Rensselaer Polytechnic Institute

Department of Physics, Applied Physics, and Astronomy

Qualifying & Candidacy Examination Handbook

2015

Qualifying and Candidacy Exam Handbook

Introduction

It is necessary to pass two key examinations at specific stages in your academic career before you are eligible to complete your Ph.D. research and defend your thesis. The first is the Qualifying Examination, which should be completed, in your 3rd semester at Rensselaer. The second is the Candidacy Examination, which should be completed by the end of your third year.

This booklet should give you, under one cover, EVERYTHING YOU WANTED TO KNOW ABOUT THESE EXAMS. If you have any further questions or comments please bring them to our attention.

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Qualifying Examination

General Guidelines

The qualifying examination consists of two five-hour sessions covering materials at the level of advanced undergraduate courses. In each session, students have the opportunity to take two parts of the four-part qualifying examination. Each of the four parts is passed individually. A student may spend the entire five hours on one part of the exam.

- Part I - Mechanics and Electrodynamics

  Intermediate Mechanics, similar to the topics presented in PHYS 4330, and Introduction to Electrodynamics, similar to the topics presented in PHYS 4210. Special relativity is included in the curriculum for PHYS 4330 and PHYS 4210.

- Part II - Quantum Mechanics and Thermodynamics / Introduction to Statistical Mechanics

  Introduction to Quantum Mechanics similar to topics presented in PHYS 4100. This part will also cover thermodynamics and introduction to statistical mechanics similar to the level of PHYS 4420.

The examination will be given twice a year, in August and in January. Candidates for the Ph.D. degree must normally pass this examination, or have it waived, within the 3rd semester of graduate study at Rensselaer. Students may take the examination in January (August) after the first Fall (Spring) semester. Those who do not pass may take the examination again in August (January) after the second semester. Each of the four parts may be passed separately. You get an extra try if you attempt to take the exam in August (January), just before the beginning of your first graduate Fall (Spring) semester at Rensselaer. We encourage all incoming students to avail themselves of this "extra shot." It would save you a lot of time if you pass it at the first attempt on your arrival at Rensselaer. If you do not pass it, your exam results will allow you and your academic advisor to realize any deficiency in your undergraduate physics background and your advisor can advise you of the proper courses to take.

In Part I of the examination, students will be presented with five mechanics problems and five problems testing electricity and magnetism. In Part II of the examination, students will be presented with six quantum mechanics problems and four statistical mechanics problems. A student is expected to make significant progress in a given problem to get a "pass" grade in that problem. Emphasis is placed on doing well on whatever is attempted, rather than accumulating points thinly over many problems.

This examination is the principal selection mode for entry into the doctoral program. Cases in which the exam, or parts of the exam, can be waived are outlined in the Graduate Handbook. The department expects that all students who pass this examination have the ability to continue successfully on to the Ph.D. degree. Of course students must also perform satisfactorily on other aspects of the program, which includes the appropriate course work (see graduate student handbook), the Candidacy Examination, and a research project leading to an acceptable thesis.

Copies of previous graduate level examinations are available from the Physics Department secretary to the Graduate Program Committee.

Recommended Reference Textbooks

Undergraduate texts relevant to the qualifying examination:

- Classical Dynamics of Particles and Systems, Fourth Edition, Jerry B. Marion and Stephen T. Thornton, HBJ Publishers.
- Introduction to Electrodynamics, Third Edition, David J. Grifftiths, Prentice Hall, 1999. or Classical Electromagnetic Radiation, Marion
- Introductory Quantum Mechanics, Liboff,
- Classical and Statistical Thermodynamics, Ashley H. Carter, Prentice Hall, 2001 or Introduction to Statistical Mechanics and Thermodynamics, Keith Stowe, Wiley & Sons, 1984.

Syllabi of intermediate mechanics

- Review of Newtonian mechanics (kinematics and dynamics) of a single particle, Newton's equations of motion in, two and three dimensions.
- Conservation of linear and angular momenta, conservative forces, for a single particle.
- Motion in a moving systemic coordinates, rotational dynamics, the Coriolis force, Euler angles and equation
- Motion of a system of particles and the corresponding conservation laws, the center of mass and related topics.
- The universal Law of Gravity. Motion in a central potential, motion in a $1/r^2$ force and Kepler's laws.
- Rotational kinematics and dynamics. The motion of rigid body and Euler's equations of motion. Introduction to tensor analysis and the rotational Inertia tensor.
- Calculus of variations as applied to mechanics.
- Lagrange's equations. Holonomic and non-Holonomic constraints. Independent generalized coordinates and generalized velocities.
  The derivation of Lagrange's equations from D'Alembert's principle.
  The derivation of Lagrange's equations from a variation principle.
  Cyclic coordinates, constant of motion
- Hamilton's equations of motion. Generalized coordinates and generalized momenta.
- Normal frequencies, coupled oscillators, normal modes, small oscillations.
- The special theory of relativity. The principle of relativity.
  The constancy of the speed of light. Lorentz transformation. Relativistic kinematics and dynamics. Collisions.

Syllabi of introduction to electrodynamics

- Review of elementary electrostatics. Coulomb's law, Gausses law, the electrostatic field and the energy of this field.
- Boundary value problems. Boundary value in two and three dimensions in rectangular coordinates, axially symmetric problems in spherical and cylindrical coordinates.
- Method of images.
- Multipole expansion for static fields.
- Fields in matter, polarization and the displacement vector.
- Magnetostatics. The Biot-Savart and Ampere laws. The static vector potential and its multipole expansion with the dipole term as the leading term. Currents and magnetic dipole moments.
- Faraday's law, Maxwell's displacement current and electrodynamics.
- Maxwell's equations in free space and in linear homogeneous dielectric materials.
- Vector and scalar potentials, the wave equation and gauge invariance.
- Energy, momentum and angular momentum of electromagnetic fields, Maxwell's stress tensor.
- Plane waves, dipole radiation, Poynting vector
- The special theory of relativity. Lorentz transformation.

Syllabi of introduction to quantum mechanics

* Fundamental concepts:
    - Observable, Uncertainty relations and their implications
    - Probabilistic interpretation, Correspondence principle, Complementarity
    - Operators
    - Matrix representation
    - Dirac notation
* Schroedinger equation:
    - Wave functions and their time evolution
    - Ehrnfest's theorem
    - Quantization of energy
    - One dimensional problems
        - Barrier reflection and tunneling
        - One dimensional box and three dimensional box
        - Quantum wells
        - Harmonic oscillator. Stepping operators
    - Three dimensional wave equation
    - Central force problems
        - Separation of variables
        - Spherically symmetric solutions, spherical harmonics
        - Quantization of angular momentum and vector model of angular momentum addition
        - Spherical square well
        - Spherical harmonic oscillator
        - Hydrogen Atom
        - Eigenfunction expansions
* Perturbation theory:
    - Time independent
    - Second order, degeneracies
    - Time dependent, Fermi's golden rule
* Scattering theory:
    - Phase shift
    - Partial wave analysis
    - Born approximation
* Electron spin:
    - Stern - Gerlach experiment
    - Spin - orbit coupling in atoms
* Identical particles and exchange symmetry:
    - Fermions, Bosons, Pauli exclusion principle
* Elementary applications:
    - Complex atoms, periodic table.
    - Homonuclear diatomic molecules.
    - Electronic, vibration, and rotation spectra.
    - Compton scattering, Photoelectric effect

Syllabi of thermodynamics and introduction to statistical mechanics

Thermodynamics
* Internal energy and equipartition
    Conservation of energy of a system of particles
    Work and heat
    1st law of thermodynamics
* Entropy
    Entropy and 2nd law of thermodynamics
    Entropy and heat
* Interactions
    Thermal --Temperature & the zeroth law, absolute zero and the 3rd law, phase transitions, Clausius-Clapeyron equations, Ehrenfest equations, heat capacity
    Mechanical -- Work, thermal expansion & compressibilities
    Diffusive -- Chemical potential, equilibrium conditions and the approach to equilibrium
* Constraints
    Ideal gas, real gas, liquids, solids
    Second law and third law constraints, Maxwell relations
* Processes (or called imposed constraints)
    Isobaric, isothermal, and adiabatic processes
    Processes in terms of entropy
    Reversibility
    Nonequilibrium processes
    Applications to engines & refrigerators
* The equation of state
    Ideal gases & real gases
    Heat capacities of an ideal monoatomic gas & an ideal polyatomic gas
* Thermodynamic functions (Helmholtz free energy, Gibbs free energy, etc), thermodynamic identities

Introduction to Statistical Mechanics
* Fundamental concepts
    Phase space
* Classical
    Ensembles, probability in a microstate, applications
    Principle of equipartition of energy, applications
    The Maxwell-Boltzmann distribution, applications to the ideal gas and transport processes in gases
* Applications to Magnetism
    Paramagnetism, ferromagnetism, and phase transitions
* Quantum
    Indistinguishability
    Fermi-Dirac distribution, applications to the electron gas
    Bose-Einstein distribution, applications to photon gas, Bose-Einstein condensation

Some Common Concerns Regarding the Qualifying Examination Raised by Students

The standard of the exam:
The qualifying exam committee follows strict instructions given to the qualifying exam committee by the entire Physics Faculty, which decides as a body the scope and syllabus of the exam. We follow advanced undergraduate level courses in intermediate mechanics, introduction to electrodynamics, introduction to quantum mechanics, thermodynamics and statistical mechanics.

What is the level of passing the written examination?
An individual problem is passed if a student scores six points or better, out of a possible ten points per problem. To pass mechanics, students must pass three of the five mechanics problems presented. To pass electricity and magnetism, students must pass three of the five electricity and magnetism problems presented. To pass quantum mechanics, students must pass four of six quantum mechanics problems. To pass statistical mechanics, students must pass two of four statistical mechanics problems. Solutions of the past examinations are available with the secretary to the Graduate Program Committee. These should give students examples of reasonable answers.

Grading:
Each member of the Qualifying Examination Committee writes, and grades an equitable number of problems. Grading is done anonymously, without the knowledge of the name of the particular student concerned.

What is the procedure by which students are evaluated?
The Qualifying Examination Committee grades the written examinations, and determines whether a student passes, based on the passing level described above. Students will receive a letter informing them of the results, in the department mailbox, by the middle of the second week of classes in the semester following the exam.

Appeal:
Appeals regarding grading of the examination are handled directly by the Qualifying Examination Committee. Please submit appeals to the Chair of the Qualifying Examination Committee, ***in writing, within a week of the publication of the results, after due consultation with the academic advisor***. In case of an appeal, the entire Qualifying Examination Committee examines the contested question(s) to avoid any bias. Further appeals can be made to the Graduate Program Committee and eventually the Physics Department Chair, in exceptional circumstances.

Deferment Procedure:
As a rule, we do not give deferment of the Qualifying Exam. In exceptional circumstances involving medical contingencies, the student in question, who cannot make the final regular attempt, may appeal to the Graduate Program Committee for a deferment. If a student enters the program with a deficient background, a deferred examination schedule can be formalized by applying immediately to the Graduate Program Committee. Part-time students may also apply for a deferred examination schedule.

Candidacy Examination

The Candidacy Examination is your last formal hurdle on the way to complete the Ph.D. thesis. It establishes the research credential of the student on a firm basis. The Candidacy Committee is assembled by the student, in consultation with the Thesis Advisor and the chair of the Graduate Program Committee. The Candidacy Committee, headed by the student's Thesis Advisor, makes sure that the research project makes good sense, and the student understands the related graduate materials very well. The candidacy exam is always given as an oral exam.

Once a Ph.D. thesis project has been chosen and a Candidacy Committee assembled, the student presents a brief written thesis proposal to that committee, along with an oral defense of the proposal. In the oral exam, members of the committee will question the student on the specific research planned, and, more generally on the physics relevant to that research. This examination is normally taken by the end of the third year. Generally, most or all of the members of the Candidacy Committee become members of the Ph.D. thesis committee.

The thesis proposal is just that, a proposal, and need not present completed or even preliminary results. Its type-written length should be limited to approximately eight pages. Longer proposals need to be approved by the student's committee. This thesis proposal should be submitted to the members of the candidacy exam committee two weeks prior to the exam.

The student is examined by a committee consisting of four faculty members, one of whom is from outside the Department of Physics. The Candidacy committee members need to be first approved by qualifying exam committee and then approved by the Dean of the Graduate School. The members of the Candidacy exam committee will continue to serve on the student's Ph.D. thesis committee, though any unavailable member can be replaced with the permission of the Dean of the Graduate School.

During the exam the committee will evaluate the student on the following:

1. Ability to discuss the physics of the proposed research.
2. Suitability of the proposed research for a Ph.D. thesis.
3. Mastery of the relevant graduate course material.

At the end of the examination the committee deliberates and the advisor informs the student of the result. In the event that the student does not pass the examination, a single re-examination may be allowed. Once the student has passed the examination, the committee will continue to monitor the student's progress to a Ph.D.

Students may request advance approval from the Graduate Program Committee for any needed adjustment of timetable exceeding the end of the third year of graduate residence. Failure to obtain such approval may cause delays in acceptance of the doctoral thesis.