â€¢ Important Announcements

- Please see the special notes on in-class laptop policies and the optional physics prep course below!
- We'll be holding a **special set of office hours Friday, August 30, 10â€“noon**, outside in the tent in front of Jefferson Lab, where we'll be answering questions about the class. (Rain location: Lyman 425.)
- If you're considering this course, **please fill out our initial survey as soon as possible**.
- Please also take a look at our Homework #0 self-assessment and the Practice Calculus Exercises.
- You can find a **completely optional** review of the mathematical concepts we'll be using in this course on the Lecture Notes page.
- If you're planning on taking the lab, which is a requirement for students intending on concentrating in physics, please self enroll on the lab Canvas page using this link as soon as possible. You can also enroll yourself in your desired lab section using the instructions on the lab Canvas page.
- In reading the syllabus below, please pay careful attention to the dates of the two midterm exams (**October 15** and **November 12** â€“ both at **6:30pm** in the evening!) and the final presentations (**December 11â€“13**).

Image credit: Shixie (used with permission)

Term: Fall 2024
Course Meeting Times: MWF 3-4:15 (three days per week)
Location: Science Center Hall C (map, 3D view)
First Class: Wednesday, September 4
Office Hours: Live-Updated Schedule and Locations (coming soon)
Note: Office hours start on Friday, August 30!
Detailed Agenda: See Below

Instructor: Jacob Barandes
Teaching Fellows (alphabetically): Filip Niewinski, Liza Rozenberg
Course Assistants (alphabetically): Ege Cakar, Isabella Gidi, Alex Gong, William Gottemoller, Sophia Kim, Elizabeth Kozlov, Nicolas L'Huillier, Sara Lia, Adi Raj, Larom Segev

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- **Course Expectations (PDF)**
- **The Hidden Curriculum (PDF)**
- **Inclusive Physics Culture (PDF)**
- **Advice to Students (PDF)**

Important Note on Laptops in Class

Based on past experience, laptops tend to be very distracting to nearby students and decrease in-class participation, so **the use of laptops in class will not be permitted**, except for students who get an exception from the instructor. Students who will need to use a laptop in class for accessibility reasons should contact the instructor for approval. (Tablet devices like iPads are generally allowed without needing to be approved, provided that they are used only for handwriting with a stylus.)

Optional Physics Prep Course

If you have any concerns about your math preparation, you may want to take the Physics department's not-for-credit, one-week prep course via Zoom, August 12-16. This prep course is designed for students who are planning to take Physics 15A or Physics 19, and who would like to get a preview of the math skills and physics background that will be helpful in these courses. The course will meet for five days, three hours each day, Noon-3:00pm Eastern Time. Goals will include enhancing specific math skills and problem-solving techniques, practice in applying math to physics, and general course strategies. The main focus is on math skills particularly important for physics (as opposed to the physics itself).

If you are interested in the prep course, please fill out this google form by Tuesday 7/30. If you have any general questions, please reach out to David Morin at djmorin@fas.harvard.edu.

â€¢ Course Description

Physics 19 is a comprehensive introduction to the foundations of theoretical physics, with a first-principles approach to its five main areas: analytical mechanics, thermodynamics, fields, relativity, and quantum theory.

The course is aimed primarily at students who are considering pursuing advanced study of physics in the concentration, as an option alongside Physics 15A and Physics 16. (Most physics concentrators start by taking either Physics 15A, 16, or 19.) The course is also open to undergraduate and graduate students in other fields of studyâ€”such as math, philosophy, astronomy, biology, chemistry, computer science, and engineeringâ€"who are interested in developing a better understanding of physics either to serve the needs of their own academic work or as a first step toward switching their area of study to physics.

â€¢ Which Introductory Physics Course Should You Take?

We often get a lot of questions from incoming first-year Harvard College students about whether they should take Physics 15A, Physics 16, or Physics 19.

All three of these courses are intended primarily for students considering concentrating in physics, although they're certainly open to a broader audience as well.

These introductory physics courses are distinct, but if you continue on to complete a physics concentration, you'll eventually learn everything covered in these classes more than once along your academic journey. So you don't have to worry that taking the â€œwrong classâ€ will put you at a disadvantage later. Once you're halfway through college, it won't matter which introductory physics course you took, except to the extent that your decision inspired you to keep going on with physics.

So if you're thinking about becoming a physics concentrator, you should make your decision based on which of these introductory courses you find to be the best fit for you, and the most inspiring for your future study in physics.

Note that Physics 15A is offered at the same class times as Physics 16 (on Tuesdays and Thursdays), and they cover similar topics for the first few weeks. So if you start with Physics 16 and decide to switch to Physics 15A after a couple of weeks, that's usually not a problem.

Physics 19 is offered on a different schedule (Mondays, Wednesdays, and Fridays), so if you're uncertain about whether you'd like to try it, you can sit in on Physics 19 along with either Physics 15A or Physics 16 for the first week or so before you make your final decision. The first few weeks of Physics 19 are very different from the first few weeks of Physics 15A and Physics 16.

Here are some descriptions of these three introductory physics classes in more detail:

- **Physics 15A** is offered every fall and spring, two days each week (Tuesdays and Thursdays). The course covers Newtonian mechanics and special relativity at a more advanced level than most physics courses offered in high school. Students should be reasonably comfortable with single-variable calculus at the level of Math 1A, and ideally have taken some physics in high school, though no previous physics experience is strictly required. Most students report that the workload is comparable to most of Harvard's other physics courses.
- **Physics 16** is offered only in the fall, two days each week (Tuesdays and Thursdays, at the same times as Physics 15A). The course covers Newtonian mechanics, special relativity, and several additional advanced topics, with an emphasis on especially challenging homework problems. Students should be very comfortable with college-level calculus and vectors, and ideally have scored a 5 on the exam for AP Physics C: Mechanics (or have equivalent preparation). Most students report that the workload is much higher than for most of Harvard's other physics courses, so be careful about taking other time-consuming classes at the same time.
- **Physics 19** (this class) is offered only in the fall. The course meets three days each week (Mondays, Wednesdays, and Fridays). The course uses the extra class time to cover a wider collection of topics, which are developed from first principles and collectively underlie modern theoretical physics. The course content includes the core material of Newtonian mechanics, though with fewer applications than in Physics 15A and Physics 16, in order to accommodate everything else. The course is designed to require roughly the same preparation and workload as Physics 15A. That is, students should be comfortable with single-variable calculus at the level of Math 1A, and ideally have seen some physics before, and the workload is similar to most of Harvard's other physics courses.

â€¢ Course Notes

The purpose of Physics 19 is to present the foundations of modern theoretical physics in a welcoming setting for students from a variety of backgrounds. The course is intended to present a clear, faithful picture of what theoretical physics looks like. We will derive nearly everything from scratch in as self-contained a manner as possibleâ€”with occasional exceptions for special cutting-edge examples. We will also introduce all the necessary mathematics along the way.

Specific topics will include Newtonian mechanics, chaos, perturbation theory, orbital mechanics, the Lagrangian and Hamiltonian formulations, the connection between symmetries and conservation laws, statistical physics and thermodynamics, electromagnetism, special relativity, relativistic gravitation, black holes, and an extensive introduction to quantum theory. In-class discussions will regularly address relevant issues in the history and philosophy of physics, as well as the conceptual implications of our modern physical theories for making sense of the world around us.

Cooperation and diversity strengthen our academic community, so the course will prioritize collaboration and aim to provide a welcoming and inclusive environment for students with diverse identities and backgrounds. The instructor will help students form study groups as needed.

â€¢ Recommended Prep

Physics 19 is mathematically intensive. The course will assume a working knowledge of single-variable differential and integral calculus at least at the level of Mathematics 1A, as well as a high comfort level with abstract concepts, but will not assume previous coursework in physics or multivariable calculus. Mathematics 1A is not a strict requirement, and students who are unsure whether they have adequate background should contact the instructor. The course will cover relevant topics from vector calculus, complex analysis, linear algebra, and other areas of mathematics as needed, so a prior familiarity with these subjects, while helpful, will not be required.

â€¢ Readings

There does not currently exist a textbook that would suit this course. Readings will consist of the instructor's typed lecture notes, which will be posted to the course website shortly after each class session. **There will be 10 to 20 pages of lecture notes posted online after each class, and students will be expected to keep up with this reading.**

â€¢ Homework

The course will have weekly homeworks (60%) consisting of questions involving both concepts and calculations. **Homeworks will be posted to the course website each Wednesday evening and will be due online by 11:59pm on the following Wednesday.**

However, students will always have a two-day grace period and will be permitted to hand in their homework online by **11:59pm** on the next Friday instead. **Students may freely take advantage of this two-day grace period as many times as needed, no questions asked, and no approval from the instructor required.**

Collaboration is encouraged and students who have difficulty finding a study group should contact the course head or teaching fellows. We're here to help.

Academic integrity should always be treated as a top priority. Students should adhere to the rules and regulations of the Harvard Honor Code. **Students must write or type up their own homework sets with their own answers and hand them in individually, as well as list all their collaborators on every homework assignment.** Full simplification of results is necessary for full credit. Use of the internet for general reference purposes is permitted provided that students cite all external resources they use, but students are not permitted to look up specific exercises or solutions on the internet or elsewhere.

In fairness to other students, late homework will not be accepted beyond the two-day grace period.

â€¢ Course Policies on the Use of Generative AI

Generative AI is becoming an increasingly important tool for science, so this course will not forbid its use altogether. Students will be allowed to use generative AI for background-knowledge purposes. That is, students should feel free to use it as something like a more powerful, interactive version of Wikipedia.

However, students will not be permitted to use generative AI to solve any of the assigned problems in this course, or even problems that are remotely similar to assigned problems.

In keeping with the course's general policies on citing outside resources, students who utilize generative AI in any way must be sure to cite the AI tool used, and explain in writing how it was used. Students who are not consistent with their citations, whether about generative AI or other external resources, will eventually lose points.

You should apply the same citation standards to your written work in this class as you would for a research publication. **When in doubt about whether a citation is necessary, err on the site of providing a citation.**

â€¢ Midterm Exams

The course will have a midterm exam (10%) on Tuesday, October 15, at 6:30pm, as well as a second midterm exam (10%) on Tuesday, November 12, at 6:30pm. The exams are intended to take no more than 1 hour and 15 minutes, but we will keep the exam rooms open for 3 hours to limit the possibility that students feel rushed.

Please note that these are both evening exams! If you have a scheduling conflict, please let us know by the end of the second week of classes at the latest.

The purpose of these midterm exams is to help students develop important test-taking skills, to encourage students to review their course materials and consolidate their understanding, and to give students important feedback on their learning. **Students are encouraged to collaborate while studying, but no collaboration will be permitted during the exams themselves.**

For each midterm exam, every student will be permitted to write up a personal formula sheet on one or both sides of a single sheet of standard (8.5inx11in) paper and bring it to the exam. Students should not share copies of their formula sheets with each other. **Students will be required to submit their formula sheets along with their exams.** We'll return all the formula sheets once the exams are graded.

â€¢ Final Projects

Physics 19 has no final exam. The course will conclude with final projects (15%), which students can either choose from a list of topics or select with the advance permission of the instructor. **Student presentations will be scheduled for December 11â€“13, and full write-ups will be due by 11:00pm on Sunday, December 15.**

â€¢ Attendance

Attendance (5%) will ordinarily be expected at every official class session. There will be an attendance sheet at the door that students can sign when they arrive. However, students will be allowed a small number of excused absences that will not count against their attendance grade, provided that each time (1) they email the head teaching fellow either before or shortly after their absence, and (2) also send a follow-up to their teaching fellow confirming in writing that they have reviewed all the material on the course website corresponding to the class session they missed.

â€¢ Office Hours

Office hours are an important component of Physics 19. The course has lots of office hours, generally on all five weekdays each week. Some office hours will be in person, either in classrooms or in outdoor tents. Other office hours will always be via Zoom. But every set of office hours will have a Zoom link as a back-up, just in case.

(**Our first office hours will be on Friday, August 30!** Click here (coming soon) for a live-updated list of locations and back-up Zoom links.)

â€¢ Recitation Sections

The course will offer several recitation sections per week. Each recitation section will be led by one of our teaching fellows, and will focus on problem-solving strategies. Section attendance is optional but strongly encouraged. Students who would like to attend should plan on going to one recitation section per week.

The first recitation sections will be on Monday, September 9, and Tuesday, September 10.

- Mondays, 6pmâ€“7:15pm, location: Jefferson 256
- Mondays, 7:30pmâ€“8:45pm, location: Jefferson 356
- Tuesdays, 6pmâ€“7:15pm, location: Jefferson 356
- Tuesdays, 7:30pmâ€“8:45pm, location: Jefferson 256

â€¢ Laboratory Component

For students intending on concentrating in physics, please note that the laboratory component of Physics 19, called Principles of Scientific Inquiry (PSI), is a departmental requirement. (For students in Physics 19 who are not planning on concentrating in physics, PSI is not required.) To sign up for PSI, use this link to self enroll in the lab Canvas page. You should also choose your lab section while you're there. PSI topics will include experimental design, model testing, measurements, data collection, data and error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester, and will emphasize collaborative teaching and learning.

Please visit the PSI Canvas site to sign up for a laboratory section.

â€¢ Accommodations for Students with Disabilities

Harvard University values inclusive excellence and providing equal educational opportunities for all students. Our goal is to remove barriers for disabled students related to inaccessible elements of instruction or design in this course. If reasonable accommodations are necessary to provide access, please contact the Disability Access Office (DAO). Accommodations do not alter fundamental requirements of the course and are not retroactive. Students should request accommodations as early as possible, since they may take time to implement. Students should notify DAO at any time during the semester if adjustments to their communicated accommodation plan are needed.

â€¢ Detailed Agenda

- Introductions
- A review of relevant topics from differential and integral calculus
- Fermi problems
- A general discussion of physics and physical systems
- Dimensional analysis
- Coarse-graining, separation of scales
- Classical kinematics and dynamics
- Taylor series
- Perturbation theory
- Chaos, fractals
- Complex numbers, vectors, tensors, parallel transport
- Newtonian mechanics, work and energy, uniform circular motion, collision problems
- Oscillation and resonance
- Rotational motion, spin
- Newtonian gravitation, central forces, orbital mechanics, tidal forces
- Reference frames
- Wave phenomena
- Matrices, linear algebra, and introductory quantum theory as matrix mechanics
- The calculus of variations, the Lagrangian formulation of classical physics, systems with constraints, Lagrange multipliers, path integrals in quantum theory
- Symmetries and conservation laws, Noether's theorem
- An introduction to the Standard Model of particle physics and to Einstein's theory of general relativity
- Breaking of dynamical symmetries, the Higgs mechanism
- The Hamiltonian formulation of classical physics, Poisson brackets, generators
- The Hamilton-Jacobi formulation of classical physics, action-angle variables, and introductory quantum theory as wave mechanics
- Thermodynamics, statistical mechanics, entropy, the arrow of time, heat engines, free energy, partition functions
- Vector calculus
- Classical fields, electromagnetism, the Maxwell equations, the Lorentz force law, electromagnetic waves
- Special relativity: time dilation, Lorentz transformations, the hyperbolic geometry of spacetime, four-vectors, relativistic dynamics, the relationship between mass and energy.
- The equivalence principle, spacetime curvature, elementary general relativity, the Einstein field equation, important solutions, cosmology
- Fourier analysis
- Early quantum theory: blackbody radiation, Heisenberg matrix mechanics, SchrÃ¶dinger wave mechanics
- Modern quantum theory: bra-ket notation, Hilbert spaces, the Dirac-von Neumann axioms, the SchrÃ¶dinger equation, the uncertainty principle, quantization of energy

- Further topics in quantum theory: the quantum measurement problem, entanglement, SchrÃ¶dinger's cat, black-hole thermodynamics