MIT Department of Physics

Doctoral Student Handbook

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Introduction

This document describes the doctoral program in the Physics Department. It supplements the Graduate Policies and Procedures, which outlines the general Institute requirements and is available on the web at https://oge.mit.edu/gpp/.

The primary goals of the graduate program in physics at MIT are to solidify and broaden your knowledge of physics and to teach you how to do research, how to identify important problems, and how to communicate scientific information effectively. In short, you will be trained to become a professional physicist and a productive member of the scientific community. The major steps involved in your graduate career are described in the various sections here.

Graduate Program Personnel

The physics graduate program is under the direction of the Physics Education Committee, which includes members with the following graduate responsibilities:

- Associate Department Head, Prof. Scott Hughes
- General Examination and Requirements Coordinator, Prof. Mehran Kardar
- Graduate Appointments Coordinator, Prof. Christoph Paus
- Graduate Student Coordinator, Graduate Officer, Prof. William Detmold
- Graduate Admissions Chair, Matthew Evans
- Assistant Director, Academic Programs, Shannon Larkin
- Graduate Coordinator, Jenni Roesch

The staff in the Academic Programs Office (APO), Room 4-315, can direct you to committee members most appropriate to your specific questions or concerns. All graduate students and faculty are affiliated with one of the Department's four research divisions. Each division is headed by a faculty member with responsibilities for aspects of the graduate program of that division's students. The current Division Heads are:

- Prof. Raymond Ashoori, Atomic, Bio-, Condensed Matter, and Plasma Physics
- Prof. Anna Frebel, Astrophysics
- Prof. Gunther Roland, Experimental Nuclear and Particle Physics
- Prof. Tracy Slatyer, Theoretical Nuclear and Particle Physics

The Associate Department Head serves as the advisor for student concerns about scientific misconduct issues including interactions with research supervisors, data integrity, and authorship. In addition, Physics REFS can provide mediation services between student peers and/or faculty members and Shannon Larkin, Assistant Director, can be helpful in dealing with sensitive issues.

Every incoming student is assigned an academic advisor. Under most circumstances this faculty member will continue to advise the student until graduation. Later, when the student joins a research group, another faculty member will become his or her research supervisor.

Funding

Note: For more detailed information regarding the cost of attendance, including specific costs for tuition and fees, books and supplies, housing and food as well as transportation, please visit the Student Financial Services (SFS) website.

PhD students in Physics are typically funded in each year they are in the program and remain in good standing. Financial support provides for full tuition, a monthly living stipend, and 12 months of health insurance. Students are expected to spend full time on education and assigned duties and may not engage in any other activity for compensation without the specific approval of the Department Head.

There are three sources of financial support:

- Research Assistantships
- Teaching Assistantships
- Fellowships (internal and external)

All Research Assistant and Teaching Assistant appointments are governed by the Graduate Student Union Collective Bargaining Agreement.

For both RAs and TAs, full tuition and health insurance is paid over and above the stipend. If a student loses RA support due to termination of a research contract, the Department will provide support for one additional term (in the form of a TA) and will make every effort to provide an alternative form of continuing support.

The periods for RA and TA appointments are as follows:

- Fall: September 1 to January 15
- Spring: January 16 to May 31
- Summer: June 1 to August 31

Research Assistantships (RAs)

These appointments are generally for the academic year, plus the summer. The amount of time a student spends on RA duties depends on the amount of course work he or she needs and on the requirements of the group in which he or she works. For new graduate students taking classes and preparing for the general examination, research duties normally require 20 hours per week or less.

Teaching Assistantships (TAs)

Some TA appointments are available during the fall and spring terms. These appointments involve teaching sections in a course or lab, tutoring, or grading homework and exams. This work requires up to 20 hours per week in addition to any research or class work the student is doing.

TA appointments are typically made after the first year. These appointments are used to encourage students who wish to hone their teaching skills, to help alleviate funding pressures on the faculty, to facilitate a student's transition to a different research group, or to support departmental teaching needs. Each of the four divisions in the department has been assigned a guaranteed number of TA positions. In the spring, each division compiles a list of students to be funded by TA appointments in the subsequent academic year. This list is submitted to the department for approval. Thus, students who desire TA support after the first year must inform their research supervisor, who will forward this information to the Division Head. If, after the divisions have submitted their TA lists to the Department, additional TAs are needed, the Department will solicit applications from the physics graduate student population as a whole.

Fellowships

Fellowships provide tuition, health insurance and a stipend without an expectation of work, unless specifically exempted by the Department Head. A student entering the Department with a fellowship has a great deal of flexibility in planning his or her graduate program and in seeking out a research group. However, the fellowship recipient is responsible for finding a research group that will provide funding upon expiration of the fellowship support. Some information on fellowships for graduate students in physics is available through Academic Programs and the Office of Graduate Education, Room 3-134.

External Fellowships

1. Students interested in applying for an outside fellowship and receiving a departmental top-up should submit the Pre-award Fellowship Top-up Application. This helps us calculate whether a fellowship top-up is possible.

2. If you are successful in an external fellowship which covers 45% of a 9 month cost (tuition + stipend), the Department can supplement (top-up) the remainder, contingent upon our funding situation, and if we have received a top-up application.

3. Physics also has a policy where any student who receives an outside fellowship covering 45% or more of a 9 month cost will also receive a $1,500 discretionary fund from the Department.

4. There are programs which are titled "Fellowship" which do not cover tuition and stipend – students should carefully review all terms before accepting a fellowship. The KITP Fellowship is an example of this. Students thinking of applying for the KITP Fellowship should read the departmental policy document (Appendix B) carefully before making their decision.

5. The Department will support a maximum of 5 years on fellowship. Any time spent at MIT after that should be as an RA or TA.

Switching Groups

Many students continue through from their first RA to a thesis in the same group. Others, however, elect to change research groups. An RA who does not wish to continue research in his or her group, or who simply wishes to investigate other possibilities, should not hesitate to talk to other professors about different opportunities. However, students are responsible for notifying their current supervisor of their intention to leave a group. Students are expected to work in the research group as long as it is providing funding. In order to facilitate the transition from one research group to another, each student is guaranteed one semester of transitional funding in the form of a TA. Once the decision has been made and approved to switch groups, the student should complete a Research Supervision Form (PDF) or Research Co-Supervision Form (PDF) and submit it to Academic Programs as soon as possible.

Guaranteed Transitional Funding

In the event that a student whose funding has been terminated is not able to secure another research position prior to the start of the next semester, the Department will guarantee **one term** of support in the form of a transitional TA. If the termination of an RA occurs at the end of the spring semester and the student is unable to find other support for the summer, the Department will make an effort to find summer support for the student. The one semester transitional TA would then be available in the fall, if needed.

Students have a responsibility to continue working in their research group as instructed by their research advisor as long as they are being supported. Questions about this process should be directed to the Assistant Director, Academic Programs. If differences arise between the research supervisor and the student concerning the interpretation of "unsatisfactory performance," the problem should be brought to the attention of the student's academic advisor, the Division Head, or the Graduate Committee. Committee members are available to discuss, in private, problems encountered by either the student or the research supervisor before formal action takes place. Additional resources are listed on the front page of the Guidelines.

Coursework and Milestones

Students should be registered for a term load of at least 36 units every semester.

Coursework:

- 8.398 Doctoral Seminar, 2 semesters in the first year
- Specialty Subjects, determined by area of specialty. Two or three, depending on research area.
- Breadth subjects, 2.

Research:

- Prior to passing oral exam, student registers in 8.391/8.392 every semester
- After passing oral exam, student registers in 8.THG every semester

Academic Milestones:

- Core requirement (completed by end of fourth semester)
- Secure research supervisor by March 1 or October 1 of second semester
- Oral Exam (passed by end of sixth semester)
- Thesis Proposal and Committee formation (completed semester after oral exam)
- Thesis defense
- Thesis submission

Satisfactory progress is demonstrated by maintaining a GPA of 3.5 or better in coursework, remaining employable in an RA or TA appointment, and meeting milestones on time.

Any student who anticipates a possible delay in this schedule should confer with his or her academic advisor; Associate Head Scott Hughes; or Assistant Director, Academic Programs Shannon Larkin before the end of the first spring term.

Progress Through the PhD

The normal degree program in the Department leads to a Ph.D. in Physics. Direct admission to a Master's degree program in Physics is available only in special cases (e.g., US military officers). On occasion, a student admitted for a Ph.D. may decide not to follow the Ph.D. program through to completion, or may fail the General Exam. In these cases the student may be able to satisfy the requirements for the Masters degree.

Requirements for the Masters Degree

Masters candidates must complete 66 units, 42 of which must be graduate-level subjects. A thesis is required; however, an oral thesis defense is not required. The thesis will be assigned a grade by the research supervisor in consultation with the thesis committee.

Core Requirement

The Core Requirement consists of demonstrated knowledge in four areas of Physics: Classical Mechanics, Electricity and Magnetism, Quantum Mechanics, and Statistical Mechanics. Each section may be satisfied either through taking a designated course, or by passing a Written Exam that indicates whether a student already has sufficient mastery of a particular area. These courses and exams are taken during the first two years of graduate study. Satisfying the Physics Core requirements demonstrates a student's sufficient grasp of four basic areas of Physics which are the building blocks for future research. The four sections of the Physics Core together constitute an important foundation required for all PhD students, regardless of the particular topic of their thesis research.

Classes

The four courses that satisfy the Core Requirement sections are:

- Classical Mechanics (8.309) offered every spring
- Electricity and Magnetism (8.311) offered every spring
- Quantum Mechanics (8.321) offered every fall
- Statistical Mechanics (8.333) offered every fall

A student satisfies any section by completing the corresponding course with a grade of B+ or higher.

After the first term, for any section of the Core Requirements not yet satisfied:

- the student is required to attempt all remaining sections of the next Core Written Exam;
- if there are remaining sections still to be completed at any time after the exam in the student's first January, the student must enroll in the corresponding course the next time it is offered.

The deadline for satisfying all four sections of the Core Requirement is the end of a student's fourth regular semester. This timeline allows a student two attempts to complete the Core Requirement by passing the corresponding courses with a B+ or better, as well as four opportunities to satisfy the requirements through the Core Written Exams.

Students experiencing unusual circumstances (e.g., serious health issues, family emergency), may request a delay of their deadline. (See the section on **Schedule Postponements** below.)

If a student has not passed all sections of the Physics Core Requirement by the appropriate deadline, an ad hoc committee will form to consider the student's individual case. This committee will report to the Associate Department Head and will consist of:

- the Faculty Graduate Program Coordinator

- the General Exam and Requirements Coordinator
- the chair of the Written Exam Committee
- the department's Assistant Director of Academic Programs (ex officio)

The committee will receive input from the student's academic and research advisors, and the student will have the opportunity to provide a written statement. The likely recommendation would be to switch the student to Master's degree status and set a schedule for completing an SM thesis. However, in unusual cases, this committee may recommend that the student be allowed to do prescribed further study and/or to have one additional attempt to complete the outstanding section by course or exam at the next opportunity. The final decision would be made by the Associate Department Head. No further extensions would be allowed.

Written Exams

The topics covered by the exams and the expected levels are documented in the syllabus (Appendix A). The Physics Core Written Exams are offered twice a year, in August and January. Entering students must take the exam upon arrival. The Associate Head may approve exceptions due to extenuating circumstances such as Visa issues or the desire to take undergraduate coursework in one of the core areas.

Each exam consists of two questions; the student selects one of the two questions to solve in a 75-minute period. The questions are prepared by a committee of four Physics faculty members, and are reviewed before the exam is finalized by additional faculty who are each assigned to grade one section of the exam.

There is no pre-determined or fixed percentage of students who pass, nor is there a fixed passing score. The difficulty of the examination may vary somewhat from year to year, and this is taken into account in determining the pass/fail line.

Exams with grades near the deciding line are reviewed in detail by all members of the Exam Committee and by the graders. If a student is repeating an exam, the earlier performance is also considered.

Exam results are communicated to students and their advisors individually by email in time for the results to be considered in the selection of classes for the upcoming term. Students are welcome to review their exams, in the Academic Programs Office, accompanied by an advisor or other faculty member.

Sample Written Exams

Sample exams, with solutions, are available as study aids for the Written Exam. The current format of four 75-minutes sections was first administered in fall 2015. Prior to 2015 our Qualifying Exams were given in 3 parts: Parts I and II comprised the Written Exam, and the Oral Exam was known as Part III.

Pre-2015 sample exams labeled 'Part II' with the 4 sections presented as a single 5-hour exam continue to be useful for Written Exam study, if reviewed as separate 75-minute topics.

Study materials are available both below, the Physics REFS webpage, and our Physics Written Exam Study Guide.

NOTE: You may see the words "Part II" mentioned in the below PDFs. Labeling of the Written Exam was changed in 2015, when what was originally two written exams was condensed into one exam.

Textbook Suggestions for the Written Exams in Physics

Most students study for the exam by reviewing the textbooks and class notes from the core subjects. The following books cover all the material that is likely to be tested on the written exam.

Classical Mechanics

- Goldstein, Poole & Safko, *Classical Mechanics*, 3rd edition

Electromagnetism

- *Introduction to Electrodynamics*, 3rd edition, by David J. Griffiths (Prentice Hall, 1999)
- Likharev, *Classical Electrodynamics* (EGP – Part EM: Classical Electrodynamics)

Quantum Mechanics

- J. J. Sakurai and Jim Napolitano, *Modern Quantum Mechanics* (3rd ed), Cambridge University Press, 2021

Statistical Mechanics

- M. Kardar, *Statistical Physics of Particles*, (Cambridge University Press, 2007)

Sample Written Exams

- Fall 2000 (PDF)
- Spring 2001 (PDF)
- Fall 2001 (PDF)
- Spring 2002 (PDF)
- Fall 2002 (PDF)
- Fall 2012 (PDF)
- Spring 2012 (PDF)
- Fall 2015 (PDF)

Sample Written Exam Solutions

- Fall 2000 (PDF)
- Spring 2001 (PDF)
- Fall 2001 (PDF)
- Spring 2002 (PDF)
- Fall 2002 (PDF)
- Fall 2012 (PDF)
- Spring 2012 (PDF)
- Fall 2015 (PDF)

Oral Qualifying Exam

The purpose of the oral portion of the general exam is to test students' broad general knowledge within their field, which is the same as that of their research supervisor; only a minor portion of the exam will concern the student's specific research topic. *Once a student has passed the Oral Exam, they are considered a PhD Candidate.*

Students may not attempt the Oral Exam until they have completed the Core Requirement.

- Two attempts at the Oral Exam are allowed.
- The first attempt at the oral exam must be taken by the first term of the third year (the fifth regular semester).
- If a second attempt is needed, it must be taken in the term immediately following the first attempt. (If a first, failed attempt was taken in the first term of the second year, or earlier, the student may postpone the second attempt until the beginning of the third year.)

At the start of the academic year, each Division appoints one committee for each research field to examine all students in that field who will take the exam within the coming year. The oral exam committee consists of:

- the chairperson
- two other faculty members
- an alternate faculty member if the student's research supervisor is a member of the standing exam committee

The Academic Programs Office notifies all students about the members of their committee; the student is then responsible for scheduling the exam with the committee and notifying Academic Programs of the exam day, time, and place. Exams are generally administered in the second half of the term.

The Committee Chair in each area should communicate exam expectations to the students taking the exam that term. Ideally, this should be done in a meeting of all examinees at the start of the term.

Currently, oral exam committees are formed in each of the following areas:

- **Astrophysics**
  Chair: Scott Hughes
- **Atomic and Optical Physics**
  Chair: Paola Cappellaro
- **Biophysics**
  Chair: Jeff Gore
- **Condensed Matter Experiment**
  Chair: Pablo Jarillo-Herrero

- **Condensed Matter Theory**
  Chair: Xiao-gang Wen
- **Nuclear and Particle Experiment**
  Chair: Phil Harris
- **Nuclear and Particle Theory**
  Chair: Barton Zwiebach
- **Quantum Information**
  Chair: Isaac Chuang
- **Plasma Physics**
  Chair: Earl Marmar

Content of the exam:

- The first question should be in the student's specific area. The Chair should have received this question from the supervisor and provided it to the student a week before the exam.
- The oral examination continues in the student's general field.
- Discussion of a student's research, when applicable, comprises no more than the final quarter of the examination.

The research supervisor may observe the exam and may provide input only if solicited by committee members. The supervisor and student will be asked to leave the examination room when the final decision is discussed. The committee should inform them of the result as soon as a decision is reached.

Scheduling Postponements

Postponements for completing any part of the General Doctoral Requirements can be granted if a student is experiencing unusual circumstances. Requests for postponement of the Physics Core Requirement must be submitted at least one month prior to the start of the next term in which a Written Exam or corresponding course would be required. Requests for postponement of the Oral Exam must be submitted by September 30th for the fall term and by February 28th for the spring term. Any request for postponement must be made in writing (e-mail is acceptable) to the research supervisor. The request must include a clear justification. The research supervisor will add comments and forward the request to the General Examination and Requirements Coordinator. A student with no research supervisor should submit the request through his or her academic advisor. Appeals should be addressed to the Associate Department Head, who will consult with appropriate faculty members when reviewing the case.

Specialty and Breadth Subject Requirements

Specialty Subjects

Students are required to take two or three basic one-semester subjects in their research specialty. These subjects are central to the research area and it is advantageous to complete them as early as possible. The specialty subjects in the various fields are listed below and each must be passed with a grade of B- or better. Substituting for any of the following subjects requires a request in writing (or e-mail) to the appropriate Division Head. After commenting, the Division Head will forward the request to the General Examination and Requirements Coordinator who will send notification of the decision.

ASTROPHYSICS
8.901, 8.902 Astrophysics I, II

ATOMIC AND OPTICAL PHYSICS
8.421, 8.422 Atomic and Optical Physics I, II

BIOPHYSICS
8.591 Systems Biology
and one of the following:
-- 8.592 Statistical Physics in Biology
-- 8.308 Introduction to Stochastic Dynamics

CONDENSED MATTER PHYSICS
8.511, 8.512 Theory of Solids I, II

EXPERIMENTAL NUCLEAR AND PARTICLE
8.701 Intro to Nuclear and Particle Physics
8.711 Nuclear Physics
8.811 Particle Physics

PLASMA PHYSICS
8.613J, 8.614J Introduction to Plasma Physics I, II

QUANTUM INFORMATION
8.371 Quantum Information Science
and one of the following:
-- 8.322 Quantum Theory II
-- 8.323 Relativistic Quantum Field Theory I
-- 8.421 Atomic and Optical Physics I
-- 8.422 Atomic and Optical Physics II
-- 8.511 Theory of Solids I
-- 8.512 Theory of Solids II
-- 8.372 Quantum Information Science III

THEORETICAL NUCLEAR AND PARTICLE
8.325 Relativistic Quantum Field Theory III
and, as appropriate, two of the following
-- 8.334 Statistical Mechanics II
-- 8.962 General Relativity
-- 8.952 Particle Physics of the Early Universe
-- 8.821 String Theory
-- 8.831J Supersymmetric Quantum Field Theories
-- 8.851 Effective Field Theory
-- 8.701 Intro to Nuclear and Particle Physics

Breadth Subject Requirement

This applies to students entering in or after Fall 2023. Students who started before Fall 2023 may follow this requirement or the old one listed in the appendix.

To enrich knowledge about physics outside of one's own research field, students must complete two breadth requirement subjects. At least one of these must be from the list below. Both must be passed with a grade of B- or better.

There are two types of breadth courses: primary breadths and secondary breadths. A student may satisfy the graduate breadth requirement by taking either: two primary breadth courses or one primary breadth course and one secondary breadth course. If two primary breadth courses are used to satisfy the requirement those must be from two different areas. A course cannot satisfy both the breadth and specialty requirement, so breadth courses cannot be from the student's own area. A student's area is determined by the Oral Exam they plan to take.

Allowable Breadth Subjects by Research Area

Astrophysics

Primary

- 8.323 - Relativistic QFT I
- 8.370 - Quantum Computation
- 8.421/8.422 - AMO
- 8.511 - Theory of Solids
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory

Secondary

- 8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- *8.962 - General Relativity (not normally accepted for breadth in a particular area, can be appealed to as substitution in rare circumstances)
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

Atomic Physics

Primary

- 8.323 - Relativistic QFT I
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 - Cosmology

Secondary

- 8.324/8.325 Relativistic Quantum Field Theory (or Harvard Equivalent)
- 8.334 – Statistical Mechanics II
- 8.370/8.371/8.372 - Quantum Computation
- 8.511/8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

BIOPHYSICS

Primary

- 8.323 - Relativistic QFT I
- 8.370 - Quantum Computation
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 – Cosmology

Secondary

- 8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.421/8.422 - AMO
- 8.511/8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

CMT

Primary

- 8.370 - Quantum Computation
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 - Cosmology

Secondary

- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.421/8.422 - AMO
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

CMX

Primary

- 8.323 - Relativistic QFT I
- 8.370 - Quantum Computation
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 - Cosmology

Secondary

- 8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.421/8.422 - AMO
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

Nuclear Physics Experiment

Primary

- 8.323 - Relativistic QFT I
- 8.370 - Quantum Computation
- 8.421/8.422 - AMO
- 8.511 - Theory of Solids
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 - Cosmology

Secondary

- 8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

Nuclear Physics Theory

Primary

- 8.370 - Quantum Computation
- 8.421/8.422 - AMO
- 8.511 - Theory of Solids
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.901 - Astrophysics
- 8.942 – Cosmology

Secondary

- 8.371/8.372 - Quantum Computation
- 8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.701/8.711/8.712/8.811 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

Plasma

Primary

- 8.323 - Relativistic QFT
- 8.370 - Quantum Computation
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 - Cosmology

Secondary

- 8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- 8.371/8.372 - Quantum Computation
- 8.421/8.422 - AMO
- 8.511/8.512/8.513/8.514 - Theory of Solids
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.962 - General Relativity
- 8.316- Data Science
- 8.750J Symmetry and its Applications to Machine Learning

Quantum Information

Primary

- 8.511 - Theory of Solids
- 8.591 - Quantitative Biology
- 8.592 - Statistical Physics in Biology
- 8.613J - Plasma Physics
- 8.701/8.711/8.811 - Nuclear & Particle Physics
- 8.821 - String Theory
- 8.901 - Astrophysics
- 8.942 – Cosmology

Secondary

- 8.323/8.324/8.325 or Harvard equivalent - Relativistic QFT
- 8.334 – Statistical Mechanics II
- *8.421/8.422 - AMO (not normally accepted for breadth, can be appealed as substitution in rare circumstances)
- 8.512/8.513/8.514 - Theory of Solids
- 8.614 - Plasma Physics
- 8.712 - Nuclear & Particle Physics
- 8.902 - Astrophysics
- 8.316- Data Science
- 8.962 - General Relativity
- 8.750J Symmetry and its Applications to Machine Learning

Internships

An internship can be used as a secondary breadth. Internships need to be arranged ~6 months in advance in coordination with the department and the research advisor. Internships may be scheduled during either summer or academic terms and the student will need to register for the correct units. Please contact the APO for more information.

Harvard Courses

The following Harvard subjects may be substituted as noted:

Harvard 253a Quantum Field Theory I for 8.323 Relativistic Quantum Field Theory
Harvard 253b Quantum Field Theory II for 8.324 Relativistic Quantum Field Theory II

Substitutions

The current breadth requirement was crafted with care. If you believe a course should be part of the breadth requirement, the instructor will need to go through the procedure for the course to be cross-listed with physics.

Research

Most graduate students are financially supported by Research Assistantship positions. RAs become involved in a research project as soon as they begin their assistantship, and this often leads to a thesis topic. **Students should look for a research group during the first year, and confirm the supervisor by March 1.** Prior to thesis research, students get academic credit for their research by registering for Pre-Thesis Research (8.391 or 8.392), which is taken every semester that research is conducted until thesis research formally commences after passing the Oral Exam.

While many students stay with their first research group, some register for Pre-Thesis Research in two or more research areas before finding a research topic suitable for a thesis. Pre-Thesis Research is graded on a Pass/Fail basis.

Starting with the semester **after a student passes the oral exam**, registration changes from Pre-Thesis Research to Thesis (8.THG).

All graduate students conduct research that eventually leads to a thesis, but there are many different paths to gaining a research project. Students are expected to register for thesis and be assigned a thesis committee by the first term of their fourth year of graduate school (see Thesis section below).

Research Supervision

Any person who holds a Faculty or Senior Research Scientist appointment in the Physics Department may serve as a research supervisor. Under special circumstances, a faculty member outside the Department may supervise a student (this includes other MIT departments). All proposals for working with a faculty member outside the department must be approved by the Associate Department Head.

Prior to embarking on a research project with an outside supervisor, the student must obtain a Physics co-supervisor. The co-supervisor will maintain close contact with the research as it progresses, guide the student through the oral exam and thesis committee formation, guarantee funding for the student, and must ultimately co-sign the thesis. The student should submit a Research Co-Supervision Form (PDF), which requires the signatures of the research supervisor and co-supervisor. This form must be submitted to Academic Programs. No funding will be administered by the Department of Physics until this form is submitted.

Students will not be permitted to have advisors at other universities, including Harvard, except through well-established collaborations e.g. the Center for Ultra-cold Atoms.

Research Internship

Physics graduate students may wish to arrange an internship in an industrial or national laboratory at some time during their graduate career. Internships may be scheduled during either summer or academic terms and can be used, with approval of the student's academic advisor, to satisfy one of the Departmental breadth requirements, even if the internship is in the student's research field; internships may not be used to satisfy the specialty requirement. The Department recognizes that the demands of MIT research may make it difficult for students to consider this opportunity, but it also believes that the benefits can outweigh the possible conflicts. Students seeking internships should discuss the issue with their research supervisor and schedule the internship to minimize disruption of research.

Thesis

Students must register for thesis (8.THG) and be assigned a thesis committee no later than one term after that in which they pass their Oral Exam. Students should consult with their Research Supervisor to discuss the Doctoral Thesis Committee Proposal Form which will list the committee chair and selected readers of the Physics Doctoral Committee and a descriptive draft thesis title. A third reader from the Physics faculty, who is not in the same research area, but whose interests, background, or special knowledge make him or her an appropriate member of the committee, is assigned by the Graduate Student Coordinator. When the departmentally-assigned reader has been selected, it is the student's responsibility to convene an initial thesis committee meeting no later than four weeks before the last day of classes.

At that meeting the student makes an oral presentation to the thesis committee of a detailed proposal for a research program that would subsequently become the Ph.D. thesis. The student should demonstrate a thorough knowledge of relevant literature, explain the significance of the research to progress in the field, and present a well-thought-out program of research, including contingency plans. After that meeting, and based on the discussion, the student may develop a written proposal consisting of a one- or two-page description of the body of work that is to comprise the thesis.

Subsequent changes in title, scope, supervisor(s), or readers may be made with the written approval of the Graduate Student Coordinator.

In some cases, the thesis research may be in a borderline field between physics and some other field of science or engineering. In these cases, a joint committee, including members of another department may be formed. This requires approval by the Dean for Graduate Education.

Students who have not submitted a thesis proposal by the end of the first term after passing their oral exam will be prevented from registering for classes until they do.

After the initial oral presentation to the thesis committee, each student must make at least one substantial oral presentation of progress to the thesis committee every 12 months. The scheduling of this presentation is arranged by the student.

Master's Thesis

Students pursuing a Master's degree are required to submit a written thesis. No oral defense is necessary. When work on the thesis commences, each student must submit a Master's Thesis Proposal Form (PDF) with the proposed title of the thesis and the signature of the research supervisor to Academic Programs, 4-315. The student should begin registering for 8.THG immediately. A second reader will be assigned by the Graduate Student Coordinator and the student will be subsequently notified. Upon completion of the thesis, the research supervisor will submit a letter grade for the work to Academic Programs. **The Master's Degree is a terminal degree, and will never be awarded enroute to a PhD.**

Thesis Oral Defense

The thesis defense is an oral presentation of the thesis research. The defense should take place at least two weeks before Departmental deadline (the last day to go off the degree list in a given semester). This oral presentation is based on an acceptable written draft of the thesis, which is provided to the thesis committee at least two weeks prior to the defense. The student is responsible for scheduling the thesis defense and arranging for the room in which it is to be held. The student should then notify the Graduate Coordinator in Academic Programs of the day, time, and place of the defense; the Graduate Coordinator will send notice to the Physics community. The defense is public and all members of the MIT community may attend. Immediately following the public presentation there will be a mandatory private session involving only the student and the thesis committee.

MIT Degree List

A student may be recommended for his or her degree in any term, but MIT only awards degrees three times a year - in February, May and September. A student must submit an Application for Advanced Degree at the beginning of the term in which he or she plans to graduate, and **must be registered in residence during that term**. Those on the September and February degree lists may participate in commencement the following June.

Thesis Submission

After passing the thesis defense and incorporating the suggested changes, students must submit to **Academic Programs**:

-A PDF/A-1 of your final thesis document (**without signatures**)
-Signature page (with signatures)

The student's research is not considered complete until the thesis document has been submitted. Student status and RA appointment are terminated upon receipt of the thesis document. Students with prospective employers may request a letter confirming completion of all degree requirements from the APO.

Career Development

Although the MIT Physics graduate program is primarily focused on training students for careers in physics research, the pursuit of an advanced degree in physics is an excellent preparation for a variety of careers, both in physics and in other fields. If you have questions, or if you need someone to talk to about your career, there are many people available and willing to help. Every incoming student is assigned an academic advisor with whom they can discuss their course schedule and professional plans. Students in research groups have excellent resources in their research supervisor and other graduate students, and teaching assistants can talk to the professors for whom they are teaching. Students can also get advice from their course instructors. The MIT Career Advising and Professional Development (CAPD, E17-294) has a variety of resources for graduate students.

Professional Development Pilot

Graduate students in the MIT Physics Department receive extensive research training through research assistantships and PhD thesis research. To pursue a career in physics and related fields, though, graduate students need to acquire a broader range of professional skills, including those related to leadership, teaching, advising, service, and advocacy.

While one goal of professional development is to prepare graduate students for a post-PhD career, there is an equally important goal of exposing students to new topics. In this spirit, students are encouraged (though not required) to choose complementary professional development activities that provide them with new experiences.

Professional Development can and does happen in many forms and is frequently not tied to coursework. Many students already participate in activities internal and external to the Institute that provide substantive professional development experiences or training.

Throughout their PhD program, students should complete a total of 15 units in three types of professional development activities.

1. **Classroom Training** — Minimum 6 units. This corresponds to a half-semester subject, which is the minimum amount of time needed to benefit from classroom-style training. These units may come from one or more subjects, or certificate programs.
2. **Practical Mentoring/Advising Training** — Minimum 3 units. Practical training spans a wide range of activities, including mentoring undergraduate students. This category requires overall fewer units because many important practical training activities require only a modest time commitment. This category provides professional development skills in advising, mentoring, and teaching.
3. **Committee/Service Training** — Minimum 1 unit. This category provides professional development skills in leadership, service and advocacy.

Note: "Unit" follows the MIT standard of 1 hour per week over a 15 week period. Committee membership should be taken as 1 unit for a 1 year service commitment, or for 1 semester for committees of limited duration, e.g. graduate admissions or faculty searches.

In the first year of the program, the requirement will be satisfied by the **Doctoral Seminar in Physics, 8.398**. After the first year, the student should create a plan each semester with their academic advisor to satisfying the requirement. If there will be activities that semester, the student should register for **8.394, Professional Development in Physics**. They will be required to upload a plan to the Canvas site at the start of the semester, and a reflection at the end of the semester. In this way, the requirement is reflected on a student's transcript.

Overall goal and learning objectives of an MIT doctoral PD requirement:

The overall goal of a doctoral PD requirement is to instill in students the lifelong desire to engage in professional and personal development through experiences they design during their PhD, with guidance.

The student learning objectives for such a requirement are:

- The student establishes a habit of self-assessing, learning, and honing or improving (non-technical) professional and personal skills.
- The student has begun to explore career paths of interest to them and considered the alignment of their doctoral training with these paths.
- The student effectively communicates their work and is capable of tailoring to a non-specialist audience, including its potential positive and negative impacts.
- The student appreciates a variety of impacts that mentorship can play on their professional development and has begun to think strategically about their own mentoring and mentoring network.
- The student recognizes the importance of knowing their core values and is using them for professional and personal decision making.
- The student appreciates how people's different values, interests, and skills can influence their behavior and response in professional settings.
- The student appreciates how leadership, collaboration, and interpersonal skills enable one to work productively in a range of professional situations.

1. Examples of *Classroom Activities*

- **Leadership Skills**
    - (3 units) LEAPS: 8.S396: Part I - Professional Strategies and Skills
    - (3 units) LEAPS: 8.S397: Part II - Leadership Training
    - (9 units) 6.9280[J]: Leading Creative Teams
- **Social Responsibility**
    - (6 units) 10.01: Ethics for Engineers: Artificial Intelligence
    - (6 units) 22.16: Nuclear Technology and Society

2. Examples of *Mentoring/Advising Activities*

- **Teaching Skills**
    - (3 units) Kaufmann Teaching Certificate Program
    - (3 units) Teaching Development Fellowship Network
- **Mentoring Skills**
    - (3 units) 8.998: Undergraduate Mentoring
- **Internship/practical skills**
    - (12 units) External research internship at a private company, National Laboratory, etc. Please note that an internship used to satisfy a departmental requirement (i.e.

Breadth subject) may not also be used to satisfy the Professional Development requirement.

3. Examples of *Committee/Service (CS-P) Activities*

- **Leadership role or major responsibility in student organization:**
    - (1 unit per year) Graduate Womxn in Physics, Physics Graduate Student Council, etc
- **Participating in mentoring program:**
    - (1 unit per year) Physics Graduate Application Assistance Program (PhysGAAP)
    - (1 unit per year) PhysREFS (Resources for Easing Friction and Stress)
    - (3 units per summer) MSRP Mentoring
    - (3 units per semester) 8.01–8.04 Mentoring Program
    - (1 unit per semester) TA pedagogy/instruction course
- **Participating in committees:**
    - (1 unit per year) Service on an MIT Physics committee
        - Graduate Admissions Committee
        - Physics Values Committee
        - Faculty Search Committee
        - Education Committee
        - Colloquium Committee
    - (1 unit per year) Service on an MIT-wide committee
        - Committee on Graduate Programs
        - Faculty Policy Committee
    - (1 unit per year) Service on a national committee
        - APS, AAS, etc.

Interdisciplinary PhD in Physics, Statistics, and Data Science

Many PhD students in the MIT Physics Department incorporate probability, statistics, computation, and data analysis into their research. These techniques are becoming increasingly important for both experimental and theoretical Physics research, with ever-growing datasets, more sophisticated physics simulations, and the development of cutting-edge machine learning tools.
The Interdisciplinary Doctoral Program in Statistics (IDPS) is designed to provide students with the highest level of competency in 21st century statistics, enabling doctoral students across MIT to better integrate computation and data analysis into their PhD thesis research.

Admission to this program is restricted to students currently enrolled in the Physics doctoral program or another participating MIT doctoral program. In addition to satisfying all of the requirements of the Physics PhD, students take one subject each in probability, statistics, computation and statistics, and data analysis, as well as the Doctoral Seminar in Statistics, and they write a dissertation in Physics utilizing statistical methods. Graduates of the program will receive their doctoral degree in the field of "Physics, Statistics, and Data Science."

Selection

Doctoral students in Physics may submit an Interdisciplinary PhD in Statistics Form between the end of their second semester and penultimate semester in their Physics program. The application must include an endorsement from the student's advisor, an up-to-date CV, current transcript, and a 1-2 page statement of interest in Statistics and Data Science.

The statement of interest can be based on the student's thesis proposal for the Physics Department, but it must demonstrate that statistical methods will be used in a substantial way in the proposed research. In their statement, applicants are encouraged to explain how specific statistical techniques would be applied in their research. Applicants should further highlight ways that their proposed research might advance the use of statistics and data science, both in their physics subfield and potentially in other disciplines. If the work is part of a larger collaborative effort, the applicant should focus on their personal contributions.

For access to the selection form or for further information, please contact the IDSS Academic Office at idss_academic_office@mit.edu.

Required Courses

Courses in this list that satisfy the Physics PhD degree requirements can count for both programs. Other similar or more advanced courses can count towards the "Computation & Statistics" and "Data Analysis" requirements, with permission from the program co-chairs. The IDS.190 requirement may be satisfied instead by *IDS.957 – Practical Experience in Data Analysis*, if that experience exposes the student to a diverse set of topics in statistics and data science. Making this substitution requires permission from the program co-chairs prior to doing the practical experience.

- **SEMINAR**

- IDS.190 – Doctoral Seminar in Statistics and Data Science
  (*may be substituted by IDS.957 – Practical Experience in Data Analysis*)

- **PROBABILITY**
  - 6.7700[J] Fundamentals of Probability ***or***
  - 18.675 – Theory of Probability
- **STATISTICS**
  - 6.7730 – Modern Mathematical Statistics
  - 6.S951 Modern Mathematical Statistics ***or***
  - 18.655 – Mathematical Statistics ***or***
  - 18.6501 – Fundamentals of Statistics ***or***
  - IDS.160[J] – Mathematical Statistics: A Non-Asymptotic Approach
- **COMP & STAT**
  - 6.7970 / 8.750 Symmetry and its Application to Machine Learning and Scientific Computing ***or***
  - 6.C51 Modeling with Machine Learning: from Algorithms to Applications + 2.C51 Physical Systems Modeling and Design Using Machine Learning ***or***
  - 6.7810 Algorithms for Inference ***or***
  - 6.8610 (6.864) Advanced Natural Language Processing ***or***
  - 6.7900 (6.867) Machine Learning ***or***
  - 6.8710 (6.874) Computational Systems Biology: Deep Learning in the Life Sciences ***or***
  - 9.520[J] – Statistical Learning Theory and Applications ***or***
  - 16.940 – Numerical Methods for Stochastic Modeling and Inference ***or***
  - 18.337 – Numerical Computing and Interactive Software
- **DATA ANALYSIS**
  - 8.316 – Data Science in Physics ***or***
  - 6.8300 (6.869) Advances in Computer Vision ***or***
  - 8.334 – Statistical Mechanics II ***or***
  - 8.371[J] – Quantum Information Science ***or***
  - 8.591[J] – Systems Biology ***or***
  - 8.592[J] – Statistical Physics in Biology ***or***
  - 8.942 – Cosmology ***or***
  - 9.583 – Functional MRI: Data Acquisition and Analysis ***or***
  - 16.456[J] – Biomedical Signal and Image Processing ***or***
  - 18.367 – Waves and Imaging ***or***
  - IDS.131[J] – Statistics, Computation, and Applications

Grade Policy

C, D, F, and O grades are unacceptable. Students should not earn more B grades than A grades, reflected by a PhysSDS GPA of ≥ 4.5. Students may be required to retake subjects graded B or lower, although generally one B grade will be tolerated.

Unless approved by the PhysSDS co-chairs, a minimum grade of B+ is required in all 12 unit courses, except IDS.190 (3 units) which requires a P grade.

Advising

Though not required, it is strongly encouraged for a member of the MIT Statistics and Data Science Center (SDSC) to serve on a student's doctoral committee. This could be an SDSC member from the Physics department or from another field relevant to the proposed thesis research.

Thesis Proposal

All students must submit a thesis proposal using the standard Physics format. Dissertation research must involve the utilization of statistical methods in a substantial way.

PhysSDS Committee

- Jesse Thaler (co-chair)
- Mike Williams (co-chair)

Advisors:

- Isaac Chuang
- Janet Conrad
- William Detmold
- Philip Harris
- Kiyoshi Masui
- Leonid Mirny
- Christoph Paus
- Phiala Shanahan
- Marin Soljačić
- Washington Taylor
- Max Tegmark

Leadership and Professional Strategies & Skills Training (LEAPS)

About LEAPS

In Spring 2020, our LEAPS courses on leadership and professional strategies and skills were offered for the first time at MIT in the School of Science. In the past, the SoS did not offer any such opportunity but it was recognized that such training is vital for advancing graduate student and postdoc careers in academia and industry.

A large variety of topics useful for all career choices together with interactive components and discussions have since been covered by the two half-semester LEAPS courses which will be offered again this coming Spring.

In Spring 2023, the LEAPS Program was awarded the Irwin Sizer Award for the "Most Significant Improvement to MIT Education" by the MIT Graduate Student Council. We are so appreciative of the wide level of support our program has received! Thank you!

The two-course LEAPS program:

To ease grad student/postdoc participation amidst everyone's busy research life and shouldering various responsibilities, the LEAPS program offers two half-semester courses (8.397 and 8.396) which can be taken on their own or consecutively.

We strongly recommend taking *both* LEAPS courses in order for participants to receive the full training and to make best use of this unique opportunity of practicing leadership and the hands-on day-to-day applications that go along with it!

Classes meet Tuesdays/Thursday 9:30-11am in-person throughout the semester. Our classroom will be Bld. 32.082 (Stata basement TEAL room).

Each of the two half-semester LEAPS courses has 3 credit units (for grad students). This means that the expected weekly workload is ~6h which includes class time (3h) and at-home personal (written) reflections (1-3h).

The LEAPS courses are kindly supported by the MIT School of Science and the Department of Physics. However, all students and postdocs from all other departments at MIT are very welcome to participate!

For questions, please contact us at: mitleaps@gmail.com.

Course Content

This course serves a large range of career ages, from new grad student to seasoned postdoc by providing a unique opportunity to either practice new(er) strategies and skills, reflect on and hone existing ones, or prepare you for what's ahead. Regardless, it allows you to take a step back to see what your advisor has or hasn't done, and in turn, what you will need to teach others one day.

8.396: Leadership through professional strategies and skills

- Learn to navigate academia better and with more confidence — being in your career's driver's seat and charting your goals with the career success matrix which is a tool for self-evaluation wrt the often unspoken rules and expectations in the academic landscape, assessing the quality if your current work relationships and how to go from there, reflecting on traits that make a good group/advisor and knowing what you need yourself, the benefits of clear communication

- Convince with clear writing and arguments — building and structuring winning texts, papers, proposals, outreach/media articles, etc. with the hourglass and the icecream cone, building up a simple but credible case for your grant/facilities proposal

- Enjoy public speaking and communication — winning different audience over with your best talks and presentations; preparing yourself and your talk, excelling at zoom talks, online lectures and interviews

- Networking, conferences and building your brand — discovering your own brand and leveraging it, establishing an online presence, making the most of attending a conference and expanding your network, the meaning of work-life balance and seemingly never getting there, combining career & family

- Scientists are humans, too — recognizing and navigating difficult situations/colleagues at work, understanding group dynamics, avoiding conflict through communication, maximizing everyone's potential, crisis leadership

- Know your transferable/non-research skills — you know more than you know, it's ok to change course from academic to expert professional, leverage existing skills in new environments, developing outreach projects, developing ideas that resonate, maximizing impact while minimizing one's workload, tying it all in with your (science) communication goals

- Prepare your successful job application package — motivation, content, and writing/formatting of CV/resume, cover letter, publication list, research statements and proposal, asking for letters of recommendation, your best job talk ever, excelling at job interviews with confidence, negotiating an offer to get what you need, starting off as an advisor and teaching all this to your students 🙂

- Leading a group/team — deriving your leadership style for good times and bad, understanding group dynamics and how everyone needs to fit in, tools for being "good" advisor, matching leadership to the task at hand, writing letters of recommendation and help others to succeed

8.397: Leading Yourself and Others

- Develop your self-awareness, a foundational leadership competency, critical to leading yourself and others – tools include introspection/meditation, Myers-Briggs Type personality test, the Reflected Best-Self Exercise, and understanding crises and crucible moments

- Grow your awareness of others and communicate optimally with different personality types – establish a clear communication strategy, learn to listen not just to what is expressed in words and adjust your message to the audience

- Strengthen your internal power, resonate with your team and master the different influencing styles in order to champion and implement change – develop the art of re-framing as a tool to help colleagues overcome their resistance to change, including key stakeholders in the strategic planning of change
- Build the right team for each job – create the team charter, assign positions and responsibilities, use work plans, adjust and monitor the process, recognize dysfunction, and master tips for early intervention
- Recognize and resolve conflict by seeing conflict as an indicator for needed change and improvement, learn how to emotionally disengage, find strength to do the "right" thing, bargain and negotiate
- Become an inclusive leader – understand bias as a necessary human survival tool for emergency situations that needs to be deconstructed to approach "objectivity" in our decisions and actions, develop cultural intelligence and curiosity for your colleagues and create effective collaborations minimizing microaggressions and maximizing microaffirmations
- Map the power landscape and empower yourself by navigating organizational politics, adapting your leadership style to the situation, managing your energy (time is finite), and learning when to trust others and how to be less controlling
- Gain the courage to be an ethical leader – see the many shades of grey (rather than the ideal black and white), distinguish the "right" thing to do in an ethical dilemma, and find your moral compass through personal and organizational values statements
- Learn to coach, mentor and sponsor others well – understand when to provide guidance and support and when to give others space to grow, evaluate yourself as a mentor, and practice listening, questioning and reflecting as a coach
- Plan your leadership journey – where are you now? What is your destination? What are your strengths? Your weaknesses? Which path should you take through this labyrinth?

Course Instructors

- **Anna Frebel,** astrophysicist and professor of physics and head of astrophysics division at MIT
  8.396: Leadership through professional strategies and skills
- **Angeliki Diane Rigos,** physical chemist
  8.397: Leading Yourself and Others

Appendix A: MIT Physics PhD Core Requirements Syllabus

Classical Mechanics:

1. Newton's laws for systems of particles (momentum, energy, center of mass, angular momentum, friction, solutions for motion, relativistic mechanics)
2. Lagrangian and Hamiltonian formulations of mechanics (calculus of variations, Lagrangian and Hamiltonian equations of motion, Legendre transformation)
3. Symmetry and Noether's theorem (cyclic coordinates, conservation laws)
4. Constraints (constraints to surfaces by elimination of variables, use of Lagrange multipliers, generalized forces such as forces of constraint)
5. Orbits and Scattering (motion in a central field, reduced mass, Kepler's problem, Rutherford scattering)
6. Vibrations and Oscillations (normal modes, simultaneous diagonalization of kinetic and potential energy matrices, superposition principle)
7. Canonical transformations (generating functions, Poisson brackets, Liouville's theorem)
8. Rigid body motion (moment of inertia tensor, Euler equations, centrifugal and Coriolis fictitious forces, precession and nutation)
9. Basics of fluid mechanics (continuity equation, ideal fluids, shear viscosity, Euler and Navier-Stokes equations, steady flows, Reynolds number)

References for these topics:

- *Latex lecture notes for 8.309,* by Iain Stewart (covers all topics in suitable depth except for A and E): [Stewart-Classical-Mechanics-III]
- *Classical Mechanics,* by Goldstein, Poole, Safko (covers all qualifying exam topics except for fluid mechanics)

Other references which may be useful include *Classical Dynamics* by Thornton and Marion (good reference at slightly lower level than Goldstein); *Mechanics* by Symon (good reference for its chapter on perfect fluids); Landau and Lifshitz volume 1 (for general mechanics) and volume 6 (for viscous fluids); Fluid Mechanics by Smits (useful for fluid problems); *Classical Dynamics: a Contemporary Approach* by Jose and Saletan (a relatively mathematical approach that also includes more modern topics and hydrodynamics)

Electromagnetism

1. Basics of EM
    - 1.1 Charges, currents
    - 1.2 Maxwell's Equations in vacuum
    - 1.3 Scalar and Vector Potentials
    - 1.4 Fields in materials (polarizability, magnetization, macroscopic fields, linear materials, Ohm's law)
    - 1.5 Boundary Conditions at Interfaces
    - 1.6 Electrostatic and magnetostatic limits
    - 1.7 Energy in electric fields and magnetic fields
2. Boundary Value Problems
    - 2.1 Method of images
    - 2.2 Separation of variables: cartesian, spherical, cylindrical coordinates
    - 2.3 Green Function methods
    - 2.4 Multipole methods
    - 2.5 Boundary value problems in materials

3. Waves and wave guides
    3.1 Electromagnetic waves in vacuum
    3.2 Polarization
    3.3 Poynting vector and intensity
    3.3 Electromagnetic waves in materials
    3.4 Reflection/refraction from an interface
    3.5 Propagation in a wave guide
4. Radiation
    4.1 Lienard-Wiechert solution of Maxwell's equations in Lorenz gauge
    4.2 Far-field and non-relativistic approximations
    4.3 Electric and magnetic dipole radiation
    4.4 Multipole radiation
5. Scattering and diffraction
    5.1 Scattering of EM waves
    5.2 Long wavelength
    5.3 Short wavelength
    5.4 Diffraction (scalar case)
6. Relativistic electrodynamics
    6.1 Covariant form of Maxwell's equations
    6.2 Lagrangian formulation of the EM field
    6.3 Energy-momentum tensor and conservation laws
    6.3 Relativistic motion of charged particles in uniform E and B fields

6.4 Solution of covariant wave equation

7. Radiation by relativistic charges
   7.1 Radiation by an accelerated point charge
   7.2 Thomson scattering
   7.3 Bremsstrahlung, synchrotron radiation

The level here is intermediate between *Introduction to Electrodynamics* by Griffiths and *Classical Electrodynamics* by Jackson. Topics 1), 3), 4), and 6) are mostly Griffiths material, while topics 2), 5), and 7) are mostly Jackson. Other useful sources are *Modern Electrodynamics* by Zangwill, Likharev's notes, volume 2 of the Feynman lectures, and Landau/Lifschitz volume 2.

Statistical Mechanics

1. Microcanonical ensemble, entropy, temperature. Examples from ideal gas, discrete systems (spins, vacancies, etc.)
2. Thermodynamics from statistical mechanics, temperature, heat, work
3. Canonical and grand canonical ensembles; classical ideal gas
4. Kinetic theory of gases (Liouville's theorem, linearized Boltzman equation, H-theorem, approach to equilibrium)
5. Quantum statistics, density matrices, fermions and bosons
6. Ideal gas of non-interacting fermions
7. Ideal gas of non-interacting bosons
8. Phase diagram of an Ising magnet (exact results in one-dimension, mean-field approach in higher dimensions)
9. Phase diagram of water; latent heat
10. Van der Waals equation, critical point, Maxwell construction
11. Random walks, Brownian motion, diffusion, Einstein relation

References:

- *Statistical Physics of Particles,* by Kardar (textbook, videos, and lecture notes)
- *Statistical Mechanics: Entropy, Order Parameters, and Complexity*, by Sethna
- Material for topic 11 is available (videos and notes) on the web-course "Mathematical methods for aspiring physicists," developed by Kardar and Detmold.

Quantum Mechanics

1. Formalism of quantum mechanics:
   1.1. Hilbert space, operators, the measurement postulate
   1.2. The uncertainty principle
   1.3. Pictures: Schrödinger, Heisenberg, Interaction
2. Quantum mechanics of particles in a potential with and without spin
   2.1. Square well potential
   2.2. Quantum harmonic oscillator - via Schrödinger equation as well as algebraically via creation/annihilation operators, coherent and squeezed states
   2.3. Orbital angular momentum
   2.4. Central potentials
   2.5. Hydrogen atom (including fine structure, hyperfine structure and Zeeman effect)
3. Symmetries

3.1. Continuous symmetries and conservation laws
3.2. Time and space translations, rotations
3.3. Spin, representations of SU(2)
3.4. Time reversal and parity
3.5. Degeneracies
3.6. Addition of angular momentum

4. Particle motion under the influence of electromagnetic fields
   4.1. Gauge invariance
   4.2. Landau levels
   4.3. Aharonov-Bohm effect
5. Approximate methods
   6. Variational principle
   7. WKB approximation and the classical limit
   7.1. Time-independent perturbation theory (including degenerate perturbation theory)
   7.2. Time-dependent perturbation theory, Fermi's Golden rule
   7.3. Interaction of atoms with classical EM fields, Einstein A and B coefficients, selection rules
   7.4. Adiabatic approximation, Berry's phase

7.5. Quantum mechanics of identical particles
   7.6. Bosons and fermions,
   7.7. Exclusion principle,
   7.8. Permutation symmetry and symmetrization
   7.9. Exchange interactions

8. Entanglement
   8.1. Density matrices
   8.2. Von Neumann entropy
   8.3. Bell inequality
9. Scattering theory
   9.1. One-dimensional scattering
   9.2. Lippmann Schwinger Equation, Born and Eikonal approximations, Optical theorem
   9.3. Scattering off of a central potential in three dimensions
   9.4. Partial waves decomposition
   9.5. Low energy scattering, bound states, resonances

References: The level for these topics should be roughly that of the textbook *Modern Quantum Mechanics* by J. J. Sakurai. The books by Shankar and Cohen-Tannoudji are also recommended as additional resources. Weinberg's book *Lectures on Quantum Mechanics* and volume 3 of Landau/Lifshitz are excellent as well, but are at a somewhat higher level.

Appendix B: Breadth Subject Requirements (pre Fall 2023)

To enrich knowledge about physics outside of one's own research field, students must complete two breadth requirement subjects. At least one of these must be from the list below. Both must be passed with a grade of B- or better.

If only one breadth requirement is taken from this list, students may request approval of a second course that is not on the list if it genuinely satisfies the two stated objectives of the breadth requirement: 1) learning about physics and 2) being outside the student's research field.

To request approval for a course, a student should write a short but clear email or letter explaining why the course satisfies these two objectives. If the course is in another department, the message should tersely explain on the basis of the course description or curriculum, why it should be considered learning about physics. The student should also succinctly state his or her research specialty and thesis topic, and explain why the course should be considered as being outside this research area. A short paragraph is sufficient to convey the necessary information.

Physics graduate students may wish to arrange an internship in an industrial or national laboratory at some time during their graduate career. Internships may be scheduled during either summer or academic terms and can be used, with approval of the student's academic advisor, to satisfy one of the Departmental breadth requirements, even if the internship is in the student's research field; internships may not be used to satisfy the specialty requirement. The Department recognizes that the demands of MIT research may make it difficult for students to consider this opportunity, but it also believes that the benefits can outweigh the possible conflicts. Students seeking internships should discuss the issue with their research supervisor and schedule the internship to minimize disruption of research.

The student should send the request to his or her academic advisor and, if necessary, discuss and modify the content to obtain the advisor's approval. The advisor should then forward the request, with his or her approval, to the General Examination and Requirements Coordinator who will send notification of the decision.

Subject #	BREADTH REQUIREMENTS Subject Title	Atomic	Biological	Condensed Matter	Plasma	Astronomy	Nuclear Exp.	Particle Exp.	Nuclear Theory	Particle Theory	QI
8.251	String Theory for Undergraduates								2	X	
8.323	Relativistic Quantum Field Theory I						2	2	X	X	
8.370	Quantum Computation										X
8.421 or 8.422	Atomic and Optical Physics I & II (only one may be used as a breadth requirement)	X		2							X
8.511	Theory of Solids I	2		X							
8.591	Quantitative Biology		X								
8.592	Statistical Physics in Biology		X								
8.613J	Introduction to Plasma Physics				X						
8.701	Introduction to Nuclear & Particle Physics						X	X	X	X	
8.711	Introduction to Nuclear Physics						X	X	X	2	
8.811	Particle Physics						X	X	2	X	
8.901 or 8.902	Astrophysics I & II (only one may be used as a breadth requirement)					X					
8.942	Cosmology					X					
8.962	General Relativity					X				X	

X indicates the subject is not allowed as a breadth requirement for students in this area
2 indicates the subject may be used as the second breadth requirement for students in this area as long as they also take one of the unmarked subjects.

Appendix C: KITP Fellows Policy

The Kavli Institute for Theoretical Physics (KITP) hosts graduate students for a residential stay at the Institute at UC Santa Barbara for an extended period of time, typically the duration of a KITP program. Students who are so hosted are known as "KITP Fellows."

Being a KITP Fellow is an outstanding opportunity for students to meet and work with colleagues in their field, and to participate in discussions on cutting-edge, topical research. We strongly encourage students and their advisors to take advantage of this program when the circumstances fit the context of the student's Ph.D. research. However, we have found several aspects of this program require clarification.

1. Although the students who participate in this program are named "KITP Fellows," this program is not a fellowship. The KITP provides housing and living expenses; it does not provide for any other cost which a fellowship covers (including tuition, stipend, health insurance). We regard the funding provided to KITP Fellows as a relocation and per diem allowance. MIT graduate students must be supported for tuition, stipend, and health insurance by RA or fellowship funds during the time that they are a KITP Fellow.

2. Particular care must be taken for non-US citizen graduate students on an F-1 visa. Such students are required to focus on academic work in support of their thesis at the institution which sponsors their visa. In order to participate as a KITP Fellow, their time in this program needs to be categorized as either Curricular Practical Training (CPT) or Occupational Practical Training (OPT); consult Shannon Larkin for details of how to proceed with these options.

a. To count as CPT, the program in which the student participates must directly contribute to a required element of their program of study. MIT Physics will count the KITP Fellows program as an internship that satisfies the second Physics Breadth requirement. As discussed below, we strongly recommend doing this when possible.

b. OPT is regarded by the US State Department as employment in a capacity that is directly related to your major or degree program. However, it should be noted that OPT is also often used by graduate students for short-term employment after completing their degree (before changing to, for example, a J-1 visa sponsored by a postdoctoral employer). The total amount of time available for OPT employment for a STEM degree is capped at 36 months. If OPT is used to categorize time spent as a KITP Fellow, it will count against this cap, potentially constraining options at the conclusion of a student's Ph.D. studies.

Practically speaking, we have found the best way to satisfy these constraints and rules is to use the KITP Fellows program to satisfy a student's second breadth requirement. Accordingly, if you and your student are considering the KITP Fellows program, we advise the student (as well as their academic advisor and research supervisor) to notify the Academic Programs Office of your plans. We will hold off on recording satisfaction of the second breadth requirement until the student has completed their stay at the KITP. This is particularly important for a student who completes coursework that satisfies the second breadth requirement before becoming a KITP Fellow. We cannot retroactively change the student's record to replace a 2nd-breadth course for a KITP internship. An F-1 visa student who has recorded completion of the breadth requirement will need to use OPT in order to be a KITP Fellow.