

## **Department of Physics Independent Work Guide**

### **Introduction**

As a discipline, physics addresses the material Universe at its most fundamental level. A surprisingly small number of physical laws are sufficient to describe natural phenomena from subatomic to cosmological scales. The goals of physics are to push to ever deeper levels of understanding of the physical world, and to push upward, extending our understanding to more complicated systems, including molecules, fluids, solids, galaxies, and living things.

Concentrating in physics will not only teach you about the structure of physical law; it will allow you to take part in its discovery. In the process you will acquire universally valuable skills, including analytic problem-solving, methods of estimation and approximation, and reasoning both inductively and from first principles. Furthermore, you will build your intuition for how the physical world works, from electricity, the phases of matter, forms of matter and energy, and the quantum realm.

Physics concentrators are prepared not only for a career in physics, but many other fields as well. Physics alumni may be found in academic and industrial physics research positions as well as consulting, medicine, law, teaching, biotechnology, university leadership, and engineering.

A unique aspect of your experience at Princeton is the degree of involvement in contemporary physics through your own independent research. Each of two junior papers provide an opportunity to explore, in depth, an active area of current research.

The senior thesis is the capstone of the physics major and an opportunity for intellectual exploration broader than courses can afford. It is a year long collaboration with a faculty member that is intended to actually contribute to current research in an area that is most of interest to you. Whether the focus of your thesis is on biophysics, gravity and cosmology, condensed matter, or string theory, it invariably represents your highest effort to come to grips with science as a living, breathing subject. Quite frequently, this research results in reports or papers published within a collaboration or in peer reviewed journals. The independent work engenders closer interaction between faculty and students -- not only in the independent work itself, but in summer research opportunities and research-related discussions. In short, we're conditioned to regard undergraduates as potential collaborators. Even for topics outside of the mainstream of physics, for example with a focus on policy, or neuroscience, or finance, we expect you to apply your undergraduate physics education to the problem you focus on.

You may build on previous work in your senior thesis, for example summer work or a junior paper. However, it is equally acceptable to start a new project in the fall of your senior year with an adviser with whom you have not previously worked. In any case, in order to ensure a level playing field, your thesis will be evaluated based on work done during the academic year.

## **Learning goals for independent work**

In addition to exercising the technical, analytic, and problem solving skills that are integral to the physics core curriculum, your independent work provides an opportunity to explore a range of topics in contemporary physics and to engage deeply with leading researchers on a particular research project. You will learn how to successfully pursue independent research, collaborate with colleagues within the department, and have the opportunity to engage with the research community both on campus and with collaborators at other institutions. You will demonstrate your ability to clearly and concisely communicate the technical results of your investigation through your written and verbal presentation of the research. These experiences will help inform and prepare you for your future endeavors, whether those include graduate school, or a career in the public or private sector.

## **How it works**

At the start of the fall term, the Senior Committee will host an informational session to introduce you to the process of finding a topic and adviser, and establish the deadlines for key milestones (see below). In AY 2022-2023, the committee members are Professor(s) Daniel Marlow (chair), Curtis Callan, Phuan Ong and Shinsei Ryu. The senior committee is assisted by Karen Kelly, the Undergraduate Administrator. You are encouraged at any time to approach members of the senior committee with questions or concerns about the progress of your thesis work.

Your adviser must have a full-time faculty appointment at Princeton University. They may be one of your junior paper advisers, but need not be. If your adviser does not have their primary appointment in the Physics Department, you must communicate your choice of second reader (in Canvas), and this second reader must hold a full-time faculty appointment at Princeton University with their primary appointment in the Physics Department.

The final version of your senior thesis is due by 3:00pm on the University's deadline for submitting the senior thesis. The requirements for formatting and submitting your final senior thesis are detailed below, in the section titled Thesis Formatting and Submission. A complete listing of dates and deadlines relevant to the senior thesis is included in the section titled Important Dates. All of this information, including the dates, are available on the department's website. In case of any confusion about dates and deadlines, the page on Important Dates should be regarded as authoritative.

At the end of the year, the Senior Committee will conduct the senior departmental examinations. This is an oral examination, and is described in more detail below.

## **Getting started**

The best advice in finding an adviser is to go to several faculty members in areas of research that you are interested in, and see what topics they propose. If you have a topic to propose yourself, great: shop it around to faculty and see what they think. Most topics come from faculty as part of the work their research groups are conducting. When you have a tentative topic in mind, start by reading some of the literature, ideally at the Scientific American level, in order to understand the highlights and context of the work you'll embark on. If you're undecided between topics, this first stage of reading should help you choose between them. Make sure to circle back to your prospective adviser with questions, and confirm with them before the deadline that they are in fact prepared to advise you on a topic that you have both agreed on. It's important to start this process at the very beginning of term, because false starts are possible.

The most important advice we can give is to make a fast start on your senior thesis, and focus on it particularly at the start of the fall term. Adjust your courses accordingly; for instance, senior fall is not the right time to shop five courses. Experience suggests that distractions and delays occur from time to time, both expected (e.g. grad school applications) and unexpected (e.g. your adviser disappears to a conference just when you need help). If you have a good start on your thesis you can put it aside briefly when such a delay occurs. If you don't, it becomes harder and harder to catch up. Regardless of where you are in the term—and especially early on—the best advice is to set your senior thesis at top priority.

Students considering thesis topics mostly or entirely outside of physics should consider the application procedure outlined in the section below entitled Alternative grading rubric.

## **Fall term draft**

A draft of content to be included in your senior thesis must be turned in at the end of the fall term. The second reader must be identified in Canvas at the time you turn in this draft of content. This draft of content will be assigned a P/D/F grade by your adviser and second reader, and the grade will be reported to the senior committee; however, it will not appear on your Princeton transcript. The draft of content is intended to serve as a status check and a way to start the conversation with your adviser and second reader about the spring term end game for your thesis. The guidelines for the draft of content are as follows:

The minimum length is 7 pages, plus front matter and bibliography.

The document should be written in full sentences and paragraphs, in the style you intend for the final version of your senior thesis. An outline of work to follow can be included at the end, but the main focus of the document should be on what you have understood and done so far.

Formatting should be the same that you intend to use in the final version of your senior thesis; in particular, front matter (including the Student Acknowledgment of Original Work, signed), introduction, main body, and bibliography should be present, with all the formatting as you intend for the final version of your senior thesis. In short, follow the guidelines in the primary grading rubric. Indicate clearly in the front matter that the document is a draft of content.

While it is anticipated that your results will be quite incomplete, make an effort to communicate the background in an accessible fashion that starts with the fundamentals and demonstrates your understanding of the context of your ongoing work.

## **Thesis formatting and submission**

You must submit your thesis electronically as a PDF file. The first few pages of your senior thesis are called the front matter. Front matter must, in the first two pages, include the title, the student's name, an abstract, the Student Acknowledgment of Original Work, and a signature following this acknowledgment. The wording of the Acknowledgment must be as set forth in the current edition of Rights, Rules, and Responsibilities: "This paper represents my own work in accordance with University regulations." The Page formatting should be suitable for printing on standard 8.5" x 11" paper with one to one and a half inch margins all around the main text. All fonts should be between 10 and 14 points, and line spacing should be anywhere between double spacing and 1.5 spacing. Pages should be numbered, with numbers no closer than half an inch to any edge of the page. Figures should be clear and legible, with descriptive captions. Figures should be your original work or else credit should be clearly given in the caption to the figure creator. You should request permission to re-use figures made by colleagues. There is no length requirement, but a total length (including front matter, bibliography, figures, appendices, etc) of 50 to 100 pages is about right for most topics.

The deadline for submission of the senior thesis is 3 pm on the University deadline for senior theses. For the spring semester of 2023, no hard copy submission will be required. By that deadline, you must submit your thesis electronically in Canvas. You must provide an electronic signature for the Student Acknowledgment of Original Work. Your signature will serve as confirmation that the submitted version is the official version. You must also send electronic copies of your thesis to your adviser and second reader on the due date. Finally, you must also submit your thesis electronically to Mudd Library in order to graduate. Details on the Mudd Library submission process will come by email.

## **Evaluation**

To set high goals for the thesis, and at the same time to accommodate the breadth of experience that physics majors seek, the Physics Department has a dual rubric approach to grading. The primary grading rubric for the senior thesis is the one set forth in detail in the

section below entitled Primary grading rubric. It should be used for all theses which are primarily focused on a topic in physics, broadly construed. Applied physics, biophysics, astrophysics, plasma physics, and mathematical physics (among others) are fields in which this primary rubric should be used. Every student should take pains to make their thesis accessible to physicists outside their discipline, written plainly and avoiding jargon. Doing so is a necessary part of a good presentation, and it is critical in demonstrating the student's own mastery of their topic. The physical principles involved should be explained clearly, starting at the level of undergraduate physics courses. Any necessary jargon should be introduced with clear explanations.

Written presentation is important and will affect the final grade. Good presentation includes all aspects of scholarly writing, including clear explanations, organization, and citations; correct spelling, grammar, and formatting; a style that is at once accessible and precise; and a logical structure including front matter, introduction, main body, conclusion, and bibliography.

### **Primary grading rubric**

The main basis for the final grade will be the *physics content* contained in the thesis as a document. Physics content could include, for example, theoretical ideas, calculations, modeling, and predictions; experimental methods, description of apparatus, results, and data analysis; and an assessment of the significance of the work reported in the thesis against the backdrop of the larger field of which it is a part. Physics content can be particularly noteworthy—for instance a really new theoretical idea or a genuinely impactful experimental result that, with some refinement, would be submitted to a peer reviewed journal—or may consist of less publishable results, such as verification or extension of published calculations, or successful calibration of an experimental device. These are more common and also highly esteemed, as they can serve as an important reference for researchers within that area of expertise. In short, new research results are desirable but not required for even the highest grades.

*Written presentation* is also important and will affect the final grade. Good presentation includes all aspects of scholarly writing, including clear explanations, organization, and citations; correct spelling, grammar, and formatting; a style that is at once accessible and precise; and a logical structure including front matter, introduction, main body, conclusion, and bibliography.

Grade recommendations from the adviser and second reader are communicated to the senior committee, along with short text descriptions describing and assessing the thesis.

The letter grade from the Oral examination will count for 10% of the senior thesis grade. The following grade descriptions are representative of Physics Department grading practices. Any individual thesis may have qualities spread across several of these descriptions, and it is ultimately up to the judgment of the Physics Department faculty to balance the considerations in any given case in order to come up with the final grade.

**A+ :** A substantial, professional-level contribution to some field of physics, with outstanding presentation and truly impressive content. For example, there may be original results suitable or almost suitable for publication in a peer-reviewed journal which physicists working in this field often publish in. Or the thesis may be a brilliantly written review paper which could usefully be shared with professional colleagues. A written statement from the adviser justifying the A+ must be included.

**A:** The thesis deals with some topic in physics in an unusually thorough way, with unexpected insights and/or an especially clear presentation. The adviser should have learned new things from it. This grade should be used for work that goes far beyond "doing a good job."

**A-:** The thesis covers some topic in physics well and goes into significant depth. It is written in a professional style with only minor flaws. The student shows mastery of the subject.

**B+:** The thesis covers a topic in physics well, and in some depth. The presentation and physics content are good but leave room for improvement.

**B:** The thesis covers a topic in physics fairly well. Presentation and physics content are fairly good, but some deficiencies may be noted.

**B-:** The thesis addresses a topic in physics but without the depth expected for senior independent work. There may be significant errors or an inadequate presentation.

**C+:** The thesis contains an overview of a topic in physics, but the physics content is mostly superficial. The presentation may be inadequate, and there may be significant errors or omissions.

**C:** The thesis contains a partial or superficial overview of a topic in physics. The thesis gives little evidence of understanding of the relevant physics. The presentation is sloppy, and there are significant errors or omissions.

**C-:** The thesis contains some correct information about a topic in physics, but it fails to show understanding of the relevant physics. The presentation is incomplete, with serious errors or omissions.

**D:** The lowest passing grade. The thesis is deficient in multiple respects, with minimal physics content, poor presentation, and/or poor scholarship.

**F:** There are several ways an F can result. One way is for the thesis to be largely incomplete and incorrect. A second way is for the thesis not to be turned in on time, accounting for any extensions granted, or for a document to be turned in without a clear written indication that it is the official version of the student's senior thesis. A third way is for the thesis to be turned in on time but with issues that prevent it from being accepted. Examples of this last are omitting from the first two pages the title, the student's name, the abstract, the Student Acknowledgment of Original Work, or a signature following this acknowledgment. Formatting that renders the thesis unreasonably difficult to read may also prevent it from being accepted and result in an F.

## **Alternative grading rubric**

Students wishing to branch out and work on a senior thesis topic that is mostly or entirely outside of physics will have their theses graded using an alternative grading rubric customized to their field of work, provided that they receive approval from the senior committee of a proposal submitted electronically in Canvas no later than the October deadline listed below. The proposal must consist of the following points:

Student's name.

Adviser's name. The adviser must sign next to their name to indicate their endorsement of the proposed grading rubric.

Second reader's name. As with all theses in the Department, your adviser and the second reader should both have full-time faculty appointments at Princeton University, and at least one of them should have their primary appointment in the Physics Department.

A tentative thesis title (200 characters or less).

Summary of proposed work (1500 to 2000 characters).

Provide a simple description of the area of scholarship your thesis falls in. For example, "Climate policy" or "Behavioral neuroscience."

Provide a short explanation of why you are interested in this area, and why it should be of general interest to professional physicists.

Provide an adaptation of the primary grading rubric that you feel is suitable to your thesis work. The text to adapt is the entire contents of the section entitled Primary grading rubric. Leave the second, third, and fourth paragraphs unchanged, as these sections will be applied in any case; likewise the criteria for an F cannot be changed. Changes to the rest of the text should be at the minimal level needed in order for it to be fairly applied to the work you are going to do. For example, if you are working on climate policy, replacing "physics" by "climate policy" throughout should be a good start. Topics which have some physics content but are primarily outside of physics should include in the grading rubric some measure of how well the physics is developed and presented.

The senior committee may adjust or rewrite the grading rubric you propose before approving it, and the final rubric will go to your adviser and second reader as well as to you. Proposals that are approved will allow a thesis to be graded at the same standard as other Physics Department senior theses. Students who do pursue a topic outside of physics should make a particular effort to make their thesis accessible to physicists and students of physics, and this effort will be counted as part of a good presentation. If a proposal is not received on time by the senior committee or is not approved, thesis work will be graded according to the Primary grading rubric: In particular, the physics content will then be the main basis for the final grade.

## **Oral examination**

The oral examination will be scheduled near the end of the academic year, after you have turned in your senior thesis. You should prepare a presentation with a planned duration of

20 minutes. Use standard visual aids, i.e. PowerPoint or similar. Presentations should be well organized and thoughtful; in particular:

If you want to use a laptop, you are responsible for making sure things work!

Have enough paper copies of your presentation material so that every committee member can have their own copy. Paper copies are useful even when you use PowerPoint from a laptop and serve as a backup in case of a technical glitch.

Limit your main presentation to approximately 15 slides (depending on your style). If you have more material, prioritize it and put extra material at the end as backup slides.

Do not expect committee members to flip through your thesis during the exam; your presentation should be self-contained.

Emphasize graphical material in your slides (including key equations).

If you have text in your slides, focus on terse summaries and avoid long segments of text.

Rehearse! You can rehearse before a group of friends, or your adviser, or a graduate student, or an empty room.

The senior committee is entitled to ask questions both about the thesis and about undergraduate physics. The grade for the oral depends on both the quality of the presentation and your ability to answer questions. The oral examination will be assigned a letter grade by the senior committee. The letter grade for the oral examination will count for 10% of the senior thesis grade.

### **Important dates (AY22/23)**

10/3/22: Submit topic & adviser, and second reader if primary is outside of the department

10/10/22: Deadline for alternative grading rubrics

10/24/22: Deadline for abstract & outline (one-page)

11/7/22: Individual meetings with committee members

1/16/23: Draft deadline / identify second reader

5/1/23: Thesis due

5/2/23: Oral presentation