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## Physical Sciences 2

Mechanics, Elasticity, Fluids, and Diffusion (122575)

*Gregory Kestin*

*Louis Deslauriers*

2020 Fall (4 Credits)

**Schedule:** TR 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**An introduction to classical mechanics, with special emphasis on the motion of organisms in fluids. Topics covered include: kinematics, Newton's laws of motion, oscillations, elasticity, random walks, diffusion, and fluids. Examples and problem set questions will be drawn from the life sciences and medicine.**

**Recommended Prep:** Physical Sciences 1 (or Chemistry 7), Mathematics 1b, or the equivalent.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physical Sciences 3

Electromagnetism, Circuits, Waves, Optics, and Imaging (122576)

*Roxanne Guenette, Louis Deslauriers, Greg Kestin*

2021 Spring (4 Credits)

**Schedule:** TR 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**This course is an introduction to electromagnetism, digital information, waves, optics and sound. Topics**

covered include: electric and magnetic fields, electrical potential, circuits, simple digital circuits, wave propagation in various media, microscopy, sound and hearing. The course will draw upon a variety of applications to the biological sciences and will use real-world examples to illustrate many of the physical principles described. There are six laboratories.

**Course Notes:** This course is part of an integrated introduction to the physical sciences intended for students who plan to pursue a concentration in the life sciences and/or satisfy pre-medical requirements in Physics. May not ordinarily be taken for credit in addition to Physics 1b, 11b, or 15b.

**Recommended Prep:** Physical Sciences 2 (or Physics 1a or 11a), Mathematics 1b, or equivalent.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | Primarily for Undergraduate Students     |

## Physical Sciences 12A

Mechanics and Statistical Physics from an Analytic, Numerical and Experimental Perspective (109274)

*Efthimios Kaxiras*

*Camille Gomez-Laberge*

2021 Spring (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

This is the first term of a two-semester introductory physical science and engineering course sequence. The focus is on quantitative scientific reasoning, with the first term's exploration framed in the context of basic mechanics. Students will gain competence in both analytic (using pencil, paper and single-variable calculus) and numerical (using computer modeling) approaches to modeling simple physical systems and for the analysis of experimental data. Topics include kinematics, linear and rotational motion, forces, energy, momentum, collisions, gravitation, oscillations, and a brief introduction to statistical physics and waves. Examples are drawn from across the physical sciences and engineering. The course is aimed at first year students who have an interest in pursuing a concentration in the sciences and/or engineering. The course structure includes lecture, discussion and laboratory components.

**Course Notes:** Physical Sciences 12a may not be taken for credit by students who have passed Physics 11a, 15a or 16.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

## Physical Sciences 12B

Electromagnetism and Quantum Physics from an Analytic, Numerical and Experimental Perspective (109457)

Susanne Yelin, Camille Gomez-Laberge

2020 Fall (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

This is the second term of a two-semester introductory physical science and engineering course sequence that uses a combination of analytic and numerical methods to understand physical systems. Topics include electrostatics and magnetostatics, electromagnetic fields, optics [all topics illustrated with applications to current technological and societal challenges], and an introduction to quantum physics, including basic concepts and their application in understanding modern devices, like the laser, the light-emitting diode and the photovoltaic cell. The course is aimed at second year students who have an interest in pursuing a concentration in the sciences and/or engineering. The course structure includes lecture, discussion and laboratory components. The course assumes familiarity with the concepts of mechanics and statistical physics as they are covered in PHYSICI-12A.

**Course Notes:** May not be taken for credit by students who have passed Physics 15b or Physics 15c.

**Recommended Prep:** Physical Sciences 12a

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physical Sciences 70

Introduction to Digital Fabrication (215717)

*Robert Hart*

2021 Spring (4 Credits)

**Schedule:** TR 0300 PM - 0415 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 20

A hands-on introduction to rapid prototyping, integrating physics and engineering, design, computer science and art. Students will learn to safely use software and hardware to fabricate programmable projects. Tools and topics will include shop safety, hand tools, laser cutting, 3D printing, computer-controlled milling, electronic circuit design, programmable microcontrollers, and molding and casting. Applications may include personal fabrication, product prototyping, fine arts and the creation of scientific research tools. The course will culminate with an individual final project, integrating as many of the topics as possible. Each student will document work on each weekly topic in a personal website, thereby finishing the course with an online portfolio that not only illustrates their new skill sets, but also contributes to a collective repository of knowledge that serves as a foundation for continued learning.

**Course website:** <https://tinyurl.com/tasr7b6>

**Related Sections:** Coursework will mostly be conducted independently through open lab time. Lab access will be 24/7 once online lab safety training is complete. TFs will be available during flexibly scheduled lab times. For some topics, supervision will be needed as students learn to operate machines safely.

**Course Notes:** Attendance is mandatory since lab safety training will occur during class times. Class will meet twice each week. The first meeting will consist of a discussion of the previous week's assignment, with each student reporting on progress, followed by a short introduction to the current week's topic and assignment. The second meeting may include a short lecture but will primarily focus on a hands-on training session

for the accompanying assignment. Meetings may also include appearances by local experts and field trips.

**Recommended Prep:**

There are no formal prerequisites for this course. Students are expected to bring their own laptop computer (tablets and Chromebooks are not sufficient for some of the software required for this course, though students will have access to lab computers). This course is accessible to those with no prior experience. For students already familiar with some of the topics, it will be an opportunity to explore further.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

# Physics

## Subject: Physics

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### Physics 15A

Introductory Mechanics and Relativity (111164)

*Julia Mundy*

*Keith Zengel*

2021 Spring (4 Credits)

**Schedule:**

TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Newtonian mechanics and special relativity. Topics include vectors; kinematics in three dimensions; Newton's laws; force, work, power; conservative forces, potential energy; momentum, collisions; rotational motion, angular momentum, torque; static equilibrium, simple harmonic motion, damped and driven oscillations; gravitation; fictitious forces; fluids; special relativity.**

**Course Notes:**

Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15a. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.

**Recommended Prep:**

Mathematics preparation at least at the level of Mathematics 1b concurrently is required. However, some elementary ideas from multivariable calculus may be used and students are encouraged to take Mathematics 21a concurrently.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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### Physics 15A

Introductory Mechanics and Relativity (111164)

*David Morin*

*Amir Yacoby*

*Keith Zengel*

2020 Fall (4 Credits)

**Schedule:**

TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Newtonian mechanics and special relativity. Topics include vectors; kinematics in three dimensions; Newton's laws; force, work, power; conservative forces, potential energy; momentum, collisions; rotational motion, angular momentum, torque; static equilibrium, simple harmonic motion, damped and driven oscillations; gravitation; fictitious forces; fluids; special relativity.**

**Course Notes:**

Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15a. Topics include experimental design, model testing, error

analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.

**Recommended Prep:** Mathematics preparation at least at the level of Mathematics 1b concurrently is required. However, some elementary ideas from multivariable calculus may be used and students are encouraged to take Mathematics 21a concurrently.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 15B

Introductory Electromagnetism and Statistical Physics (111896)

*Girma Hailu*

*Robert Westervelt*      *Keith Zengel*

2020 Fall (4 Credits)

**Schedule:**

TR 1200 PM - 0115 PM

**Instructor Permissions:**    None

**Enrollment Cap:**

n/a

**Electricity and magnetism. Topics include electrostatics, electric currents, magnetic field, electromagnetic induction, Maxwell's equations, electromagnetic radiation, magnetic fields in materials, and some basic notions in kinetic theory, entropy, temperature, and phase transition associated with electricity and magnetism.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15b. Students use creative problem-solving in applying theoretical topics to explore physical phenomena and design real life applications. Topics include experimental design, model testing, error analysis, basic programming, introductory circuit analysis, and practical applications of electromagnetism. PSI will meet weekly throughout the semester.**

**Recommended Prep:**

**Physics 15a, Physics 16, or written permission of the Head Tutor in Physics. Mathematics preparation at least at the level of Mathematics 21a taken concurrently is required. Vector calculus, (div, grad and curl) are used extensively--in principle, this is taught in the course. Students taking Mathematics 21a concurrently will likely find that some concepts are introduced in Physics 15b before they have seen them in Mathematics 21a. Some students may wish to postpone Physics 15b until they have completed Mathematics 21a.**

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 15B

Introductory Electromagnetism and Statistical Physics (111896)

2021 Spring (4 Credits) **Instructor Permissions:** None **Schedule:** TR 1200 PM - 0115 PM  
**Enrollment Cap:** n/a

**Electricity and magnetism.** Topics include electrostatics, electric currents, magnetic field, electromagnetic induction, Maxwell's equations, electromagnetic radiation, magnetic fields in materials, and some basic notions in kinetic theory, entropy, temperature, and phase transition associated with electricity and magnetism.

**Course Notes:** Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15b. Students use creative problem-solving in applying theoretical topics to explore physical phenomena and design real life applications. Topics include experimental design, model testing, error analysis, basic programming, introductory circuit analysis, and practical applications of electromagnetism. PSI will meet weekly throughout the semester.

**Recommended Prep:** Physics 15a, Physics 16, or written permission of the Head Tutor in Physics. Mathematics preparation at least at the level of Mathematics 21a taken concurrently is required. Vector calculus, (div, grad and curl) are used extensively--in principle, this is taught in the course. Students taking Mathematics 21a concurrently will likely find that some concepts are introduced in Physics 15b before they have seen them in Mathematics 21a. Some students may wish to postpone Physics 15b until they have completed Mathematics 21a.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 15C

Wave Phenomena (124154)

Matteo Mitrano

Markus Greiner

2020 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM  
**Instructor Permissions:** None **Enrollment Cap:** n/a

**Forced oscillation and resonance; coupled oscillators and normal modes; Fourier series; Electromagnetic waves, radiation, longitudinal oscillations, sound; traveling waves; signals, wave packets and group velocity; two- and three-dimensional waves; polarization; geometrical and physical optics; interference and diffraction. Optional topics: Water waves, holography, x-ray crystallography, solitons, music, quantum mechanics, and waves in the early universe.**

**Course Notes:** Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15c. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.

**Recommended Prep:** Physics 15a, Physics 15b, or written permission of the Head Tutor in Physics. Mathematics preparation at least at the level of Mathematics

21b taken concurrently is required. Some prior knowledge of complex numbers (for example as taught in Mathematics 1b) is helpful. Linear algebra and differential equations are used extensively. Students taking Mathematics 21b concurrently will likely find that some concepts are introduced in Physics 15c before they have seen them in Mathematics 21b. Some students may wish to postpone Physics 15c until they have completed Mathematics 21b.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

## Physics 15C

Wave Phenomena (124154)

*John Huth*

*Mara Prentiss*

2021 Spring (4 Credits)

**Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Forced oscillation and resonance; coupled oscillators and normal modes; Fourier series; Electromagnetic waves, radiation, longitudinal oscillations, sound; traveling waves; signals, wave packets and group velocity; two- and three-dimensional waves; polarization; geometrical and physical optics; interference and diffraction. Optional topics: Water waves, holography, x-ray crystallography, solitons, music, quantum mechanics, and waves in the early universe.**

**Course Notes:** Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15c. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.

**Recommended Prep:** Physics 15a, Physics 15b, or written permission of the Head Tutor in Physics. Mathematics preparation at least at the level of Mathematics 21b taken concurrently is required. Some prior knowledge of complex numbers (for example as taught in Mathematics 1b) is helpful. Linear algebra and differential equations are used extensively. Students taking Mathematics 21b concurrently will likely find that some concepts are introduced in Physics 15c before they have seen them in Mathematics 21b. Some students may wish to postpone Physics 15c until they have completed Mathematics 21b.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | Primarily for Undergraduate Students     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

## Physics 16

Mechanics and Special Relativity (111197)

Howard Georgi

Keith Zengel

2020 Fall (4 Credits)

Schedule:

TR 1200 PM - 0115 PM

Instructor Permissions: None

Enrollment Cap:

n/a

Newtonian mechanics and special relativity for students with good preparation in physics and mathematics at the level of the advanced placement curriculum. Topics include oscillators damped and driven and resonance (how to rock your car out of a snow bank or use a swing), an introduction to Lagrangian mechanics and optimization, symmetries and Noether's theorem, special relativity, collisions and scattering, rotational motion, angular momentum, torque, the inertia tensor (dynamic balance), gravitation, planetary motion and a little glimpse of quantum mechanics.

**Course Notes:**

Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 16. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester. Emphasis is placed on collaborative teaching and learning. Many class materials are Mathematics notebooks.

**Recommended Prep:**

Score of 5 on the mechanics section of the Physics C Advanced Placement exam, or equivalent. Mathematics preparation at least at the level of Mathematics 21a taken concurrently is required. Thorough knowledge of calculus of one variable and vectors plus some mathematical sophistication. The mathematical level will be significantly higher than that of Physics 15a. If in doubt, check the Canvas site ahead of time, or email the professor at [hgeorgi@fas.harvard.edu](mailto:hgeorgi@fas.harvard.edu), or just shop.

**Additional Course Attributes:**

| Attribute                        | Value(s)                                 |
|----------------------------------|--|
| FAS Divisional Distribution      | Science & Engineering & Applied Science  |
| Quantitative Reasoning with Data | Yes                                      |
| FAS: Course Level                | Primarily for Undergraduate Students     |
| All: Cross Reg Availability      | Available for Harvard Cross Registration |

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## Physics 90R

Supervised Research (111672)

David Morin

2020 Fall (4 Credits)

Schedule:

TBD

Instructor Permissions: Instructor

Enrollment Cap:

n/a

Primarily for selected concentrators in Physics, or in Chemistry and Physics, who have obtained honor grades in Physics 15 and a number of intermediate-level courses. The student must be accepted by some member of the faculty doing research in the student's field of interest. The form of the research depends on the student's interest and experience, the nature of the particular field of physics, and facilities and support available. Students wishing to write a senior thesis can do so by arranging for a sponsor and enrolling in this course.

**Course Notes:**

A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department Web page. Course enrollment forms may be obtained from Lyman 238.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 90R

Supervised Research (111672)

*David Morin*

2021 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Primarily for selected concentrators in Physics, or in Chemistry and Physics, who have obtained honor grades in Physics 15 and a number of intermediate-level courses. The student must be accepted by some member of the faculty doing research in the student's field of interest. The form of the research depends on the student's interest and experience, the nature of the particular field of physics, and facilities and support available. Students wishing to write a senior thesis can do so by arranging for a sponsor and enrolling in this course.

**Course Notes:** A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department Web page. Course enrollment forms may be obtained from Lyman 238.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 91R

Supervised Reading Course for Undergraduates (110569)

*David Morin*

2020 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

Open to selected concentrators in Physics, Chemistry and Physics, and other fields who wish to do supervised reading and studying of special topics in physics. Ordinarily such topics do not include those covered in a regular course of the Department. Honor grades in Physics 15 and a number of intermediate-level courses are ordinarily required. The student must be accepted by a member of the faculty.

**Course Notes:** A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department's website. Course enrollment forms may be obtained from Lyman 238.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Undergraduate Students     |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 91R

Supervised Reading Course for Undergraduates (110569)

*David Morin*

2021 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

Open to selected concentrators in Physics, Chemistry and Physics, and other fields who wish to do supervised reading and studying of special topics in physics. Ordinarily such topics do not include those covered in a regular course of the Department. Honor grades in Physics 15 and a number of intermediate-level courses are ordinarily required. The student must be accepted by a member of the faculty.

**Course Notes:** A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department's website. Course enrollment forms may be obtained from Lyman 238.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Undergraduate Students     |

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## Physics 95

Topics in Current Research (111967)

*Eric Mazur*

2020 Fall (4 Credits)

**Schedule:** W 0715 PM - 0845 PM  
M 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

The goal of this tutorial is twofold. First, students will learn about a range of modern physics research topics from experts at Harvard as well as from one another. Every Wednesday evening a faculty member speaks on his/her area of research, preceded by assigned reading and a student presentation designed to introduce the basic physics, as well as important developments and burning problems at the frontiers of that particular research area. Second, the tutorial provides structured activities to help students develop practical skills for their future careers, expanding knowledge on unfamiliar subjects, participating in discussions, presenting and writing clearly about complex topics, and engaging in self and peer evaluation.

**Course Notes:** Primarily for junior and senior concentrators, however interested sophomores are welcome. Individual meetings for students will be held Tuesdays, 9:00am - 10:15am, in Prof. Mazur's office, Pierce 233.

**Class Notes:** Additional one-on-one meetings will be scheduled on Tuesdays from 9:00-10:15am.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Undergraduate Students     |

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## Physics 123

Laboratory Electronics (124108)

*Thomas Hayes*

2021 Spring (4 Credits)

**Schedule:** TR 0130 PM - 0545 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 20

**A lab-intensive introduction to electronic circuit design. Develops circuit intuition and debugging skills through daily hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. Moves quickly from passive circuits, to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters. The digital half of the course treats analog-digital interfacing, emphasizes the use of microcontrollers and programmable logic devices (PLDs).**

**Course Notes:**

**Physics 123 is the same course as Physics 223; if you are a graduate student, please enroll in 223. Limited to 20 students. Physics 123 is also offered as Engineering Sciences 153. Students may not take both for credit. Undergraduate engineering students should enroll in Engineering Sciences 153.**

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

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## Physics 123

Laboratory Electronics (124108)

*David Abrams*

2020 Fall (4 Credits)

**Schedule:** TR 0130 PM - 0545 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 20

**A lab-intensive introduction to electronic circuit design. Develops circuit intuition and debugging skills through daily hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. Moves quickly from passive circuits, to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters. The digital half of the course treats analog-digital interfacing, emphasizes the use of microcontrollers and programmable logic devices (PLDs).**

**Course Notes:**

**Physics 123 is the same course as Physics 223; if you are a graduate student, please enroll in 223. Limited to 20 students. Physics 123 is also offered as Engineering Sciences 153. Students may not take both for credit. Undergraduate engineering students should enroll in Engineering Sciences 153.**

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

**Physics 125**

Widely Applied Physics (120167)

*David Morin*

2021 Spring (4 Credits)

**Schedule:** WF 1200 PM - 0115 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

Uses physics to analyze important technologies and real-world systems. Stresses estimation and "back of the envelope" calculations, as are commonly used by research physicists. New physical concepts are introduced as necessary. Example topics: energy production and storage, nuclear physics, nuclear power and weapons, health effects of radiation, risk analysis, airplanes, spy satellites, rockets, fluids, water waves, mechanical design and failure, global warming, and cosmology. Emphasis is on developing physical intuition and the ability to do order-of-magnitude calculations.

**Recommended Prep:** Physics 15a, b, c, and mathematics at the level of Mathematics 21a. Physics 143a and 181 are very helpful, and may be taken concurrently.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

**Physics 129**

Energy Science (125656)

*Lene Hau*

2021 Spring (4 Credits)

**Schedule:** TR 0130 PM - 0245 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

Non-fossil energy sources and energy storage are important for our future. We cover four main subjects to which students with a background in physics and physical chemistry could make paradigm changing contributions: photovoltaic cells, nuclear power, batteries, and photosynthesis. Fundamentals of electrodynamics, statistical/thermal physics, and quantum mechanics are taught as needed to give students an understanding of the topics covered.

**Recommended Prep:** Physics 15a (or 16), 15b,c or 11a,b. Pre/co-requisite Physics 143a or Chemistry 160 or equivalent.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

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## Physics 141

The Physics of Sensory Systems in Biology (121885)

*Aravinthan Samuel*

2020 Fall (4 Credits)

**Schedule:**

TR 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

Living organisms use sensory systems to inform themselves of the sights, sounds, and smells of their surrounding environments. Sensory systems are physical measuring devices, and are therefore subject to certain limits imposed by physics. Here we will consider the physics of sensory measurement and perception, and study ways that biological systems have solved their underlying physical problems. We will discuss specific cases in vision, olfaction, and hearing from a physicist's point of view.

**Recommended Prep:** Math 21a,b, Physics 12 or 15, or by permission of the instructor.

**Requirements:** **Anti-Requisite:** Cannot be taken for credit if NEURO 141 already complete.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 143A

Quantum Mechanics I (108465)

*Masahiro Morii*

2021 Spring (4 Credits)

**Schedule:**

TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

Introduction to nonrelativistic quantum mechanics: uncertainty relations; Schrödinger equation; Dirac notation; matrix mechanics; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; angular momentum, hydrogen atom, spin, Pauli principle; and if time allows: time-independent perturbation theory; and scattering.

**Recommended Prep:** Linear algebra including matrix diagonalization; Physics 15c or written permission of the Head Tutor.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 143A

Quantum Mechanics I (108465)

*John Doyle*

2020 Fall (4 Credits)

**Schedule:**

TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Introduction to nonrelativistic quantum mechanics: uncertainty relations; Schrödinger equation; Dirac notation; matrix mechanics; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; angular momentum, hydrogen atom, spin, Pauli principle; and if time allows: time-independent perturbation theory; and scattering.**

**Recommended Prep:** Linear algebra including matrix diagonalization; Physics 15c or written permission of the Head Tutor.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

## Physics 143B

Quantum Mechanics II (111731)

*Lisa Randall*

2020 Fall (4 Credits)

**Schedule:**

WF 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Introduction to path integrals, identical particles, many-electron theory, WKB approximation, time-dependent perturbation theory, scattering theory, relativistic quantum mechanics, and basics of quantum information.**

**Recommended Prep:** Physics 143a.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

## Physics 145

Elementary Particle Physics (117719)

*Melissa Franklin*

2020 Fall (4 Credits)

**Schedule:**

WF 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Introduction to elementary particle physics. Emphasis on concepts and phenomenology rather than on detailed calculational development of theories. Starts with the discovery of the electron in 1897 and ends with the theoretical motivations for the Higgs boson, and attempts to cover everything important in between. Students will also have a brief experience of particle physics research using Atlas experiment open data.**

**Recommended Prep:** Physics 143a. Physics 143b or equivalent is useful.

**Additional Course Attributes:**

| Attribute                        | Value(s)                                 |
|----------------------------------|--|
| All: Cross Reg Availability      | Available for Harvard Cross Registration |
| FAS: Course Level                | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution      | Science & Engineering & Applied Science  |
| Quantitative Reasoning with Data | Yes                                      |

**Physics 151**

Mechanics (111231)

*Arthur Jaffe*

2020 Fall (4 Credits)

**Schedule:**

TR 1200 PM - 0115 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**Fundamental ideas of classical mechanics including contact with modern work and applications. Topics include Lagrange's equations, the role of variational principles, symmetry and conservation laws, Hamilton's equations, Hamilton-Jacobi theory and phase space dynamics. Applications to celestial mechanics, quantum mechanics, the theory of small oscillations and classical fields, and nonlinear oscillations, including chaotic systems presented.**

**Recommended Prep:** Physics 15a, 15b or written permission of the Head Tutor; Mathematics 21a, b or equivalent.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 153**

Electrodynamics (111822)

*Girma Hailu*

2021 Spring (4 Credits)

**Schedule:**

MW 1200 PM - 0115 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**Aimed at advanced undergraduates. Emphasis on the properties and sources of the electromagnetic fields and on the wave aspects of the fields. Course starts with electrostatics and subsequently develops the Maxwell equations. Topics: electrostatics, dielectrics, magnetostatics, electrodynamics, radiation, wave propagation in various media, wave optics, diffraction and interference. A number of applications of electrodynamics and optics in modern physics are discussed.**

**Recommended Prep:** Physics 15a, b, and c, or written permission of the Head Tutor; Mathematics 21a, b or equivalent.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |

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## Physics 175

Laser Physics and Modern Optical Physics (121941)

Markus Greiner

2021 Spring (4 Credits)

**Schedule:** WF 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduction to laser physics and modern optical physics aimed at advanced undergraduates. Review of electromagnetic theory and relevant aspects of quantum mechanics. Wave nature of light. Physics of basic optical elements. Propagation of focused beams, optical resonators, dielectric waveguides. Interaction of light with matter, introduction to quantum optics. Lasers. Physics of specific laser systems. Introduction to nonlinear optics. Modern applications.**

**Recommended Prep:** Physics 15b, 15c, 143a, or permission of the instructor.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 181

Statistical Mechanics and Thermodynamics (143450)

Matthew Schwartz

2021 Spring (4 Credits)

**Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**This course provides an introduction to statistical mechanics and thermal physics. It surveys the fundamental elements of classical and quantum statistical mechanics (ensembles and partition functions) and thermodynamics (temperature, heat, work, free energy) and their application to a variety of physical systems. Topics covered may include heat engines, solid-state physics, blackbody radiation, phase transitions, physical chemistry, stellar physics, quantum information, Bose-Einstein condensation, and transport phenomena.**

**Course Notes:** May not be taken for credit in addition to Engineering Sciences 181.

**Recommended Prep:** Physics 143a or equivalent.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 191

Advanced Laboratory (121993)

Isaac Silvera

**NOT OFFERED**

Jenny Hoffman

2020 Fall (4 Credits)

Schedule: TR 0130 PM - 0530 PM

Instructor Permissions: Instructor

Enrollment Cap: 20

Students carry out three experimental projects selected from those available representing condensed matter, atomic, nuclear, and particle physics. Included are pulsed nuclear magnetic resonance (with MRI), microwave spectroscopy, optical pumping, Raman scattering, scattering of laser light, nitrogen vacancies in diamond, neutron activation of radioactive isotopes, Compton scattering, relativistic mass of the electron, recoil free gamma-ray resonance, lifetime of the muon, studies of superfluid helium, positron annihilation, superconductivity, the quantum Hall effect, properties of semiconductors, and plasma physics. The facilities of the laboratory include several computer controlled experiments as well as computers for analysis.

Course Notes: A substantial amount of outside reading is expected. Physics 191 is the same course as Physics 247; if you are a graduate students, please enroll in 247.

The course is offered in Science Center 204.

Recommended Prep: Physics 15a or 16, 15b, 15c. Physics 143a is highly recommended; 181 is also useful.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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**Physics 191** Section: 001L

Advanced Laboratory (121993)

Isaac Silvera

Jenny Hoffman

2021 Spring (4 Credits)

Schedule: TR 0130 PM - 0530 PM

Instructor Permissions: Instructor

Enrollment Cap: n/a

Students carry out three experimental projects selected from those available representing condensed matter, atomic, nuclear, and particle physics. Included are pulsed nuclear magnetic resonance (with MRI), microwave spectroscopy, optical pumping, Raman scattering, scattering of laser light, nitrogen vacancies in diamond, neutron activation of radioactive isotopes, Compton scattering, relativistic mass of the electron, recoil free gamma-ray resonance, lifetime of the muon, studies of superfluid helium, positron annihilation, superconductivity, the quantum Hall effect, properties of semiconductors, and plasma physics. The facilities of the laboratory include several computer controlled experiments as well as computers for analysis.

Course Notes: A substantial amount of outside reading is expected. Physics 191 is the same course as Physics 247; if you are a graduate students, please enroll in 247.

The course is offered in Science Center 204.

Recommended Prep: Physics 15a or 16, 15b, 15c. Physics 143a is highly recommended; 181 is also useful.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 195**

Introduction to Solid State Physics (112107)

*Julia Mundy*

2020 Fall (4 Credits)

**Schedule:** MW 0300 PM - 0415 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

The physics of crystalline solids and their electric, magnetic, optical, and thermal properties. Designed as a first course in solid-state physics. Topics: free electron model; Drude model; the physics of crystal binding; crystal structure and vibration (phonons); x-ray diffraction; electrons in solids (Bloch theorem) and electronic band structures; metals and insulators; semiconductors (and their applications in pn junctions and transistors); magnetism; superconductivity.

**Course Notes:** Physics 195 is also offered as Applied Physics 195. Students may not take both for credit.

**Recommended Prep:** Physics 15a, 15b and 15c or the equivalent. Physics 143a. Physics 181 and Physics 143b (taken concurrently) helpful but not required.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | For Undergraduate and Graduate Students  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 201**

Data Analysis for Physicists (161201)

*Vinothan Manoharan*

2021 Spring (4 Credits)

**Schedule:** MWF 1030 AM - 1145 AM**Instructor Permissions:** None**Enrollment Cap:** n/a

This course covers methods for analyzing experimental data. Students will learn both frequentist and Bayesian frameworks for statistical inference, modern computational methods such as Markov-chain Monte Carlo techniques, and the application to problems in particle physics, biophysics, condensed matter, applied physics, astrophysics, and other fields. The course emphasizes an intuitive, principled approach to data analysis and will involve discussions of ethics and reproducible research.

**Course Notes:** This course is suitable for students with limited or rusty programming skills. Students with more advanced programming skills may wish to take APMTH 207 or ENG-SCI 255.

**Recommended Prep:** Research experience commensurate with that of a first-year (or higher) PhD student in experimental physics. Students without such experimental experience must have taken Physics 191 or Physics 247

(or equivalent) first.

**Additional Course Attributes:**

| Attribute                        | Value(s)                                 |
|----------------------------------|--|
| All: Cross Reg Availability      | Available for Harvard Cross Registration |
| FAS Divisional Distribution      | None                                     |
| Quantitative Reasoning with Data | Yes                                      |
| FAS: Course Level                | Primarily for Graduate Students          |

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## Physics 210

General Theory of Relativity (114266)

*Jacob Barandes*

2021 Spring (4 Credits)

**Schedule:**

MWF 0300 PM - 0415 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**An introduction to general relativity: the principle of equivalence, Riemannian geometry, Einstein's field equation, the Schwarzschild solution, the Newtonian limit, experimental tests, black holes.**

**Recommended Prep:** Physics 143a (quantum mechanics), 151 (mechanics) and 153 (electromagnetism), and Mathematics 21 (multivariable calculus) or equivalents.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 212

Cosmology (203431)

*Cora Dvorkin*

2020 Fall (4 Credits)

**Schedule:**

TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Graduate course on Physical Cosmology. Topics will include: the physics of Inflation, Cosmic Microwave Background anisotropies, evidence for Dark Matter, discovery of the accelerated expansion of the Universe, primordial gravitational waves, gravitational lensing, likelihood analysis, structure formation.**

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 220

Fluid Dynamics (110144)

L Mahadevan

2020 Fall (4 Credits)

Schedule: TBD

Instructor Permissions: None

Enrollment Cap: n/a

Continuum mechanics; conservation of mass and momentum, energy; stress, kinematics, and constitutive equations; vector and tensor calculus. Dimensional analysis and scaling. Navier-Stokes equations, Reynolds number. Solutions for simple flow states. Low Reynolds number flows; porous media flows; lubrication theory; gravity currents. Inviscid flows, Kelvin circulation theorem, Bernoulli integrals, Vortical flows. Waves in fluids; acoustics, shocks, water waves. Airfoil theory. Boundary layers. Flow instabilities. Mixing, and turbulence in unbounded and bounded flows.

Recommended Prep: Familiarity with dynamics, vectors, multivariable calculus, and partial differential equations. An undergraduate course in fluid dynamics or other continuum mechanics is strongly recommended.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | Primarily for Graduate Students          |

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## Physics 223

Electronics for Scientists (109346)

Thomas Hayes

2021 Spring (4 Credits)

Schedule: TR 0130 PM - 0545 PM

Instructor Permissions: Instructor

Enrollment Cap: 20

An introduction to electronic circuit design intended to develop circuit intuition and debugging skills through daily design exercises, discussion and hands-on lab exercises. The approach is intensely practical, minimizing theory. Moves quickly from passive circuits to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters. The digital half of the course treats analog-digital interfacing, emphasizes the use of microcontrollers and programmable logic devices (PLDs).

Course Notes: Physics 223 is the same course as Physics 123; if you are an undergraduate student, please enroll in 123. Limited to 20 students.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 223

Electronics for Scientists (109346)

David Abrams

2020 Fall (4 Credits)

Schedule:

TR 0130 PM - 0545 PM

Instructor Permissions: Instructor

Enrollment Cap:

20

An introduction to electronic circuit design intended to develop circuit intuition and debugging skills through daily design exercises, discussion and hands-on lab exercises. The approach is intensely practical, minimizing theory. Moves quickly from passive circuits to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters. The digital half of the course treats analog-digital interfacing, emphasizes the use of microcontrollers and programmable logic devices (PLDs).

Course Notes: Physics 223 is the same course as Physics 123; if you are an undergraduate student, please enroll in 123. Limited to 20 students.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

### Physics 232

Advanced Electromagnetism (112263)

Girma Hailu

2021 Spring (4 Credits)

Schedule:

MWF 0300 PM - 0415 PM

Instructor Permissions: None

Enrollment Cap:

n/a

Maxwell's equations in macroscopic media, conservation laws, Green's functions, time-dependent solutions and radiation, scattering and diffraction, and gauge invariance. Time permitting: geometrical optics and caustics, negative refractive index materials and radiation from rapidly accelerating charges.

Recommended Prep: Physics 153 and Applied Mathematics 105a, 105b, or equivalent.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

### Physics 247

Laboratory Course in Contemporary Physics (145024)

Isaac Silvera

Jenny Hoffman

2021 Spring (4 Credits)

Schedule:

TR 0130 PM - 0530 PM

Instructor Permissions: Instructor

Enrollment Cap:

20

Students carry out three experimental projects selected from those available representing condensed matter, atomic, nuclear, and particle physics. Included are pulsed nuclear magnetic resonance (with MRI), microwave spectroscopy, optical pumping, Raman scattering, scattering of laser light, nitrogen vacancies in diamond, neutron activation of radioactive isotopes, Compton scattering, relativistic mass of the

**LIKELY CANCELLED IN SPRING 2021**

electron, recoil free gamma-ray resonance, lifetime of the muon, studies of superfluid helium, positron annihilation, superconductivity, the quantum Hall effect, properties of semiconductors, and plasma physics. The facilities of the laboratory include several computer controlled experiments as well as computers for analysis.

**Course Notes:** A substantial amount of outside reading is expected. Physics 247 is the same course as Physics 191; if you are an undergraduate, please enroll in 191.

The course is offered in Science Center 204.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

## Physics 247

Laboratory Course in Contemporary Physics (145024)

*Isaac Silvera*

*Jenny Hoffman*

2020 Fall (4 Credits)

**Schedule:**

TR 0130 PM - 0530 PM

**Instructor Permissions:**

Instructor

**Enrollment Cap:**

20

Students carry out three experimental projects selected from those available representing condensed matter, atomic, nuclear, and particle physics. Included are pulsed nuclear magnetic resonance (with MRI), microwave spectroscopy, optical pumping, Raman scattering, scattering of laser light, nitrogen vacancies in diamond, neutron activation of radioactive isotopes, Compton scattering, relativistic mass of the electron, recoil free gamma-ray resonance, lifetime of the muon, studies of superfluid helium, positron annihilation, superconductivity, the quantum Hall effect, properties of semiconductors, and plasma physics. The facilities of the laboratory include several computer controlled experiments as well as computers for analysis.

**Course Notes:** A substantial amount of outside reading is expected. Physics 247 is the same course as Physics 191; if you are an undergraduate, please enroll in 191.

The course is offered in Science Center 204.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

## Physics 248R

Topics in Experimental Particle Physics (109993)

*Masahiro Morii*

2020 Fall (4 Credits)

**Schedule:**

MW 0900 AM - 1015 AM

Instructor Permissions: None

Enrollment Cap: n/a

Topics in the elementary particle physics, focusing on experimental studies of the Standard Model and new physics beyond the Standard Model in the past 20 years. Half of the course will review ongoing experimental research in particle physics, with or without accelerators. The other half will cover particle detector technologies and data analysis methods.

Prerequisite: Physics 145 or equivalent, i.e. a course at the level of Griffiths, Introduction to Elementary Particles.

Recommended Prep: Prerequisite: Physics 145 or equivalent, i.e. a course at the level of Griffiths, Introduction to Elementary Particles.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 251A

Advanced Quantum Mechanics I (111314)

C. Vafa

2020 Fall (4 Credits)

Schedule: MW 0300 PM - 0415 PM

Instructor Permissions: None

Enrollment Cap: n/a

Basic course in nonrelativistic quantum mechanics. Review of wave functions and the Schrödinger Equation; Hilbert space; the WKB approximation; central forces and angular momentum; spins and their addition, measurement theory; the density matrix; perturbation theory.

Recommended Prep: Physics 143a, b or equivalent, or permission of instructor.

Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 251B

Advanced Quantum Mechanics II (111876)

Matthew Reece

2021 Spring (4 Credits)

Schedule: TR 0130 PM - 0245 PM

Instructor Permissions: None

Enrollment Cap: n/a

Path integrals; relativistic quantum mechanics and quantum fields; identical particles; scattering theory; quantum information theory.

Recommended Prep: Physics 251a.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 253A**

Quantum Field Theory I (122930)

*Matthew Schwartz*

2020 Fall (4 Credits)

**Schedule:** TR 0130 PM - 0245 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**Introduction to relativistic quantum field theory. This course covers quantum electrodynamics. Topics include canonical quantization, Feynman diagrams, spinors, gauge invariance, path integrals, ultraviolet and infrared divergences, renormalization and applications to the quantum theory of the weak and gravitational forces.**

**Recommended Prep:** Physics 143a, b or equivalents.**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 253B**

Quantum Field Theory II (115442)

*Xi Yin*

2021 Spring (4 Credits)

**Schedule:** WF 0130 PM - 0245 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**A continuation of Physics 253a. Topics include: the renormalization group, implications of unitarity, Yang-Mills theories, spontaneous symmetry breaking, weak interactions, anomalies, and quantum chromodynamics. Additional advanced topics may be covered depending on time and interest.**

**Recommended Prep:** Physics 253a.**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 253C**

Quantum Field Theory III (118459)

*Daniel Jafferis*

2020 Fall (4 Credits)

**Schedule:**

TR 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Selected advanced topics in quantum field theory, including, but not necessarily limited to: instantons, bosonization, anomalies, confinement, magnetic monopoles, large N expansions, and generalized global symmetries.**

**Recommended Prep:** Quantum field theory at the level of Physics 253a.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 254

The Standard Model (109328)

*Matthew Reece*

2020 Fall (4 Credits)

**Schedule:**

WF 0130 PM - 0245 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**The Standard Model of particle physics: theory and experimental implications. Topics include nonabelian gauge theory, spontaneous symmetry breaking, anomalies, the chiral Lagrangian, QCD and jets, collider physics and simulation, the Higgs at the LHC.**

**Recommended Prep:** Introductory relativistic field theory, at the level of Physics 253a.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | Primarily for Graduate Students          |

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## Physics 262

Statistical Mechanics (110526)

*Eugene Demler*

2020 Fall (4 Credits)

**Schedule:**

MWF 1200 PM - 0115 PM

**Instructor Permissions:** None

**Enrollment Cap:**

n/a

**Basic principles of statistical physics and thermodynamics, with applications including: the equilibrium properties of classical and quantum gases; phase diagrams, phase transitions and critical phenomena, as illustrated by the liquid-gas transition and simple magnetic models. Time permitting, introduction to nonequilibrium phenomena including Langevin dynamics and Boltzmann equation.**

**Course Notes:** Also offered as Applied Physics 284. Either course can be used to satisfy the statistical mechanics requirement in the Physics PhD program or the Applied Physics model PhD program.

**Recommended Prep:** Physics 143a and Physics 181 or Engineering Sciences 181.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

**Physics 268R**

Special Topics in Quantum Matter (122818)

*Subir Sachdev*

2020 Fall (4 Credits)

**Schedule:** MWF 0300 PM - 0415 PM**Instructor Permissions:** None**Enrollment Cap:** n/a

**This is a special topics course on quantum systems of many particles, i.e. quantum matter. We will study well defined microscopic models, eg. simple spin models, representing electrons in solids or atoms in optical lattices, which will be shown, at long distances, to give rise to remarkable new excitations, from 'sound' and 'light', to fermions and even more exotic 'anyon' excitations. Often, (but not always) we will use field theory to describe this physics, which may also help demystify the origin of quantum field theory in a physical setting free from 'infinities'.**

**This course will make contact with recent research directions such as topological order, quantum criticality and dualities.**

**Two criteria are applied when selecting topics. First, that they be of experimental relevance and, second, that they illustrate a central concept of quantum many body physics such as (i) the importance of locality in many body systems (ii) symmetry and its spontaneous breaking (iii) origin of gauge theories (iv) finding the right variables to describe the physics (a.k.a. dualities) (v) topological order (vi) scale invariance.**

**Planned Topics:**

- 1. The 1+1D transverse field Ising model - duality, fermionization, chiral symmetry. Experimental realization of "E<sub>8</sub>" in CoNb<sub>2</sub>O<sub>6</sub>.**
- 2. Continuous symmetry breaking in 2+1D. Goldstone modes and the Anderson Tower. Non-perturbative approaches such as dualities and large-N expansions. The Mott-superfluid transition.**
- 3. Symmetry and Topological Phases . - Integer quantum Hall effect and Chern insulators. The periodic table of topological insulators and superconductors.**
- 4. Emergent Gauge Theories and topological order. Confinement and topological order. Chern Simons theories. Fractional quantum Hall states and gapped quantum spin liquids. Emergent electromagnetism in quantum magnets and "Spin-ice".**
- 5. Special Topics (if time permits): Quantum entanglement in many body systems. Scale invariance.**

**Evaluation: Assignments (roughly biweekly) and a final reading/small research project in groups of 2-3 based on enrollment. There will be no examinations.**

**Suggested Text Books:**

- 1. Gauge Fields and Strings: A. Polyakov**

## 2. Quantum Field Theory of Many Body Systems: X. G. Wen

## 3. Quantum Phase Transitions. Subir Sachdev

**Recommended Prep:** Previous offerings of this course have been taken mainly by condensed matter/AMO and high energy theory graduate students, although the only real requirements are a strong background in quantum mechanics and some exposure to critical phenomena and renormalization group ideas in statistical mechanics.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 271

Topics in the Physics of Quantum Information (121970)

*Mikhail Lukin*

2020 Fall (4 Credits)

**Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduction to physics of quantum information, with emphasis on ideas and experiments ranging from quantum optics to condensed matter physics. Background and theoretical tools will be introduced. The format is a combination of lectures and class presentations.**

**Recommended Prep:** Quantum mechanics at the level of introductory graduate courses.

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

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## Physics 285A

Modern Atomic and Optical Physics I (118734)

*Susanne Yelin*

2021 Spring (4 Credits)

**Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Introduction to modern atomic physics. The fundamental concepts and modern experimental techniques will be introduced. Topics will include: Two-state systems, magnetic resonance, interaction of radiation with atoms, transition probabilities, spontaneous and stimulated emission, dressed atoms, trapping, laser cooling. Structure of simple atoms, coupling to fields, light scattering. Fundamental symmetries and introduction to molecules and artificial atoms. Selected experiments. The first of a two-term subject sequence that provides the foundations for contemporary research.**

**Recommended Prep:** One course in quantum mechanics (143a and b, or equivalent).

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| FAS: Course Level           | Primarily for Graduate Students          |

**Physics 287A**

Introduction to String Theory (111191)

*Xi Yin*

2020 Fall (4 Credits)

**Schedule:**

TR 0300 PM - 0415 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**Introduction to the perturbative formulation of string theories and dualities. Quantization of bosonic and superstrings, perturbative aspects of scattering amplitudes, supergravity, D-branes, T-duality and mirror symmetry. Also a brief overview of recent developments in string theory.**

**Recommended Prep:** Physics 253a, b or equivalent.**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

**Physics 289R**

Euclidean Random Fields, Relativistic Quantum Fields and Positive Temperature (118733)

*Arthur Jaffe*

2021 Spring (4 Credits)

**Schedule:**

TR 0130 PM - 0245 PM

**Instructor Permissions:** None**Enrollment Cap:**

n/a

**The course will give the reconstruction of relativistic quantum fields from Euclidean fields as well as the relation between representations of the Poincaré group to those of Euclidean group. Related topics are reflection positivity and Osterwalder-Schrader quantization, and supersymmetry, some of which will be covered.**

**Recommended Prep:** Physics 253a.**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |

**Physics 295A**

Introduction to Quantum Theory of Solids (127980)

*Prineha Narang*

2020 Fall (4 Credits)

**Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Lattices and symmetries. Phonons. Electronic Structure of Crystals. Semiclassical Transport Theory. Semiconductors. Localization. Integer Quantum Hall effect. Topological Insulators. Additional topics from the theory of interacting electrons, including introduction to magnetism and superconductivity.**

**Recommended Prep:** Physics 181 or equivalent, Applied Physics 195 or equivalent, and a graduate level quantum mechanics course similar to Physics 251a. (Physics 251b would be helpful and may be taken concurrently.)

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | Science & Engineering & Applied Science  |
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |

## Physics 295B

Quantum Theory of Solids (127979)

*Yahui Zhang*

2021 Spring (4 Credits) **Instructor**

**Schedule:** MW 1200 PM - 0115 PM

**Permissions:** None

**Enrollment Cap:** n/a

**This course presents theoretical description of solids focusing on the effects of interactions between electrons. Topics include Fermi liquid theory, dielectric response and RPA approximation, ferro and antiferromagnetism, RKKY interactions and Kondo effect, electron-phonon interactions and superconductivity.**

**Course Notes:** Physics 295b is also offered as Applied Physics 295b. Students may not take both for credit.

**Recommended Prep:** Physics 251a,b, an introductory course in solid state physics, or permission of instructor.

**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Primarily for Graduate Students          |
| FAS Divisional Distribution | Science & Engineering & Applied Science  |

## Physics 300C

Course-Related Work (210875)

2021 Spring (4 Credits)

**Schedule:**

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Additional Course Attributes:**

| Attribute         | Value(s)        |
|-------------------|-----------------|
| FAS: Course Level | Graduate Course |

|                             |                                      |
|-----------------------------|--------------------------------------|
| All: Cross Reg Availability | Not Available for Cross Registration |
| FAS Divisional Distribution | None                                 |

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## Physics 300C

Course-Related Work (210875)

2020 Fall (4 Credits)

**Schedule:**

**Instructor Permissions:** None

**Enrollment Cap:** n/a

### Additional Course Attributes:

| Attribute                   | Value(s)                             |
|-----------------------------|--------------------------------------|
| All: Cross Reg Availability | Not Available for Cross Registration |
| FAS Divisional Distribution | None                                 |
| FAS: Course Level           | Graduate Course                      |

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## Physics 300R

Research-Related Work (210873)

2020 Fall (4 Credits)

**Schedule:**

**Instructor Permissions:** None

**Enrollment Cap:** n/a

### Additional Course Attributes:

| Attribute                   | Value(s)                             |
|-----------------------------|--------------------------------------|
| FAS: Course Level           | Graduate Course                      |
| FAS Divisional Distribution | None                                 |
| All: Cross Reg Availability | Not Available for Cross Registration |

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## Physics 300R

Research-Related Work (210873)

2021 Spring (4 Credits)

**Schedule:**

**Instructor Permissions:** None

**Enrollment Cap:** n/a

### Additional Course Attributes:

| Attribute                   | Value(s)                             |
|-----------------------------|--------------------------------------|
| All: Cross Reg Availability | Not Available for Cross Registration |
| FAS: Course Level           | Graduate Course                      |
| FAS Divisional Distribution | None                                 |

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## Physics 300T

Teaching-Related Work (210874)

2020 Fall (4 Credits)

**Schedule:**

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**Additional Course Attributes:**

| Attribute                   | Value(s)                             |
|-----------------------------|--------------------------------------|
| FAS: Course Level           | Graduate Course                      |
| FAS Divisional Distribution | None                                 |
| All: Cross Reg Availability | Not Available for Cross Registration |

**Physics 300T**

Teaching-Related Work (210874)

2021 Spring (4 Credits)

**Schedule:****Instructor Permissions:** None**Enrollment Cap:** n/a**Additional Course Attributes:**

| Attribute                   | Value(s)                             |
|-----------------------------|--------------------------------------|
| FAS Divisional Distribution | None                                 |
| All: Cross Reg Availability | Not Available for Cross Registration |
| FAS: Course Level           | Graduate Course                      |

**Physics 301A**

Experimental Atomic and Elementary Particle Physics (110965)

*Gerald Gabrielse*

2021 Spring (4 Credits)

**Schedule:** TBD**Instructor Permissions:** None**Enrollment Cap:** n/a**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| All: Cross Reg Availability | Available for Harvard Cross Registration |
| FAS: Course Level           | Graduate Course                          |
| FAS Divisional Distribution | None                                     |

**Physics 301A**

Experimental Atomic and Elementary Particle Physics (110965)

*Gerald Gabrielse*

2020 Fall (4 Credits)

**Schedule:** TBD**Instructor Permissions:** Instructor**Enrollment Cap:** n/a**Additional Course Attributes:**

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | None                                     |
| FAS: Course Level           | Graduate Course                          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 301B

Experimental Atomic and Elementary Particle Physics (110966)

*Gerald Gabrielse*

2020 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Graduate Course                          |
| FAS Divisional Distribution | None                                     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 301B

Experimental Atomic and Elementary Particle Physics (110966)

*Gerald Gabrielse*

2021 Spring (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** None

**Enrollment Cap:** n/a

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS: Course Level           | Graduate Course                          |
| FAS Divisional Distribution | None                                     |
| All: Cross Reg Availability | Available for Harvard Cross Registration |

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## Physics 302A Section: 001S

Teaching and Communicating Physics (107899)

*Jacob Barandes*

2021 Spring (4 Credits)

**Schedule:** W 0600 PM - 0715 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 45

**Hands-on, experienced-based course for graduate students on teaching and communicating physics, conducted through practice, observation, feedback, and discussion. Departmental rules for teaching fellows, section and laboratory teaching, office hours, assignments, grading, and difficult classroom situations.**

### Additional Course Attributes:

| Attribute                   | Value(s)                                 |
|-----------------------------|--|
| FAS Divisional Distribution | None                                     |
| FAS: Course Level           | Graduate Course                          |
| All: Cross Reg Availability | Available for Harvard Cross Registration |