strong technical skills. Students will:

- Develop strong mathematical skills required to address technical scientific problems.
- Gain hands-on experimental skills, including common methodology, experimental design, troubleshooting, analysis, and interpretation.
- Acquire computational skills, including numerical methods, implementation of models, visualization of results, and analysis of data sets.
- Understand how to read, interpret, and evaluate technical articles, and how to perform literature searches.

Physics majors will develop strong communication skills. Students will:

- Clearly articulate complex technical ideas in speech in preparation for both formal and informal scientific settings.
- Clearly articulate complex technical ideas in writing in preparation for both formal and informal scientific settings.
- Be able to explain complex science to the general public.
- Communicate effectively in collaborative group settings.
- Effectively ask and respond to questions with confidence.

Physics majors will develop an appreciation for how physics and science enriches their experience of the world. Students will:

- Understand the technical role of science in the modern world; for example, applications of scientific reasoning to policy decisions, technological innovations, etc.
- Consider the complex intersection of science and culture, including public opinion, power structures, and changing norms.
- Appreciate how science progresses as an evolving, self-correcting process.
- Specifically, appreciate the historical and philosophical developments in physics.
- Develop an appreciation of physics as a discipline that develops quantitative models, based on foundational principles, resulting in specific predictions to be tested by experiment, to describe the world.
- Appreciate the relationship of physics to the other sciences, and the interdisciplinary nature of modern challenges.

## Faculty

**This area of study is administered by the Department of Physics:**

Katherine Aidala, Kennedy-Schelkunoff Professor of Physics; Director of the Fimbel Maker Innovation Lab

Alexi Arango, Associate Professor of Physics

Kerstin Nordstrom, Associate Professor of Physics

Spencer Smith, Associate Professor of Physics, On Leave 2024-2025

Supraja Balasubramanian, Assistant Professor of Physics

Scott Bassler, Visiting Assistant Professor in Physics

Shaun Marshall, Visiting Assistant Professor in Physics

# Requirements for the Major

A minimum of 37 credits:

| Code | Title | Credits |
|---|---|---|
| As a prerequisite for PHYS-110: | | |
| MATH-101 | Calculus I | |
| PHYS-110 | Force, Motion, and Energy [1] | 4 |
| As a prerequisite for PHYS-201: | | |
| MATH-102 | Calculus II | |
| PHYS-201 | Electromagnetism [1] | 4 |
| PHYS-205 | Introduction to Mathematical Methods for Scientists | 4 |
| PHYS-210 | Waves and Optics | 4 |
| PHYS-250 | Quantum Mechanical Phenomena | 4 |
| PHYS-231 | Techniques of Experimental Physics [2] | 1 |
| Students must also take two of: | | 8 |
| PHYS-315 | Analytical Mechanics | |
| PHYS-325 | Electromagnetic Theory | |
| PHYS-326 | Statistical Mechanics and Thermodynamics | |
| **Laboratory Work:** | | |
| PHYS-220 | Intermediate Lab in Physics | 4 |
| or PHYS-308 | Electronics | |
| And 4 additional credits of laboratory work from: | | 4 |
| PHYS-295 | Independent Study | |
| PHYS-295P | Independent Study with Practicum | |
| PHYS-395 | Independent Study | |
| PHYS-395P | Independent Study with Practicum | |
| PHYS-220 or PHYS-308, if you didn't count it already above | | |
| or laboratory courses offered at other institutions, as arranged on a case-by-case basis. [3] | | |
| **Total Credits** | | **37** |

1. Students who can demonstrate proficiency in one or both introductory courses by taking placement exams administered by the department may begin their physics study at the appropriate level but must still complete 37 credits of college-level physics courses for the major
2. PHYS-231 should be taken during the first or second year
3. As arranged on a case-by-case basis
4. PHYS-336 (offered in alternate years) is recommended, as is MATH-211.

## Additional Specifications

- Course substitutions for the above requirements will be allowed on a case-by-case basis where it makes sense for a student's academic goals.
- Up to 4 credits of PHYS-295P or PHYS-395P may be earned through summer research, following college guidelines for awarding PHYS-295P/PHYS-395P credit. Note that PHYS-295P and PHYS-395P credit must be arranged with the department before the summer research experience begins; typically, a single eight to ten-week summer research program will account for no more than 2 credits of PHYS-295P or PHYS-395P.
- Normally, no more than 12 credits of PHYS-295, PHYS-295P, PHYS-395, or PHYS-395P will count towards the major.
- Physics majors are also encouraged to take CHEM-150.
- MATH-203 (Calculus III – multivariate calculus) and MATH-211 (linear algebra), while not required, are recommended for those students planning to take advanced physics courses or to pursue graduate study. MATH-302 (complex analysis) and MATH-333 (differential equations) are also recommended for students planning to pursue graduate study in physics or engineering.
- Students planning to pursue graduate study in physics are encouraged to take at least one graduate-level course in physics at UMass.
- For advising purposes, several Plans of Study (p. 2) are available in the physics suite showing recommended sequences of course-taking to complete the major.

# Sample Plans of Study for the Physics Major

*Courses with a footnote are required for the major.*

The recommended programs are based on the assumption that the student will undertake an independent project leading to honors in the fourth year. It is important for students to take mathematics courses which teach the specific skills needed for physics. Both integral and differential calculus are necessary for mathematical manipulation of formulas in the introductory physics courses.

Elective courses include:

| Code | Title | Credits |
|---|---|---|
| PHYS-104 | Renewable Energy | 4 |
| PHYS-220 | Intermediate Lab in Physics | 4 |
| PHYS-295 | Independent Study | 1-4 |
| PHYS-308 | Electronics | 4 |
| PHYS-336 | Quantum Mechanics | 4 |
| PHYS-395 | Independent Study | 1-8 |

Or a wide range of Five College options

## For students beginning physics in the first semester of the first year:

**First Year**

| Fall | Credits | Spring | Credits |
|---|---|---|---|
| PHYS-110[1] | 4 | PHYS-201[1] | 4 |
| MATH-102 or 101 | 4 | MATH-102 if needed | 4 |
| | **8** | | **8** |

**Sophomore**

| Fall | Credits | Spring | Credits |
|---|---|---|---|
| PHYS-205[1] | 4 | PHYS-250[1] | 4 |
| PHYS-210[1] | 4 | PHYS-220 | 4 |
| | **8** | | **8** |

**Junior**

| Fall | Credits | Spring | Credits |
|---|---|---|---|
| PHYS-311 | 4 | PHYS-315 | 4 |
| PHYS-326 | 4 | PHYS-325 | |
| | **8** | | **4** |

| Senior | | | |
|---|---|---|---|
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-308 | 4 | PHYS-336 | 4 |
| PHYS-395 | 1-8 | PHYS-395 | 1-8 |
| | **5-12** | | **5-12** |
| **Total Credits 54-68** | | | |

[1] *Required for the major*

## For students beginning physics in the second semester of the first year:

| First Year | | | |
|---|---|---|---|
| **Fall** | **Credits** | **Spring** | **Credits** |
| MATH-101 | 4 | MATH-102 | 4 |
| | | PHYS-110[1] | 4 |
| | **4** | | **8** |
| **Sophomore** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-201[1] | 4 | PHYS-220 | 4 |
| PHYS-205[1] | 4 | PHYS-315 | 4 |
| | **8** | | **8** |
| **Junior** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-210[1] | 4 | PHYS-250[1] | 4 |
| PHYS-311 | 4 | Physics elective | |
| | **8** | | **4** |
| **Senior** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-308 | 4 | PHYS-325 | 4 |
| PHYS-326 | 4 | PHYS-395 | 1-8 |
| | **8** | | **5-12** |
| **Total Credits 53-60** | | | |

[1] *Required for the major*

## For students beginning physics in the first sophomore semester:

| First Year | | | |
|---|---|---|---|
| **Fall** | **Credits** | **Spring** | **Credits** |
| MATH-101 | 4 | MATH-102 | 4 |
| | **4** | | **4** |
| **Sophomore** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-110[1] | 4 | PHYS-201[1] | 4 |
| | **4** | | **4** |
| **Junior** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-205[1] | 4 | PHYS-220 | 4 |
| PHYS-210[1] | 4 | PHYS-250[1] | 4 |
| | **8** | | **8** |
| **Senior** | | | |
| **Fall** | **Credits** | **Spring** | **Credits** |
| PHYS-326 | 4 | PHYS-315 | 4 |
| PHYS-395 or 308 | 1-8 | PHYS-325 | 4 |
| | **5-12** | | **8** |
| **Total Credits 45-52** | | | |

[1] *Required for the major*

- PHYS-231 should be taken during the junior or senior year
- PHYS-336, offered in alternate years, is recommended, as is MATH-211.

# Requirements for the Minor

A minimum of 16 credits:

| Code | Title | Credits |
|---|---|---|
| Normally, courses for the minor consist of: [1] | | |
| PHYS-201 | Electromagnetism | 4 |
| Any three of: | | 12 |
| PHYS-205 | Introduction to Mathematical Methods for Scientists | |
| PHYS-210 | Waves and Optics | |
| PHYS-250 | Quantum Mechanical Phenomena | |
| PHYS-308 | Electronics | |
| **Total Credits** | | **16** |

[1] Other combinations of courses are also possible with permission of the department chair. Courses must be at or above the 200 level in Physics

# Teacher Licensure

Students interested in pursuing licensure in the field of physics can combine their course work in physics with a minor in education. In some instances, course work in the major coincides with course work required for licensure; in other cases, it does not. For specific course requirements for licensure within the major of physics, please consult your advisor or the chair of the physics department. Further information about the minor in education (http://catalog.mtholyoke.edu/areas-study/psychology-education/#minortext) and the Teacher Licensure program (http://catalog.mtholyoke.edu/areas-study/psychology-education/#teacherlicensuretext) is available in other sections of the catalog, and consult Professor. Lawrence in the psychology and education department.

Licensure also requires a formal application, as well as passing scores on the Massachusetts Test of Educator Licensure (MTEL) in both the literacy component and the subject matter component. Copies of the test objectives for the MTEL are available in the physics department and in the Department of Psychology and Education.

Additional information about the Licensure Program, including application materials, can be found on the Teacher Licensure Program website (https://www.mtholyoke.edu/academics/find-your-program/teacher-licensure/).

# Course Advice

## Getting Started in Physics

Entering students considering a major in physics are strongly urged to take PHYS-110 in the first year. While it is possible to complete the major by taking PHYS-110 and PHYS-201 as late as the second year, such a program is not recommended because this delay limits the student's opportunities for advanced electives or honors work.

## Introductory Courses and Distribution Requirements

PHYS-100–PHYS-150 is a non-calculus introductory course sequence in physics, appropriate for students in the life sciences and for students with a general, nonprofessional interest in physics. This sequence satisfies the physics requirements of medical school.

PHYS-110–PHYS-201 is a calculus-based introductory course sequence in physics, appropriate for students intending to major in a physical science. To major in physics, a student must complete PHYS-201 by the end of the sophomore year. A student with excellent preparation in physics may take a departmental placement exam to place out of one or both of these introductory courses. Any 200 or 300-level 4-credit physics course will then count for distribution in physics. PHYS-110 and PHYS-201 do not cover the full range of topics on the MCAT syllabus; the PHYS-100 and PHYS-150 sequence has a better coverage of these topics.

# Course Offerings

**PHYS-100 Foundations of Physics**
*Fall. Credits: 4*
This is an algebra-based first-semester physics course geared towards students intending on careers in health professions, though it is open to all. Topics are drawn from the MCAT syllabus, and include optics, motion, forces, energy, and fluids.
*Applies to requirement(s): Math Sciences*
*S. Bassler*
*Coreq: PHYS-100L.*

**PHYS-104 Renewable Energy**
*Not Scheduled for This Year. Credits: 4*
We will examine the feasibility of converting the entire energy infrastructure of the US from one that is dependent on fossil fuels to one that utilizes mostly renewable sources of energy. We will examine the potential scale of energy production and the associated costs, natural resource requirements and land usage needs for both renewables, such as solar, wind and biofuel, and non-renewables, such as coal, natural gas, petroleum and nuclear. By applying extensive use of basic algebra and an elementary understanding of the physical processes underpinning each energy technology, we will arrive at a number of urgent conclusions about the challenges facing our energy infrastructure.
*Crosslisted as: ENVST-104*
*Applies to requirement(s): Math Sciences*
*A. Arango*

**PHYS-109 Science on Screen**
*Spring. Credits: 4*
For our entire lives, movies have captured our attention, whether at the theater or on our phones. Filmmaking is a highly technical art, and scientific principles determine what is possible. Filmmakers develop creative solutions within these principles to trick the viewer into believing what they see. Advances in science also advance filmmaking, influencing photography, production design, and so on. Additionally, scientists use these techniques to carry out their research. This course will explore the many intersections of science and filmmaking. Students will use basic mathematics (algebra, geometry) to complete brief weekly homework assignments, and will prepare a final video project.
*Applies to requirement(s): Math Sciences*
*K. Nordstrom*

**PHYS-110 Force, Motion, and Energy**
*Fall and Spring. Credits: 4*
This a calculus-based physics course designed for students intending to major in physics, astronomy, or another physical science, though all are welcome. It also fulfills pre-health requirements. Students will learn how to apply fundamental physics concepts such as force, energy, momentum to a variety of mechanical situations, including projectile motion, human movement, fluid motion, and planetary motion.
*Applies to requirement(s): Math Sciences*
*S. Marshall, K. Nordstrom*
*Prereq: MATH-101 or equivalent. Coreq: PHYS-110L.*

**PHYS-132 Engineering for Everyone**
*Not Scheduled for This Year. Credits: 4*
Engineers change the world we live in every day by developing technologies that influence nearly every aspect of our lives. In this course, we will study how engineered things shape the world we live in. Students will engage in a team-based, hands-on engineering design project, from brainstorming solutions to a contemporary problem, to building, testing, and iterating design solutions. In the process, students will learn basic programming and fabrication skills. We will reflect together on the ethics of engineering design, and leave with a more nuanced understanding of the ways technology and society interact. Who decides what technologies matter? What is a "good" technological solution, and for whom is it "good"?
*Crosslisted as: COMSC-132*
*Applies to requirement(s): Math Sciences*
*M. Su*
*Advisory: This course has no prerequisites and is recommended for all students interested in engineering and technology.*
*Notes: Students interested in continuing with the Engineering Nexus are strongly recommended to take the course.*

**PHYS-150 Phenomena of Physics**
*Spring. Credits: 4*
This is an algebra-based second-semester physics course geared towards students intending on careers in health professions, though it is open to all. Topics are drawn from the MCAT syllabus, and include electricity, magnetism, waves (sound and light), and nuclear physics. This is the spring semester continuation of the Physics 100 course in the fall, but students who have taken Physics 110 (or any equivalent) are also eligible to join.
*Applies to requirement(s): Math Sciences*
*S. Bassler*
*Prereq: PHYS-100 or PHYS-110. Coreq: PHYS-150L.*

**PHYS-201 Electromagnetism**
*Fall and Spring. Credits: 4*
This a calculus-based physics course designed for students intending to major in physics, astronomy, or another physical science, though all are welcome. It also fulfills pre-health requirements. This is the second semester of the physics introductory sequence, with Physics 110 as a prerequisite. Students will use concepts learned in 110 such as force and energy, and learn new concepts such as charge, fields, and potentials. Students will apply these concepts to situations involving electromagnetic phenomena, including electric circuits, magnetism, induction, and radiation.
*Applies to requirement(s): Math Sciences*
*S. Balasubramanian*
*Prereq: PHYS-110 and MATH-102. Coreq: PHYS-201L.*

**PHYS-205 Introduction to Mathematical Methods for Scientists**
*Fall. Credits: 4*
Topics include Taylor series, complex numbers, partial differentiation, multiple integration, selected topics in linear algebra and vector calculus, ordinary differential equations, and Fourier series. The course includes a weekly computational lab using Python, in addition to a traditional emphasis on analytic solutions.
*Applies to requirement(s): Math Sciences*
*A. Arango*
*Prereq: PHYS-201 (or concurrent enrollment with permission).*

**PHYS-210 Waves and Optics**
*Fall. Credits: 4*
A comprehensive treatment of wave phenomena, particularly light, leading to an introductory study of quantum mechanics. Topics include wave propagation, polarization, interference and interferometry, diffraction, and special relativity.
*Applies to requirement(s): Math Sciences*
*A. Arango*
*Prereq: Electromagnetism (PHYS-201) and Intro to Math Methods (PHYS-205) or concurrent enrollment in PHYS-205 with permission.*

**PHYS-220 Intermediate Lab in Physics**
*Spring. Credits: 4*
This lab-based course is an introduction to modern, investigative, experimental physics. The course is intended as a bridge between the structured introductory lab experience and independent research. In addition to exploring key physical phenomena crucial to modern understandings and gaining familiarity with modern experimental apparatus and techniques, students complete exploratory projects of various sorts and then extended, multi-week experimental projects, participating in experimental design, construction, debugging and implementation. Students will present and interpret their experimental results and develop follow-up questions which they will answer experimentally. This course will introduce students to scientific communications skills and is speaking- and writing-intensive.
*Applies to requirement(s): Meets No Distribution Requirement*
*Other Attribute(s): Speaking-Intensive, Writing-Intensive*
*K. Nordstrom*
*Prereq: PHYS-201.*

**PHYS-231 Techniques of Experimental Physics**
*Fall and Spring. Credits: 1*
Provides training in the techniques employed in the construction of scientific equipment.
*Applies to requirement(s): Meets No Distribution Requirement*
*R. Higley*
*Restrictions: Course limited to sophomores, juniors and seniors*
*Advisory: Second-semester first-year students by permission.*
*Notes: 1 meeting (2 hours) for 3 weeks. Credit/no credit grading.*

**PHYS-250 Quantum Mechanical Phenomena**
*Spring. Credits: 4*
This course provides an introduction to quantum phenomena and quantum mechanics. Topics include relativistic dynamics, blackbody radiation, and wave properties of matter. The Uncertainty Principle, Schrodinger's Equation, simple harmonic oscillators and the hydrogen atom are studied in depth, with emphasis on angular momentum, electron spin and the Pauli Exclusion Principle.
*Applies to requirement(s): Math Sciences*
*K. Aidala*
*Prereq: PHYS-205 and PHYS-210.*

**PHYS-290 Advanced Laboratory Practicum**
*Spring. Credits: 1 - 8*
This course is a hands-on practicum, intended to introduce students to the practice of modern physics research. Depending on student interest, topics include external research seminars by practitioners in the field, training in oral and written scientific communication, presentation and interpretation of research results, scientific modeling, and hands-on experimental skills. Research projects are an integral part of this course; credit will be apportioned in relation to the intensity of the project.
*Applies to requirement(s): Meets No Distribution Requirement*
*Other Attribute(s): Speaking-Intensive, Writing-Intensive*
*A. Arango*
*Prereq: 8 credits in Physics.*
*Advisory: Student must be concurrently enrolled in PHYS-295 or PHYS-395 to register in this course.*
*Notes: Repeatable for credit.*

**PHYS-295 Independent Study**
*Fall and Spring. Credits: 1 - 4*
*The department*
*Instructor permission required.*

**PHYS-295P Independent Study with Practicum**
*Fall and Spring. Credits: 1 - 4*
*The department*
*Instructor permission required.*

**PHYS-308 Electronics**
*Not Scheduled for This Year. Credits: 4*
This course is a study of electrical circuits and components with emphasis on the underlying physical principles; solid-state active devices with applications to simple systems such as linear amplifiers; feedback-controlled instrumentation; and analog and digital computing devices.
*Applies to requirement(s): Math Sciences*
*K. Aidala*
*Prereq: PHYS-150 or PHYS-201.*
*Notes: Meetings combine lecture and hands-on lab*

**PHYS-311 Computational Physics Laboratory**
*Fall. Credits: 4*
Computers bring a new dimension to the mathematical theories of physics, including new methods of visualization and new ways to explore theory through computer experiments. This laboratory course will combine mathematics, physics, and computation in projects that make essential use of all three together. Topics from various subfields of physics will be packaged into self-contained modules for exploration through the use of high-level computational tools.
*Applies to requirement(s): Math Sciences*
*S. Marshall*
*Prereq: PHYS-201 and 205.*
*Advisory: Students who have completed PHYS 110, 201 (or equivalents), and have taken separate math courses including: i) multivariable calculus, ii) linear algebra, and iii) differential equations may also be qualified. Contact the instructor to discuss.*

**PHYS-315 Analytical Mechanics**
*Spring. Credits: 4*
Newton's great innovation was the description of the world by differential equations, the beginning of physics as we know it. This course studies Newtonian mechanics for a point particle in 1, 2, and 3 dimensions, systems of particles, rigid bodies, and the Lagrangian and Hamiltonian formulations.
*Applies to requirement(s): Math Sciences*
*S. Marshall*
*Prereq: PHYS-205.*

**PHYS-325 Electromagnetic Theory**
*Spring. Credits: 4*
This course presents the development of mathematical descriptions of electric and magnetic fields; study of interactions of fields with matter in static and dynamic situations; mathematical description of waves; and development of Maxwell's equations with a few applications to the reflection and refraction of light and microwave cavities.
*Applies to requirement(s): Math Sciences*
*A. Arango*
*Prereq: PHYS-205 and PHYS-210.*

**PHYS-326 Statistical Mechanics and Thermodynamics**
*Fall. Credits: 4*
This course presents thermodynamic and statistical descriptions of many-particle systems. Topics include classical and quantum ideal gases with applications to paramagnetism; black-body radiation; Bose-Einstein condensation; and the Einstein and Debye solid; the specific heat of solids.
*Applies to requirement(s): Math Sciences*
*K. Nordstrom*
*Prereq: Quantum Mechanical Phenomena (PHYS-250) and Intro to Math Methods (PHYS-205) or permission from department.*

**PHYS-328 From Lilliput to Brobdingnag: Bridging the Scales Between Science and Engineering**
*Spring. Credits: 4*
The performance of many engineered devices is dependent on macroscopic factors (pressure, temperature, flow, conductivity). As a result, engineers often model devices macroscopically considering atomistic level details only through fixed parameters. These parameters do not always capture the full atomistic level picture. More accurate multi-scale approaches for modeling macroscopic properties use basic atomistic level chemistry at key points in larger scale simulations. This course is an introduction to such approaches focusing on fuel cells as a concrete example. Through project/case studies, basic scientific principles will be developed along side of basic engineering principles.
*Crosslisted as: CHEM-328*
*Applies to requirement(s): Math Sciences*
*Other Attribute(s): Writing-Intensive*
*M. Gomez*
*Prereq: MATH-102 and any chemistry or physics course.*

**PHYS-336 Quantum Mechanics**
*Fall. Credits: 4*
This course is an introduction to formal quantum theory: the wave function and its interpretation, observables and linear operators, matrix mechanics and the uncertainty principle; solutions of one-dimensional problems; solutions of three-dimensional problems and angular momentum; and perturbative methods.
*Applies to requirement(s): Math Sciences*
*S. Bassler*
*Prereq: PHYS-250.*

**PHYS-390 Advanced Laboratory Practicum**
*Spring. Credits: 1 - 8*
This course is a hands-on practicum, intended to introduce students to the practice of modern physics research. Depending on student interest, topics include external research seminars by practitioners in the field, training in oral and written scientific communication, presentation and interpretation of research results, scientific modeling, and hands-on experimental skills. Research projects are an integral part of this course; credit will be apportioned in relation to the intensity of the project.
*Applies to requirement(s): Meets No Distribution Requirement*
*Other Attribute(s): Speaking-Intensive, Writing-Intensive*
*A. Arango*
*Instructor permission required.*
*Prereq: 16 credits in Physics.*
*Advisory: Student must be concurrently enrolled in PHYS-295 or PHYS-395 to register in this course.*
*Notes: Repeatable for credit.*

**PHYS-395 Independent Study**
*Fall and Spring. Credits: 1 - 8*
*The department*
*Instructor permission required.*

**PHYS-395P Independent Study with Practicum**
*Fall and Spring. Credits: 1 - 8*
*The department*
*Instructor permission required.*