PHYSICS (Div III)
Chair: Associate Professor Frederick W. Strauch


On leave fall/spring: C. Kealhofer

What is light? How does a laser work? What is a black hole? What are the fundamental building blocks of the universe? Physics majors and Astrophysics majors study these and related questions to understand the physical world around us, from the very small to the very large. A physics student practices the experimental methods used to learn about this world and explores the mathematical techniques and theories developed to explain these physical phenomena. A Physics major or Astrophysics major serves as preparation for further work in physics, astrophysics, applied physics, other sciences, engineering, medical research, science teaching and writing, and other careers involving critical thinking, problem-solving, and insight into the fundamental principles of nature.

ASTROPHYSICS MAJOR

The Physics Department, in cooperation with the Astronomy Department, offers a major in Astrophysics. More information about the Astrophysics major can be found on the Astronomy Department site.

PHYSICS MAJOR

Introductory Courses

Students considering a major in physics should take both physics and mathematics as first-year students. A student normally begins with either Physics 131 or Physics 141.

Physics 131 Introduction to Mechanics. This is designed as a first course in physics. It is suitable for students who either have not had physics before or have had some physics but are not comfortable solving “word problems” that require calculus.

Physics 141 Mechanics and Waves. Students in this course should have solid backgrounds in science and calculus, either from high school or college, including at least a year of high school physics.

The Department of Mathematics will place students in the appropriate introductory calculus course. The physics major sequence courses all make use of calculus at increasingly sophisticated levels. Therefore, students considering a Physics major should continue their mathematical preparation without interruption through the introductory calculus sequence (Mathematics 130, 140, and 150 or 151). Students are encouraged to take Physics 210 as early as possible. Physics 210 is cross listed as Mathematics 210 for the benefit of those students who wish to have the course listed with a MATH prefix.

ADVANCED PLACEMENT

Students with unusually strong backgrounds in calculus and physics may place out of Physics 141 and either: 1) begin with the special seminar course Physics 151 in the fall (typically followed by Physics 210 in the spring), or 2) begin with Physics 142 in the spring (possibly along with Physics 210). Students may take either 151 or 142 but not both. On rare occasions a student with an exceptional background will be offered the option of enrolling in Physics 201.

Placement is based on AP scores, consultation with the department, and results of a placement exam administered during First Days. The exam can also be taken later in the year by arrangement with the department chair. The exam covers classical mechanics, basic wave phenomena, and includes some use of calculus techniques.

REQUIREMENTS FOR THE MAJOR

A total of ten courses, nine in physics and one in mathematics, are required to complete the Physics major. Students who place out of both Physics 141 and Physics 142 and begin their studies in Physics 201 are required to take a total of nine courses (eight in physics).

Required Physics Sequence Courses

Physics 141 Mechanics and Waves

or Physics 131 Introduction to Mechanics

Physics 142 Foundations of Modern Physics

or Physics 151 Seminar in Modern Physics

Physics 201 Electricity and Magnetism
Required Mathematics Course

Mathematics 150 or 151 (formerly 105 or 106) Multivariable Calculus

Students entering with Advanced Placement in mathematics may obtain credit toward the major for the equivalent Mathematics 150 or 151 taken elsewhere.

At least two more physics courses above the 100 level (or other approved courses as noted below) must be taken, bringing the total number of courses for the major to ten.

Options

Mathematics 140 may be counted if taken at Williams.

Mathematics 209 or 309 may substitute for Physics 210.

Astronomy 111 may count in place of Physics 141 if a student places out of 141 (see “advanced placement” above).

An additional Astronomy or Astrophysics course above the introductory level that is acceptable for the astrophysics major may be counted.

Two approved Division III courses above the introductory level may be substituted for one Physics course. Approval is on an individual basis at the discretion of the department chair.

Honors work is in addition to completion of the basic major so Physics 493 and 494 do not count towards the ten courses in the major.

PREPARATION FOR ADVANCED STUDY

Students who may wish to do graduate work in physics, astrophysics, or engineering should elect courses in both physics and mathematics beyond the minimum major requirements. The first-year graduate school curriculum in physics usually includes courses in quantum mechanics, electromagnetic theory, and classical mechanics that presuppose intermediate level study of these subjects as an undergraduate. Therefore, students planning graduate work in physics should elect all of the following courses:

Physics 402T Applications of Quantum Mechanics

Physics 405T Electromagnetic Theory

Physics 411T Classical Mechanics

ADVISING

Both majors and non-majors are encouraged to consult with the department chair or course instructors about course selections or other matters.

THE DEGREE WITH HONORS IN PHYSICS

The degree with honors in Physics will be awarded on the basis of a senior thesis presenting the results of a substantial experimental or theoretical investigation carried out under the direction of a faculty member in the department. There is no rigid grade point average required for admission to the program or for the awarding of the degree with honors, but it is normally expected that honors students will maintain at least a B average in physics and mathematics. Students will normally apply for admission to the program early in the spring of their junior year and during senior year these students will normally elect Physics 493, W31, and 494 in addition to the usual requirements for the major. At the end of winter study, the department will decide whether the student will be admitted to honors candidacy. Both a written thesis and a colloquium presentation of the results are required. The degree with honors will be awarded to those who meet these requirements with distinction. The degree with highest honors will be awarded to those who fulfill them with unusually high distinction.

Honors candidates will also be required to participate in departmental colloquium talks.

STUDY ABROAD

The physics community is international in scope and a career in physics (or a related field) can provide many opportunities for travel and contact with individuals from outside the United States. The physics major at Williams is a carefully structured four-year program designed to prepare students who are so inclined for graduate study at leading research institutions. While it is possible to complete the major requirements in three years, such a major will not usually not lead to further study in the field. With careful early planning on the part of a student, and close consultation with the
department chair, it is possible to complete a strong major and still study abroad provided the foreign institution can provide courses which reasonably substitute or supplement those in the Williams major program. Students MUST contact departments/programs BEFORE assuming study away credit will be granted toward the major or concentration.

Here are answers to frequently asked questions related to study abroad:

**Can your department or program typically pre-approve courses for major/concentration credit?**
Yes, in many cases, though students should be sure to contact the department.

**What criteria will typically be used/required to determine whether a student may receive major/concentration credit for a course taken while on study away?**
Course title and description.

**Does your department/program place restrictions on the number of major/concentration credits that a student might earn through study away?**
No.

**Does your department/program place restrictions on the types of courses that can be awarded credit towards your major?**
No.

**Are there specific major requirements that cannot be fulfilled while on study away?**
No.

**Are there specific major requirements in your department/program that students should be particularly aware of when weighing study away options?** (Some examples might include a required course that is always taught in one semester, laboratory requirements.)
Yes. The laboratory component of Physics 301 serves as our "advanced lab course." Students often cannot get equivalent experience abroad and must take this when they return senior year (non-credit). Unless there has been a recent change, our own Oxford Program is one place students cannot get lab experience.

**OPTIONS FOR NON-MAJORS**

Many students want to take a self-contained and rigorous full-year survey of physics. For such students, the most appropriate sequence will be either Physics 131 or Physics 141 followed by Physics 132, depending on the student’s background in science and mathematics (see Introductory Courses above). Either of these sequences satisfies the physics requirement for medical school.

The department also offers one-semester courses designed for non-majors, including Physics 107, Physics 108, and Physics 109.

**PHYS 12  (W)  Drawing as a Learnable Skill**

Representational drawing is not merely a gift of birth, but a learnable skill. If you wanted to draw, but have never had the time to learn; or you enjoy drawing and wish to deepen your understanding and abilities, then this course is for you. This intensive course utilizes traditional drawing exercises to teach representational drawing. By using simple techniques and extensive exercises you will develop your ability to accurately see and realistically represent the physical world. You will learn to draw a convincing portrait, interior, and still life. This course is designed to develop your powers of observation and teach creative problem solving abilities. Students need no previous artistic experience, just the willingness and desire to learn. Students will be expected to attend and participate in all sessions. The class will meet twice a week on Tuesday and Thursday mornings. Students will also be required to keep a sketchbook for all assignments (both in class and out-of-class work) and complete a final project. There will be a final exhibition of student work on the last day of class. Adjunct Instructor Bio: Stella Ehrich is a professional painter whose work includes portraits, landscapes and still life subjects. She studied for seven years at Studio Simi in Florence, she holds an MFA in painting from Bennington College and a BFA from the Memphis Academy of Art. Stella studied for seven years in Florence, Italy in the studio of Nerina Simi and latter earned an Master’s degree from Bennington College with a concentration in painting. She is a portrait painter who lives and works in Vermont.

**Requirements/Evaluation:** final project or presentation

**Prerequisites:** none

**Enrollment Limit:** 18

**Enrollment Preferences:** seniority

**Grading:** pass/fail only
Materials/Lab Fee: $12
Distributions: (D3)

Not offered current academic year

PHYS 14  (W)  Light and Holography
This course will examine the art and science of holography. It will introduce modern optics at a level appropriate for a non-science major, giving the necessary theoretical background in lectures and discussions. Demonstrations will be presented and students will make several kinds of holograms in the lab. Thanks to a grant from the National Science Foundation, we have 7 well-equipped holography darkrooms available for student use. At the beginning of WSP, the class will meet for lecture and discussion three mornings a week and for lab 2 afternoons a week. The later part of the month will be mainly open laboratory time during which students, working in small groups, will conduct an independent project in holography approved by the instructor. Attendance at lectures and laboratory is required.

Requirements/Evaluation: regular attendance, completion of 4 laboratory exercises, and a holography laboratory project (approved by the instructor) with a poster presentation to the class at the end of WSP; attendance at all classes and labs is required for a passing grade
Prerequisites: none
Enrollment Limit: 30
Enrollment Preferences: preference to students with no physics above Physics 109; then seniors, juniors, sophomores and first-years
Grading: pass/fail only
Materials/Lab Fee: $50
Distributions: (D3)
Not offered current academic year

PHYS 14  Experimental Music: Species, Monsters, and Things Artificial
In this project-based course we will make rooms into resonant instruments, create topographies of sound through interference patterns, and temper our tastes through chance procedures. We will study the tradition of North American experimental music through listening, performing, composing, and reading. Students will complete audio editing assignments in the software Reaper and carry out composition/performance projects. Listening and reading will be assigned for most class meetings. For the final project students will make a piece of experimental music. "If this word 'music' is sacred and reserved for 18th- and 19th-century instruments, we can substitute a more meaningful term: organization of sound." So wrote John Cage in 1937, voicing the new attitude of the experimental music tradition. In this class we explore the expanded field of the modes of intervention into the flux of sound. Adjunct Instructor Bio: Daniel Fox is a composer and a mathematician based in New York City. His writing has appeared in Hyperallergic, Van Magazine, Perspectives of New Music, and Transactions of the American Mathematical Society. His compositions have been performed by the Jack Quartet, Mivos Quartet, Talea Ensemble, Miranda Cuckson, and Contemporaneous. His doctoral dissertation is on the role of acoustic resonance in American experimental music. His website is thoughtstooedfinite.com.

Requirements/Evaluation: short technical assignments, two mid-term projects, and a final project
Prerequisites: none
Enrollment Limit: 20
Enrollment Preferences: seniority
Grading:
Materials/Lab Fee: $20
Not offered current academic year

PHYS 15  (W)  Cooking for the Real World
Cross-listings: PHYS 15  SPEC 13
Primary Cross-listing
Students will learn the basic cooking techniques needed to survive for their lives after graduation. They will learn how to make cookies, pasta, pies, protein cookery, and knife skills to better prepare themselves after their time at William's. Please when applying for the class include year of graduation and why food matters so much to you. Normally students will email me why and how food means to them. Emails will help determine who gets into the class of 10. Adjunct Instructor Bio: CJ Hazell is currently working in Williams' dining services, preparing meals for over 2000 students. Prior to coming
to the college, he ran a small cafe and before that was the kitchen manager and saucier at a French Fine Dining establishment.

Requirements/Evaluation: students will write a reflection comparing their initial email application and what they have learned throughout class

Prerequisites: Junior or Senior

Enrollment Limit: 10

Enrollment Preferences: email application explaining how much food means to them

Grading: pass/fail only

Materials/Lab Fee: cost of books

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 15 SPEC 13

Attributes: EXPE Experiential Education Courses

Not offered current academic year

PHYS 16 (W) The Way Things Work

How does a motor run? What do chocolate and steel have in common? How does Williams heat and power the campus? Can paper be washed? What's inside everyday appliances? How do you build a speaker? From simple machines to complex processes, in this course we'll explore the way things work! Class will meet four afternoons a week for a mixture of lecture, discussion, build time, local field trips, and lots of hands-on exploration. Homework will primarily consist of readings and exercises relevant to the current class topics and extra tinker-time. Early in the course we'll team-engineer and build a large project as a class. In the last part of the course, students will have a chance to explore the functioning of some process, object, or technology of their choice. These will culminate in either building a final project with a short writeup or writing a 6-page paper, and a presentation to the class.

Requirements/Evaluation: class participation; midterm group project; final project with short writeup or a 6-page paper; presentation of final project/paper to the class

Prerequisites: none

Enrollment Limit: 16

Enrollment Preferences: by seniority, and by requesting an interest statement

Grading: pass/fail only

Materials/Lab Fee: $40 and approximately $35 for books

Attributes: EXPE Experiential Education Courses

Not offered current academic year

PHYS 22 (W) Research Participation

Several members of the department will have student projects available dealing with their own research or that of current senior thesis students. Approximately 35 hours per week of study and actual research participation will be expected from each student.

Class Format: to be arranged with instructor

Requirements/Evaluation: students will be required to keep a notebook and write a 5-page paper summarizing their work

Prerequisites: permission of instructor

Enrollment Limit: 1-2

Enrollment Preferences: permission of instructor

Grading: pass/fail only

Materials/Lab Fee: none

Distributions: (D3)

Not offered current academic year

PHYS 31 (W) Senior Research: Physics

To be taken by students registered for Physics 493, 494.
**PHYS 32 (W) Senior Research: Astrophysics**
To be taken by students registered for Astrophysics 493, 494.

**Class Format**: independent study  
**Grading**: pass/fail only  
**Distributions**: (D3)

Winter 2020  
HON Section: 01   TBA   Frederick W. Strauch

**PHYS 99 (W) Independent Study: Physics**
Open to upperclass students. Students interested in doing an independent project (99) during Winter Study must make prior arrangements with a faculty sponsor. The student and professor then complete the independent study proposal form available online. The deadline is typically in late September. Proposals are reviewed by the pertinent department and the Winter Study Committee. Students will be notified if their proposal is approved prior to the Winter Study registration period.

**Class Format**: independent study  
**Grading**: pass/fail only  
**Distributions**: (D3)

Winter 2020  
IND Section: 01   TBA   Frederick W. Strauch

**PHYS 106 (F) Being Human in STEM**  
**Cross-listings**: GEOS 106  PHYS 106  STS 106  

**Primary Cross-listing**
This course combines academic inquiry and community engagement to investigate the themes of diversity and social climate within STEM (science, technology, engineering and mathematics) disciplines. Students will examine how diverse identities including but not limited to gender, race, disability, sexuality, national origin, socioeconomic status, religion, and ethnicity shape the STEM experience both at Williams and nationally. We will ground our understanding through critical reading of primary scholarly research on topics such as implicit bias, identity threat, and effects of team diversity on excellence. From there, we will execute small group projects. Students will design, execute, and evaluate interventions that relate to the course goals and that have direct relevance to Williams students, faculty, and staff. For example, a student group could implement a survey of minoritized STEM students, or create a qualitative interview-based assessment of how socioeconomic status impacts students’ abilities to participate in STEM fields. Course work includes weekly readings, reflective/opinion writing, in class discussion, and the development and presentation of a group project.

**Class Format**: Class discussions, group project work (out of class time required)  
**Requirements/Evaluation**: Short response papers, class discussion participation, leading class discussions, group work, and final project.  
**Enrollment Limit**: 15  
**Enrollment Preferences**: DIV III majors; statement of interest may be requested if course over-enrolls  
**Expected Class Size**: 15  
**Grading**: no pass/fail option, yes fifth course option  
**Unit Notes**: Does not count towards GEOS or PHYS major credit
Distributions: (D3) (DPE)

This course is cross-listed and the prefixes carry the following divisional credit:

GEOS 106 (D3) PHYS 106 (D3) STS 106 (D2)

Difference, Power, and Equity Notes: This course explicitly addresses the intersection of marginalized identities and the STEM experience. Students will learn how to critically address how issues such as gender, race, ethnicity, and disability impact participation in and the experience of STEM fields. For example, students will read and critique literature documenting bias in STEM fields, and will also learn about and create interventions that can address these biases.

Fall 2019
SEM Section: 01    W 1:10 pm - 3:50 pm    Savan Kharel, Phoebe A. Cohen

PHYS 107  (F) Spacetime and Quanta  (QFR)
Quantum mechanics and Einstein's relativity both drastically altered our view of the physical world when they were developed in the early twentieth century. In this course we will learn about the central concepts that define relativity and quantum mechanics, along with some of the diverse phenomena the two theories describe. These investigations will prepare us to discuss developments in condensed matter: explaining what makes materials different along with discussing exotic effects like superconductivity and superfluidity. We will also discuss recent developments in cosmology, where observations have produced a surprising picture for the make-up of our universe. This course is intended for students whose primary interests lie outside of the natural sciences and mathematics. The mathematics used will be algebra and trigonometry.

Class Format: lecture twice a week and conference section once a week (20 per conference section)
Requirements/Evaluation: weekly problem sets, quizzes, two midterms, and a final exam, all with a significant quantitative component
Prerequisites: none
Enrollment Limit: 40
Enrollment Preferences: by seniority
Expected Class Size: 25
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3) (QFR)

Not offered current academic year

PHYS 108  (F) Energy Science and Technology  (QFR)
Cross-listings: ENVI 108  PHYS 108

Primary Cross-listing
Energy use has skyrocketed in the United States and elsewhere in the world, causing significant economic and political shifts, as well as concerns for the environment. This course will address the physics and technology of energy generation, consumption, and conservation. It will cover a wide range of energy sources, including fossil fuels, hydropower, solar energy, wind energy, and nuclear energy. We will discuss energy use in transportation, manufacturing, building heating, and building lighting. Students will learn to compare the efficiencies and environmental impacts of various energy sources and uses.

Class Format: lecture twice a week, occasional lab exercises, and a field trip to the college heating plant, all during class hours
Requirements/Evaluation: evaluation will be based on weekly assignments, two hour tests, and a final project culminating in an oral presentation to the class and a 10-page paper; all of these will be substantially quantitative
Prerequisites: high school physics, high school chemistry, and mathematics at the level of MATH 130
Enrollment Limit: 20
Expected Class Size: 20
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3) (QFR)

This course is cross-listed and the prefixes carry the following divisional credit:
ENVI 108 (D3) PHYS 108 (D3)
Attributes: ENVI Natural World Electives

Fall 2019

LEC Section: 01    MR 2:35 pm - 3:50 pm    Kevin M. Jones

PHYS 109  (F)  Sound, Light, and Perception  (QFR)
Light and sound allow us to perceive the world around us, from appreciating music and art to learning the details of atomic structure. Because of their importance in human experience, light and sound have long been the subject of scientific inquiry. How are sound and light related? How do physiology and neural processing allow us to hear and see the world around us? What are the origins of color and musical pitch? This course introduces the science and technology of light and sound to students not majoring in physics. We will start with the origins of sound and light as wave phenomena, and go on to topics including color, the optics of vision, the meaning of musical pitch and tone, and the physical basis of hearing. We will also discuss some recent technological applications of light, such as lasers and optical communications. The class will meet for two 75-minute periods each week for a variable mixture of lecture, discussion, and hands-on, interactive experiments.

Class Format: lecture/lab/discussion; each student will attend one lecture plus one conference section weekly
Requirements/Evaluation: evaluation will be based on class participation, problem sets, in-class exams, oral presentations, and a final exam, all with a quantitative component
Extra Info: Note: Students signing up for the Thursday 2:35 PM conference section must also be available on Thursdays from 1:10-2:25 PM
Prerequisites: none
Enrollment Limit: 40
Expected Class Size: 40
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3) (QFR)

Fall 2019
LEC Section: 01    MR 1:10 pm - 2:25 pm M 2:35 pm - 3:50 pm    Protik K. Majumder

PHYS 131  (F)  Introduction to Mechanics  (QFR)
We focus first on the Newtonian mechanics of point particles: the relationship between velocity, acceleration, and position; the puzzle of circular motion; forces, Newton's laws, and gravitation; energy and momentum; and the physics of vibrations. Then we turn to the basic properties of waves, such as interference and refraction, as exemplified by sound and light waves. We also study the optics of lenses, mirrors and the human eye. This course is not intended for students who have successfully completed an AP physics course in high school.

Class Format: lecture, three hours per week; laboratory, three hours approximately every other week
Requirements/Evaluation: exams, labs, and weekly problem sets, all of which have a substantial quantitative component
Prerequisites: MATH 130; students who scored 4 or 5 on an AP physics exam, or 6 or 7 on the IB Physics HL exam may not take this course and are encouraged to take PHYS 141 instead
Enrollment Limit: 24/lab
Expected Class Size: 60
Grading: yes pass/fail option, yes fifth course option
Unit Notes: PHYS 131 can lead to either PHYS 132 (for students wanting a one-year survey of physics) or PHYS 142 (for students considering a Physics or Astrophysics major)
Distributions: (D3) (QFR)
PHYS 132 (S) Electromagnetism and the Physics of Matter (QFR)

This course is intended as the second half of a one-year survey of physics with some emphasis on applications to medicine. In the first part of the semester we will focus on electromagnetic phenomena. We will introduce the concept of electric and magnetic fields and study in detail the way in which electrical circuits and circuit elements work. The deep connection between electric and magnetic phenomena is highlighted with a discussion of Faraday's Law of Induction. Following our introduction to electromagnetism we will discuss some of the most central topics in twentieth-century physics, including Einstein's theory of special relativity and some aspects of quantum theory. We will end with a treatment of nuclear physics, radioactivity, and uses of radiation.

Class Format: lecture, three hours per week; laboratory, three hours approximately every other week; conference section 1 hour approximately every other week

Requirements/Evaluation: evaluation will be based on weekly problem sets, labs, quizzes and exams

Prerequisites: PHYS 131 or 141 or permission of instructor, and MATH 130 (formerly 103)

Enrollment Limit: 22 per lab

Expected Class Size: 60

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Spring 2020

LEC Section: 01 MWF 11:00 am - 11:50 am Savan Kharel
LAB Section: 02 M 1:00 pm - 4:00 pm Savan Kharel
LAB Section: 03 T 1:00 pm - 4:00 pm Savan Kharel

PHYS 141 (F) Mechanics and Waves (QFR)

This is the typical first course for a prospective physics major. It covers the same topics as PHYS 131, but with a higher level of mathematical sophistication. It is intended for students with solid backgrounds in the sciences, either from high school or college, who are comfortable with basic calculus.

Class Format: lecture, three hours per week; laboratory, three hours approximately every other week; conference section, one hour approximately every other week

Requirements/Evaluation: weekly problem sets, labs, 2 one-hour tests, and a final exam, all of which have a substantial quantitative component

Prerequisites: high school physics and MATH 130 or equivalent placement

Enrollment Limit: 22 per lab

Expected Class Size: 50

Grading: yes pass/fail option, yes fifth course option

Unit Notes: PHYS 141 can lead to either PHYS 132 (for students wanting a one-year survey of physics) or PHYS 142 (for students considering a Physics or Astrophysics major)

Distributions: (D3) (QFR)

Fall 2019

LEC Section: 01 MWF 11:00 am - 11:50 am Katharine E. Jensen
LAB Section: 02 M 1:00 pm - 4:00 pm Katharine E. Jensen
LAB Section: 03 T 1:00 pm - 4:00 pm Katharine E. Jensen

PHYS 142 (S) Foundations of Modern Physics (QFR)

Newtonian Mechanics, spectacular as it is in describing planetary motion and a wide range of other phenomena, only hints at the richness of behaviors seen in the universe. Special relativity, which extends physics into the realm of high speeds and high energies, requires us rethink our basic notions of space and time. Quantum mechanics successfully describes atoms, molecules, and solids while at the same time calling into question our expectation
of what can be predicted by a physical theory. Statistical physics reveals new behaviors that emerge when many particles are present in a system. This course will survey ideas from each of these three arenas, and can serve either as a terminal course for those seeking to complete a year of physics or the basis for future advanced study of these topics.

Class Format: lecture, two hours weekly; problem-solving conference session, one hour weekly; laboratory, alternating between three hours and one hour approximately every other week (limit 22 per lab, 18 per conference section)

Requirements/Evaluation: weekly homework, labs, two hour tests, and a final exam, all of which have a substantial quantitative component

Prerequisites: PHYS 141 and MATH 130 (formerly 103), or equivalent; PHYS 131 may substitute for PHYS 141 with the permission of instructor. Students may not take both PHYS 142 and PHYS 151

Enrollment Limit: 18 per CON

Expected Class Size: 30

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Spring 2020

LEC Section: 01 MW 11:00 am - 11:50 am Charlie Doret
CON Section: 02 F 11:00 am - 11:50 pm Charlie Doret
CON Section: 03 F 12:00 pm - 12:50 pm Charlie Doret
LAB Section: 04 M 1:00 pm - 4:00 pm Charlie Doret
LAB Section: 05 T 1:00 pm - 4:00 pm Charlie Doret

PHYS 151 (F) Seminar in Modern Physics (QFR)

Newtonian Mechanics, spectacular as it is in describing planetary motion and a wide range of other phenomena, only hints at the richness of behaviors seen in the universe. Special relativity has extended physics into the realm of high speeds and high energies and requires us to rethink our basic notions of space and time. Quantum mechanics successfully describes atoms, molecules, and solids while at the same time calling into question our notions of what can be predicted by a physical theory. Statistical physics reveals new behaviors that emerge when many particles are present in a system. This course covers the same basic material as PHYS 142 but in a small seminar format for students with strong prior preparation in physics.

Class Format: lecture/discussion, three hours per week; laboratory, 3 hours approximately every other week; conference section 1 hour approximately every other week

Requirements/Evaluation: evaluation will be based on class participation, labs, weekly problem sets, an oral presentation, two hour-exams and a final exam, all of which have a substantial quantitative component

Extra Info: this is a small seminar designed for first-year students who have placed out of PHYS 141

Prerequisites: placement by the department (see "advanced placement" section in the description about the department). Students may take either PHYS 142 or PHYS 151 but not both

Enrollment Limit: 18

Expected Class Size: 18

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Fall 2019

LEC Section: 01 MWF 11:00 am - 11:50 am Frederick W. Strauch
LAB Section: 02 W 1:00 pm - 4:00 pm Frederick W. Strauch

PHYS 201 (F) Electricity and Magnetism (QFR)

The classical theory of electricity and magnetism is very rich yet it can be written in a remarkably succinct form using Maxwell’s equations. This course is an introduction to electricity and magnetism and their mathematical description, connecting electric and magnetic phenomena via the special theory of relativity. Topics include electrostatics, magnetic fields, electromagnetic induction, DC and AC circuits, and the electromagnetic properties of
matter. The laboratory component of the course is an introduction to electronics where students will develop skills in building and debugging electrical circuits.

Class Format: lecture, three hours per week; laboratory, three hours per week

Requirements/Evaluation: evaluation will be based on problem sets, labs, two take-home midterms, and a final exam, all of which have a substantial quantitative component

Prerequisites: PHYS 142 OR 151; MATH 150 or 151; with a preference for MATH 151

Enrollment Limit: 20 per lab

Expected Class Size: 25

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Fall 2019

LEC Section: 01 MWF 10:00 am - 10:50 am David R. Tucker-Smith
LAB Section: 02 T 1:00 pm - 4:00 pm David R. Tucker-Smith
LAB Section: 03 W 1:00 pm - 4:00 pm David R. Tucker-Smith

PHYS 202 (S) Vibrations, Waves and Optics (QFR)

Waves and oscillations characterize many different physical systems, including vibrating strings, springs, water waves, sound waves, electromagnetic waves, and gravitational waves. Quantum mechanics even describes particles with wave functions. Despite these diverse settings waves exhibit several common characteristics, so that the understanding of a few simple systems can provide insight into a wide array of phenomena. In this course we begin with the study of oscillations of simple systems with only a few degrees of freedom. We then move on to study transverse and longitudinal waves in continuous media in order to gain a general description of wave behavior. The rest of the course focuses on electromagnetic waves and in particular on optical examples of wave phenomena. In addition to well known optical effects such as interference and diffraction, we will study a number of modern applications of optics such as short pulse lasers and optical communications. Throughout the course mathematical methods useful for higher-level physics will be introduced.

Class Format: lecture, three hours per week; laboratory, three hours per week

Requirements/Evaluation: evaluation will be based on problem sets, labs, two one-hour tests, and a final exam, all of which have a substantial quantitative component

Prerequisites: PHYS 201; co-requisite: PHYS/MATH 210 or MATH 209 or permission of instructor

Enrollment Limit: none

Expected Class Size: 20

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

Spring 2020

LEC Section: 01 MWF 10:00 am - 10:50 am Graham K. Giovanetti
LAB Section: 02 T 1:00 pm - 4:00 pm Graham K. Giovanetti
LAB Section: 03 W 1:00 pm - 4:00 pm Graham K. Giovanetti

PHYS 210 (S) Mathematical Methods for Scientists (QFR)

Cross-listings: MATH 210 PHYS 210

Primary Cross-listing

This course covers a variety of mathematical methods used in the sciences, focusing particularly on the solution of ordinary and partial differential equations. In addition to calling attention to certain special equations that arise frequently in the study of waves and diffusion, we develop general techniques such as looking for series solutions and, in the case of nonlinear equations, using phase portraits and linearizing around fixed points. We study some simple numerical techniques for solving differential equations. A series of optional sessions in Mathematica will be offered for students
who are not already familiar with this computational tool.

**Class Format:** lecture, three hours per week

**Requirements/Evaluation:** evaluation will be based on several exams and on weekly problem sets, all of which have a substantial quantitative component

**Prerequisites:** MATH 150 or 151 and familiarity with Newtonian mechanics at the level of PHYS 131

**Enrollment Limit:** 50

**Expected Class Size:** 30

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3) (QFR)

**This course is cross-listed and the prefixes carry the following divisional credit:**

MATH 210 (D3) PHYS 210 (D3)

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**PHYS 234 (S) Introduction to Materials Science (QFR)**

**Cross-listings:** PHYS 234 GEOS 234

**Primary Cross-listing**

Materials Science is the study of how the microscopic structure of materials—whether steel, carbon fiber, glass, wood, plastic, or mayonnaise—determines their macroscopic mechanical, thermal, electric, and other properties. Topics of this course include classifying materials; material structure; thermodynamics and phase transformations; material properties and testing; how solids bend, flow, and ultimately break; and how to choose the right material for design applications. Materials Science is a highly interdisciplinary field and as a result the course prerequisites are broad but also flexible. Interested students who are unsure about their preparation are strongly encouraged to contact the instructor.

**Class Format:** lecture (3 hours per week), plus three to four small-group laboratory sessions throughout the semester (to be scheduled with instructor)

**Requirements/Evaluation:** based on weekly problem sets, class participation, and midterm and final exams, all of which have a substantial quantitative component

**Prerequisites:** high school physics and chemistry, preferably at the AP level, and MATH 140 or AP Calculus (BC), and one 200-level PHYS, CHEM, or GEOS course; or permission of instructor

**Enrollment Limit:** 20

**Enrollment Preferences:** based on students’ scientific background and seniority

**Expected Class Size:** 10

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3) (QFR)

**This course is cross-listed and the prefixes carry the following divisional credit:**

PHYS 234 (D3) GEOS 234 (D3)

**Attributes:** MTSC Courses

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**PHYS 301 (F) Quantum Physics (QFR)**

This course serves as a one-semester introduction to the history, formalism, and phenomenology of quantum mechanics. We begin with a discussion of the historical origins of the quantum theory, and the Schroedinger wave equation. The concepts of matter waves and wave-packets are introduced. Solutions to one-dimensional problems will be treated prior to introducing the system which serves as a hallmark of the success of quantum theory, the three-dimensional hydrogen atom. In the second half of the course, we will develop the important connection between the underlying mathematical formalism and the physical predictions of the quantum theory and introduce the Heisenberg formalism. We then go on to apply this knowledge to
several important problems within the realm of atomic and nuclear physics concentrating on applications involving angular momentum and spins.

**Class Format:** lecture, three hours per week; laboratory, three hours per week

**Requirements/Evaluation:** evaluation will be based on weekly problem sets, labs, a midterm exam, and final exam, all of which have a substantial quantitative component

**Prerequisites:** PHYS 202 and PHYS/MATH 210 or MATH 209

**Enrollment Limit:** none

**Expected Class Size:** 15

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3) (QFR)

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**PHYS 302 (S) Stat Mechanics & Thermodynamics (QFR)**

Macroscopic objects are made up of huge numbers of fundamental particles interacting in simple ways--obeying the Schrödinger equation, Newton's and Coulomb's Laws--and these objects can be described by macroscopic properties like temperature, pressure, magnetization, heat capacity, conductivity, etc. In this course we will develop the tools of statistical physics, which will allow us to predict the cooperative phenomena that emerge in large ensembles of interacting particles. We will apply those tools to a wide variety of physical questions, including the behavior of gases, polymers, heat engines, biological and astrophysical systems, magnets, and electrons in solids.

**Class Format:** lecture/discussion, three hours per week; laboratory, three hours per week

**Requirements/Evaluation:** evaluation will be based on weekly problem sets, exams, and labs, all of which have a substantial quantitative component

**Prerequisites:** required: PHYS 201, PHYS/MATH 210 or MATH 209; recommended: PHYS 202, PHYS 301

**Enrollment Limit:** 24

**Expected Class Size:** 15

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3) (QFR)

**Attributes:** BIGP Related Courses

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**PHYS 312 (S) Philosophical Implications of Modern Physics (QFR)**

Cross-listings: PHIIL 312 SCST 312 PHYS 312

**Primary Cross-listing**

Some of the discoveries made by physicists over the last century seem to show that our common sense views are deeply at odds with our most sophisticated and best confirmed scientific theories. The course will present the essential ideas of relativity theory and quantum theory and explore their implications for philosophy. We will ask, for example, what these theories tell us about the nature of space, time, probability and causality.

**Class Format:** lecture

**Requirements/Evaluation:** attendance, participation, problem sets, exams, six 1- to 2-page papers and a 12- to 15-page term paper

**Prerequisites:** MATH 140, high-school physics, and either a 200-level course in PHIL or a 100-level course in PHYS

**Enrollment Limit:** 20
PHYS 314 (S) Controlling Quanta  (QFR)
This course will explore modern developments in the control of individual quantum systems. Topics covered will include basic physical theories of atoms coupled to photons, underlying mathematical tools (including Lie algebras and groups), and computational methods to simulate and analyze quantum systems. Applications to quantum computing, teleportation, and experimental metaphysics (Bell's inequality) will also be discussed.
Class Format: tutorial
Requirements/Evaluation: tutorial preparation and participation, weekly problem sets/papers, and a final project
Prerequisites: PHYS/MATH 210 or MATH 209 or MATH 250
Enrollment Limit: 10
Enrollment Preferences: sophomores and junior Physics majors
Expected Class Size: 10
Grading: no pass/fail option, no fifth course option
Distributions: (D3) (QFR)

Spring 2020
TUT Section: T1 TBA Frederick W. Strauch

PHYS 315 (S) Computational Biology  (QFR)
Cross-listings: PHYS 315 CSCI 315
Primary Cross-listing
This course will provide an overview of Computational Biology, the application of computational, mathematical, statistical, and physical problem-solving techniques to interpret the rapidly expanding amount of biological data. Topics covered will include database searching, DNA sequence alignment, clustering, RNA structure prediction, protein structural alignment, methods of analyzing gene expression, networks, and genome assembly using techniques such as string matching, dynamic programming, hidden Markov models, and expectation-maximization.
Class Format: lab three hours per week plus weekly tutorial meeting
Requirements/Evaluation: evaluation will be based on weekly Python programming assignments, problem sets, a few quizzes and a final project
Prerequisites: programming experience (e.g., CSCI 136), mathematics (PHYS/MATH 210 or MATH 150), and physical science (PHYS 142 or 151, or CHEM 151 or 153 or 155), or permission of instructor
Enrollment Limit: 10
Enrollment Preferences: based on seniority
Expected Class Size: 8
Grading: no pass/fail option, no fifth course option
Distributions: (D3) (QFR)
This course is cross-listed and the prefixes carry the following divisional credit:
PHYS 315 (D3) CSCI 315 (D3)
Attributes: BIGP Recommended Courses
PHYS 316 (S) Protecting Information: Applications of Abstract Algebra and Quantum Physics (QFR)

Secondary Cross-listing

Living in the information age, we find ourselves depending more and more on codes that protect messages against either noise or eavesdropping. This course examines some of the most important codes currently being used to protect information, including linear codes, which in addition to being mathematically elegant are the most practical codes for error correction, and the RSA public key cryptographic scheme, popular nowadays for internet applications. We also study the standard AES system as well as an increasingly popular cryptographic strategy based on elliptic curves. Looking ahead by a decade or more, we show how a quantum computer could crack the RSA scheme in short order, and how quantum cryptographic devices will achieve security through the inherent unpredictability of quantum events.

Class Format: lecture

Requirements/Evaluation: homework sets and exams

Prerequisites: PHYS/MATH 210 or MATH 250 (possibly concurrent) or permission of instructors; students not satisfying the course prerequisites but who have completed MATH 200 or MATH 209 are particularly encouraged to ask to be admitted

Enrollment Limit: 50

Enrollment Preferences: discretion of the instructors

Expected Class Size: 35

Grading: yes pass/fail option, yes fifth course option

Distributions: (D3) (QFR)

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 316 (D3) MATH 316 (D3)

Not offered current academic year

PHYS 319 (F) Integrative Bioinformatics, Genomics, and Proteomics Lab (QFR)

Secondary Cross-listing

What can computational biology teach us about cancer? In this capstone experience for the Genomics, Proteomics, and Bioinformatics program, computational analysis and wet-lab investigations will inform each other, as students majoring in biology, chemistry, computer science, mathematics/statistics, and physics contribute their own expertise to explore how ever-growing gene and protein data-sets can provide key insights into human disease. In this course, we will take advantage of one well-studied system, the highly conserved Ras-related family of proteins, which play a central role in numerous fundamental processes within the cell. The course will integrate bioinformatics and molecular biology, using database searching, alignments and pattern matching, phylogenetics, and recombinant DNA techniques to reconstruct the evolution of gene families by focusing on the gene duplication events and gene rearrangements that have occurred over the course of eukaryotic speciation. By utilizing high through-put approaches to investigate genes involved in the MAPK signal transduction pathway in human colon cancer cell lines, students will uncover regulatory mechanisms that are aberrantly altered by siRNA knockdown of putative regulatory components. This functional genomic strategy will be coupled with independent projects using phosphorylation-state specific antisera to test our hypotheses. Proteomic analysis will introduce the students to de novo structural prediction and threading algorithms, as well as data-mining approaches and Bayesian modeling of protein network dynamics in single cells. Flow cytometry and mass spectrometry will be used to study networks of interacting proteins in colon tumor cells.

Class Format: two afternoons of lab, with one hour of lecture, per week

Requirements/Evaluation: lab participation, several short homework assignments, one lab report, a programming project, and a grant proposal

Prerequisites: BIOL 202; students who have not taken BIOL 202 but have taken BIOL 101 and CSCI 315 or PHYS 315, may enroll with permission of instructor. No prior computer programming experience is required.

Enrollment Limit: 12

Enrollment Preferences: seniors, then juniors, then sophomores
Expected Class Size: 12
Grading: yes pass/fail option, yes fifth course option
Unit Notes: does not satisfy the distribution requirement for the Biology major
Distributions: (D3) (QFR)
This course is cross-listed and the prefixes carry the following divisional credit:
BIOL 319 (D3) CSCI 319 (D3) MATH 319 (D3) PHYS 319 (D3) CHEM 319 (D3)
Attributes: BIGP Core Courses BIMO Interdepartmental Electives
Not offered current academic year

PHYS 321  (F) Introduction to Particle Physics  (QFR)
The Standard Model of particle physics incorporates special relativity, quantum mechanics, and almost all that we know about elementary particles and their interactions. This course introduces some of the main ideas and phenomena associated with the Standard Model. After a review of relativistic kinematics, we will learn about symmetries in particle physics, Feynman diagrams, and selected applications of quantum electrodynamics, the weak interactions, and quantum chromodynamics. We will conclude with a discussion of spontaneous symmetry breaking and the Higgs mechanism.

Class Format: lecture / seminar, three hours a week
Requirements/Evaluation: weekly problem sets and a final exam
Prerequisites: PHYS 301, which may be taken concurrently, plus permission of instructor
Enrollment Limit: 15
Expected Class Size: 10
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3) (QFR)

Fall 2019
LEC Section: 01    MW 11:00 am - 12:15 pm     Savan Kharel

PHYS 402  (S) Applications of Quantum Mechanics  (QFR)
This course will explore a number of important topics in the application of quantum mechanics to physical systems, including perturbation theory, the variational principle and the semiclassical interaction of atoms and radiation. The course will finish up with three weeks on quantum optics including an experimental project on non-classical interference phenomena. Applications and examples will be taken mostly from atomic physics with some discussion of solid state systems.

Class Format: tutorial, 1 and 1/4 hours per week; lecture, one hour per week
Requirements/Evaluation: evaluation will be based on weekly problem sets, tutorial participation, presentations, and a final exam, all of which have a substantial quantitative component
Prerequisites: PHYS 301
Enrollment Limit: 10 per sec
Expected Class Size: 16
Grading: no pass/fail option, no fifth course option
Distributions: (D3) (QFR)
Not offered current academic year

PHYS 404  (S) Unsolved Problems in Galaxy Evolution
Cross-listings: PHYS 404 ASTR 404
Secondary Cross-listing
In this tutorial, we will learn about galaxies and their evolution by focusing on some of the key mysteries astronomers are trying to solve. Questions may include: How do galaxies turn their gas supply into stars? Is there a universal initial mass function for star formation? What is the origin of multiple stellar populations in globular clusters? Why do some galaxies cease star formation? Which galaxies reionized the universe? We will discuss the
nature of each unsolved problem, debate the theories proposed to answer it, and consider how future progress might be made.

Class Format: tutorial

Requirements/Evaluation: based on the student's papers, responses to the partner's papers, and problem sets

Prerequisites: ASTR 111 and PHYS 142 or 151 or permission of instructor

Enrollment Limit: 10

Expected Class Size: 6

Grading: no pass/fail option, no fifth course option

Distributions: (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 404 (D3) ASTR 404 (D3)

Spring 2020

TUT Section: T1   TBA   Anne Jaskot

PHYS 405 (F) Electromagnetic Theory (QFR)

This course builds on the material of Physics 201, and explores the application of Maxwell's Equations to understand a range of topics including electric fields and matter, magnetic materials, light, and radiation. As we explore diverse phenomena, we will learn useful approximation techniques and beautiful mathematical tools. In addition to weekly tutorial meetings, the class will meet once a week as a whole to introduce new material.

Class Format: tutorial, one hour per week; lecture, one hour per week

Requirements/Evaluation: evaluation will be based on weekly problem sets, tutorial participation, presentations, and a final exam or final project, all of which have a substantial quantitative component

Prerequisites: PHYS 202 and PHYS/MATH 210 or MATH 209 or MATH 309

Enrollment Limit: 10/section

Expected Class Size: 16

Grading: no pass/fail option, no fifth course option

Distributions: (D3) (QFR)

Fall 2019

TUT Section: T1   F 1:10 pm - 2:25 pm   Daniel P. Aalberts
TUT Section: T2   F 1:10 pm - 2:25 pm   Daniel P. Aalberts
TUT Section: T3   F 1:10 pm - 2:25 pm   Daniel P. Aalberts

PHYS 411 (F) Classical Mechanics (QFR)

This course will explore advanced topics in classical mechanics including the calculus of variations, the Lagrangian and Hamiltonian formulations of mechanics, phase space, non-linear dynamics and chaos, central-force motion, non-inertial reference frames (including implications for physics on a rotating Earth), and rigid-body rotations. Numerical and perturbative techniques will be developed and used extensively. We will also examine the ways in which classical mechanics informs other fields of physics. In addition to weekly tutorial meetings the class with will meet once a week as a whole to discuss new material.

Class Format: tutorial, 1 and 1/4 hours per week; lecture, one hour per week

Requirements/Evaluation: evaluation will be based on weekly problem sets, tutorial participation, presentations, a final project, and a final exam, all of which have a substantial quantitative component

Prerequisites: PHYS 202 and PHYS/MATH 210 or MATH 209

Enrollment Limit: 10/section

Expected Class Size: 25

Grading: no pass/fail option, no fifth course option
**Distributions:** (D3) (QFR)

**Not offered current academic year**

**PHYS 412 (F) Heliophysics**

**Cross-listings:** ASTR 412  PHYS 412

**Secondary Cross-listing**

We study all aspects of the Sun, our nearest star. This semester follows the total solar eclipses of August 21, 2017, whose totality crossed the U.S. from coast to coast, and the July 2, 2019, total solar eclipse that crossed Chile and Argentina. In addition to discussing our observations of these eclipses and what has been learned about the solar atmosphere from eclipse research, we discuss the solar interior (including the Nobel-prize-winning solar neutrino experiment and helioseismology), the photosphere, the chromosphere, the corona, and the solar wind. We discuss the Sun as an example of stars in general. We discuss both theoretical aspects and observational techniques, including work at recent total solar eclipses. We discuss results from current spacecraft, including the Solar and Heliospheric Observatory (SOHO), the Solar Dynamics Observatory, the Sun Watcher (SWAP), and Hinode (Sunrise), and the new GOES/UVSI (Solar Ultraviolet Imager) run by an alumnus as well as additional Total Solar Irradiance measurements from ACRIMSAT and SORCE. We will discuss the role of solar observations in confirming Einstein's General Theory of Relativity with the bending of light at the 1919, 1922, and 2017 total solar eclipses as well as gravitational redshift measurements in solar spectral lines, extending our discussion to the recent "chirp" of gravitational radiation reported from several colliding black holes and neutron stars observed with the Laser Interferometer Gravitational-wave Observatory (LIGO). We hope to observe the transit of Mercury across the face of the Sun on November 11, 2019, during the semester; we also discuss our data analysis of recent transits of Mercury we observed from the ground and from space (most recently in May 2016). We will highlight the 2004 and 2012 transits of Venus across the face of the Sun as observed from Earth, the first such transits of Venus since 1882, as well as our work in observing transits of Venus from Jupiter with the Hubble.

**Class Format:** tutorial

**Requirements/Evaluation:** biweekly tutorial presentations; biweekly response to colleagues' presentations

**Prerequisites:** ASTR 111 or a 200-level Physics course; or permission of the instructor

**Enrollment Limit:** 10

**Expected Class Size:** 10

**Grading:** no pass/fail option, no fifth course option

**Distributions:** (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

ASTR 412 (D3) PHYS 412 (D3)

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**PHYS 418 (S) Gravity** (QFR)

This course is an introduction Einstein's theory of general relativity. We begin with a review of special relativity, emphasizing geometrical aspects of Minkowski spacetime. Working from the equivalence principle, we then motivate gravity as spacetime curvature, and study in detail the Schwarzschild geometry around a spherically symmetric mass. After this application, we use tensors to develop Einstein's equation, which describes how energy density curves spacetime. With this equation in hand we study the Friedmann-Robertson-Walker geometries for an expanding universe, and finally, we linearize Einstein's equation to develop the theory of gravitational waves.

**Class Format:** lecture

**Requirements/Evaluation:** evaluation will be based on weekly problem sets, a midterm exam, and a final exam, all of which have a substantial quantitative component

**Prerequisites:** PHYS 301 or PHYS 405 or PHYS 411. PLEASE DELETE: *students with strong math backgrounds are invited to consult with the instructor

**Enrollment Limit:** none

**Expected Class Size:** 10

**Grading:** no pass/fail option, yes fifth course option
PHYS 451 (S) Condensed Matter Physics (QFR)
Condensed matter physics is an important area of current research and serves as the basis for modern electronic technology. We plan to explore the physics of metals, insulators, semiconductors, superconductors, and photonic crystals, with particular attention to structure, thermal properties, energy bands, and electronic properties.

Class Format: seminar
Requirements/Evaluation: weekly readings and problem sets, and exams
Prerequisites: Phys 301, Phys 302 (may be taken simultaneously) preferred; or permission of instructor
Enrollment Limit: 10
Enrollment Preferences: Physics majors
Expected Class Size: 4-6
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3) (QFR)
Attributes: MTSC Courses
Not offered current academic year

PHYS 493 (F) Senior Research: Physics
An original experimental or theoretical investigation is carried out under the direction of a faculty member in Physics, as discussed above under the heading of The Degree with Honors in Physics.

Class Format: independent study
Prerequisites: permission of department; senior course
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3)

PHYS 494 (S) Senior Research: Physics
An original experimental or theoretical investigation is carried out under the direction of a faculty member in Physics, as discussed above under the heading of The Degree with Honors in Physics.

Class Format: independent study
Prerequisites: permission of department; senior course
Grading: yes pass/fail option, yes fifth course option
Distributions: (D3)

PHYS 495 (F) Senior Research: Astrophysics
Cross-listings: PHYS 495 ASTR 495
Secondary Cross-listing
An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy or Physics, as discussed under the heading of the degree with honors in Astrophysics above.

**Class Format:** independent study

**Prerequisites:** permission of department

**Grading:** no pass/fail option, no fifth course option

**Distributions:** (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 495 (D3) ASTR 495 (D3)

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**PHYS 496 (S) Senior Research: Astrophysics**

**Cross-listings:** PHYS 496 ASTR 496

**Secondary Cross-listing**

An original experimental or theoretical investigation is carried out under the direction of a faculty member in Astronomy or Physics, as discussed under the heading of the degree with honors in Astrophysics above.

**Class Format:** independent study

**Prerequisites:** permission of department

**Grading:** no pass/fail option, no fifth course option

**Distributions:** (D3)

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 496 (D3) ASTR 496 (D3)

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**PHYS 497 (F) Independent Study: Physics**

Physics independent study.

**Class Format:** independent study

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3)

Fall 2019

IND Section: 01 TBA Frederick W. Strauch

**PHYS 498 (S) Independent Study: Physics**

Physics independent study.

**Class Format:** independent study

**Grading:** yes pass/fail option, yes fifth course option

**Distributions:** (D3)

Spring 2020

IND Section: 01 TBA Frederick W. Strauch
PHYS 499  (F)(S)  Physics and Astronomy Colloquium

Cross-listings:  PHYS 499  ASTR 499

Primary Cross-listing

Physicists and Astronomers from around the country come to explain their research. Students of Physics and Astronomy at any level are welcome. Registration is not necessary to attend. A non-credit course.

Class Format: colloquium

Requirements/Evaluation:  not a for-credit course

Extra Info:  registration not necessary to attend

Prerequisites:  none

Enrollment Limit:  none

Grading:  non-graded

Distributions:  No divisional credit

This course is cross-listed and the prefixes carry the following divisional credit:

PHYS 499 No divisional credit  ASTR 499 No divisional credit

Fall 2019

LEC Section: 01  F 2:30 pm - 4:00 pm  Frederick W. Strauch

Spring 2020

LEC Section: 01  F 2:30 pm - 4:00 pm  Frederick W. Strauch