Update 8/11/05

Qualifying Exam Information

The qualifying exam serves to ascertain that a Ph.D. candidate demonstrates competency across a broad spectrum of core subjects. Furthermore, the preparation process for taking the exam is a learning and integration opportunity that allows the student to develop a more global understanding of physics, in an independent setting (meaning outside the normal course setting that students have experienced up to this point).

Satisfactory Progress

Students are expected to take the qualifying exam just before the start of their second year of graduate study. If a student does not wish to take the exam at that time, he or she must petition the Graduate Program Coordinator for a postponement. Possible reasons include not having taken all of the standard first-year graduate courses or poor performance in these courses.

Students can take the exam earlier, either before the Autumn Quarter or before the Spring Quarter of their first year. A student's decision to take the exam early should, however, be made only after consultation with their faculty advisor, and typically works best for students having advanced preparation, such as those who have obtained a Master's degree before entering the program.

Students who do not pass the exam on their first attempt are automatically allowed to retake the exam. They are expected to make their second attempt the next time the exam is offered. Each attempt at any part of the exam constitutes an attempt at the entire exam; the exam cannot be attempted piecemeal.

A student who has not passed after two attempts can appeal to the Qualifying Exam Review Committee[1] who may grant a third attempt. Factors included in their decision are research promise, achievements in graduate course work, and performance on earlier exams.

Students who do not pass the exam after their final attempt will be given one quarter to complete the requirements for a Masters degree. In exceptional circumstances, students may be granted a second quarter.

Students who have not passed the exam by the beginning of Spring Quarter of their third year will be placed on probation in the absence of extenuating circumstances. They will only be allowed to register for Autumn Quarter of the following academic year if they successfully petition to take the exam at the beginning of that quarter. If they pass at that

[1] The qualifying exam review committee is composed of the graduate program coordinator, department chair, department associate chairs, graduate committee chair, and qualifying exam committee chair. Occasionally, one of the department associate chairs and the graduate committee chair may be the same person.

time, they will be taken off probation. If they do not pass, they may complete the requirements for a Masters degree during the Autumn Quarter, but will not be allowed to register for the Winter Quarter.

Schedule and Format

The qualifying exam is given twice a year, two weeks before Autumn Quarter begins and during the break between Winter and Spring Quarters. The exam is administered on a Wednesday and Thursday from 9:00 a.m. to 5:00 p.m.

The qualifying exam is composed of five sections: classical mechanics, electricity and magnetism, quantum mechanics, basic physics, and statistical and thermal physics. Students taking the exam for the first or second time have two hours to complete each section while students taking the exam for the third time have three hours to complete each section. Students work on only one section at a time. One-hour breaks are given between sections. Light refreshments are provided, but students are expected to bring a lunch.

Students taking the next exam should refer to the Current Exam Schedule.

Registration

Students should email Graduate Program Assistant at grad@phys.washington.edu indicating that they would like to register for the qualifying exam.

Letters of Recommendation

Students taking the exam for the second or third time are required to obtain letters of recommendation from the faculty. They should send the Graduate Program Assistant the names and email addresses of two or more faculty members who have agreed to write letters. The Graduate Program Assistant will contact them. Students should choose faculty with whom they have worked or who otherwise know them well. Students taking the exam for the first time do not need to obtain letters.

Preparation

To prepare for the qualifying exam, students should attempt previous exams, study their notes from the first-year courses, attend the qualifying exam information session and student panel, form study groups, talk with students who have passed the exam, and study the section topics listed below. Students taking the exam for the first time are expected to study for and take all sections of the exam.

Previous Exams

The Graduate Program Assistant keeps several binders of qualifying exams from the past 10 years. Students may check out these binders or make copies of the exams. Copies of old exams are also on reserve in the Physics Library. Students might consider asking students who have passed the exam for their notes. Lastly, exams are available on the Web at:
http://www.phys.washington.edu/grad/phdupdates/quals2/
http://www.phys.washington.edu/grad/phdupdates/quals/

Qualifying Exam Information Sessions

In early February and late May, the chair of the Qualifying Exam Committee[2] holds an information session for students taking the next qualifying exam. During these meetings, the chair and other committee members answer students' questions and describe the writing, administration, and grading of the exam. Student representatives on the Exam Committee are also present.

Qualifying Exam Student Panel

In early July, the graduate student representatives to the Qualifying Exam and Graduate Committees organize a panel moderated by the Graduate Program Assistant. On the panel, students who have recently passed the qualifying exam talk about how they prepared for the exam and managed their stress. They also offer tips for success and help students organize study groups.

Exam Content

Topics that may appear on each section of the qualifying exam are listed below. These lists include topics that may not be covered in the first year graduate curriculum in any given year; however, they are still considered part of the broad spectrum of core subjects tested by the qualifying exam.

Basic Physics

This section covers topics typically included in lower division physics courses. The level of the Basic Physics section is comparable to that of the most challenging problems in *Physics* by Halliday, Resnick, and Krane. This section also covers the topics typically included in sophomore level Modern Physics courses at the level of *Modern Physics* by Tipler and Llewellyn and *Modern Physics* by Eisberg.

Mechanics

- Kinematics of point particles (non-relativistic)
- Newton's laws
- Kinematics of rigid bodies in pure rotation and combined rotation and translation
- Conservation of linear momentum, angular momentum, and energy

Electricity and Magnetism

- Electrostatics: Coulomb's law, electric fields and potential, Gauss' law
- Resistance, capacitance, inductance, DC circuits, RC circuits, LRC circuits
- Biot-Savart law, Ampere's law, Faraday's law, Lenz's law

Optics, waves, and oscillations

- Geometrical optics: thin lenses, plane mirrors, curved mirrors, refraction
- Physical optics: diffraction, interference, gratings, thin film interference, polarization
- Simple harmonic motion
- Mechanical waves
- Sound, Doppler effect (non-relativistic)

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[2] The names of members of the qualifying exam committee can be found under Faculty Committees at http://www.phys.washington.edu/Home.html.

Thermal physics

- First law of thermodynamics

Basic Physics, continued

- Entropy and the second law of thermodynamics
- Ideal gas law
- Simple kinetic theory of ideal gases
- Heat capacity

Fluid dynamics

- Hydrostatic pressure
- Buoyancy
- Bernoulli’s equation

Relativity

- Experimental basis
- Lorentz transformations
- Time dilation and length contraction
- Doppler effect
- Relativistic momentum and energy
- Invariant mass

Basic evidence for quantization

- Blackbody radiation
- Photoelectric effect
- Heat capacities of solids, the Einstein model
- Atomic spectra and Bohr model of the atom
- Frank-Hertz experiment

Wave properties of matter

- De Broglie's hypothesis
- Wave packets
- Uncertainty principle
- Wave-particle duality

The Schroedinger Equation

- Schroedinger equation in one dimension
- Infinite/finite square well
- Reflection and transmission in step potentials
- Harmonic oscillator

Atomic Physics

- Schroedinger equation in three dimensions
- Quantization of angular momentum and energy
- Hydrogen atom wave functions
- Electron spin
- Stern-Gerlach experiment
- Total angular momentum and spin-orbit interaction
- Ground state of atoms, the periodic table

Quantum Statistics

- Bose-Einstein and Fermi-Dirac distributions
- Bose-Einstein condensation
- Photon gas

Basic Physics, continued

Molecular structure

- Ionic bonds
- Covalent bonds

Lasers and Masers

- Stimulated and spontaneous emission
- Absorption
- Scattering

Nuclear Physics

- Composition
- Size
- Alpha, beta, and gamma decay
- The shell model
- Basics of nuclear reactions
- Fission, fusion

Particle Physics

- Particles and antiparticles
- Fundamental interactions
- Classification of particles
- Conservation laws and symmetries
- The Standard model

Classical Mechanics

This section covers material typically included in the first year graduate course in Classical Mechanics. The Classical Mechanics section is at the level of *Theoretical Mechanics of Particles and Continua* by Fetter and Walecka.

Newtonian Mechanics

- Conservation laws
- Central forces
- Orbits and scattering
- Rotating coordinate systems
- Projectile motion
- Foucault pendulum

Lagrangian dynamics

- Generalized coordinates
- Constrained motion
- Lagrange's equations
- Variational principle
- Lagrange multipliers and forces of constraint

Small oscillations

- Normal modes and QM analogs
- N-body problems in 1- and 2-d (string+masses) with fixed and continuum boundary conditions
- Continuous limits and effective theories

Classical Mechanics, continued

Continuum Mechanics

Elasticity, youngs modulus,…

Coupled Oscillators

Adiabatic and non-adiabatic crossings

Analogs with neutrino mass/flavor eigenstates and matter enhanced neutrino oscillations

Anharmonic motion

x^3 and x^4 potentials, and dependence of frequencies on amplitudes

Resonances and hysteresis

Simple numerical methods

Hamilton's equations

Conservation of H

Hamilton-Jacobi theory

Rotational motion

Moment of inertia tensor

Projectile motion for symmetric objects

"sweet spots"

Statistical Mechanics

This section covers the material typically included in the first year graduate level course in Statistical Mechanics (524).

Basic Thermodynamics

First and second laws of thermodynamics

Elementary kinetic gas theory calculations

Examples of reversible and irreversible quasistatic processes

Engines, heat pumps and refrigerators

Entropy from the thermodynamic perspective

Maximum entropy principle

Foundations of Statistical Mechanics

Kinetic theory of gases

Microcanonical ensemble

Boltzmann factors

Statistical interpretation of entropy

Gibbs paradox

Equipartition theorem from the micro-canonical perspective

Applications -- monoatomic and diatomic gases, law of Dulong-Petit, etc.

Thermodynamic Potentials

Thermodynamic potentials

Generalized extensive versus intensive variables

Plucker line geometry geometric interpretation of Legendre transformations

Free energies, Gibbs-Duhem relation, Maxwell relations

Clausius-Clapeyron relation

Applications – throttling processes, etc.

Classical Statistical Ensembles

Microcanonical ensemble and ergodicity

Statistical Mechanics, continued

- Changing ensembles: the canonical and grand-canonical ensemble
- Central limit theorem, fluctuations, finite size effects
- Entropy and information theory
- Ensembles from the principle of maximum entropy and Lagrange multipliers
- Equipartition theorem, from canonical ensemble perspective
- Applications – paramagentism and other problems with classical magnetic moments, classical ideal gases, absorption isotherms, interstitials in solids, etc.

Quantum Statistical Mechanics

- Phase space, micro states, and the density matrix
- Harmonic oscilators and the specific heat of solids
- Rotational degrees of freedom in diatomic gases, especially H_2 and HD
- Bose-Einstein and Fermi-Dirac distributions
- Electrons in metals as example of a Fermi-gas
- Stephan's law and Planck's law for blackbody radiation
- Bose-Einstein condensation

Phase Transitions

Quantum Mechanics

This section covers the material typically included in the first-year graduate course in Quantum Mechanics (517, 518, 519). The Quantum Mechanics section is at the level of *Modern Quantum Mechanics* by Sakurai.

Elementary Phenomenology

- Two-slit experiment
- Stern-Gerlach experiment
- Neutron interferometry

The Formalism associated with Quantum Mechanics

- Linear vector spaces
- Bras, kets
- Operators, projectors, matrix representations
- Measurement
- Compatible and incompatible observables
- Uncertainty principle
- Change of basis
- Continuous spectra
- Position eigenkets
- Translation Operator
- Momentum
- Position-Momentum Uncertainty
- Wavefunctions
- Gaussian Wavepackets
- Commutation Relations
- Mixed States and Density Matrices

Time evolution

- Spin-1/2 system in a B-field
- Schrodinger verses Heisenberg “Pictures”

Quantum Mechanics, continued

Time dependence of operators and matrix elements, Ehrenfest's theorem
Time-ordered products
Green's Functions
Propagators
Path integrals, $V(\mathbf{x}) = \mathbf{F} \bullet \mathbf{x}$, $V(x) = 1/2\, kx^2$

One-Dimensional Wave Mechanics

Step potentials
Infinite square well potentials
Finite square wells
Delta function potentials
1-dim harmonic oscillator, annihilation and creation operators
Analytic structure of scattering amplitude
Time delays and phase shifts
WKB
Coherent states

Potentials in Quantum Mechanics

U(1) symmetry and electrodynamics, minimal substitution
Ahronov-Bohm Effect

Angular Momentum

Rotations in 2-d, SO(2) and its generator
Rotations in 3-d, SO(3) and its generators
Transformation of Generators
Rotations about arbitrary axes
Euler Angles
SO(3) in Quantum Mechanics
"D" matrices, "d" matrices, j=1/2, 1
Orbital Angular Momentum, Spherical Harmonics, $|r, \theta, \phi\rangle$ basis
Addition of angular momentum
Projection Theorem
Clebsch-Gordan Coefficients
Tensor operators
Wigner-Eckart Theorem

Three-Dimensional Schrodinger equation

Diatomic Molecules
3-d harmonic oscillator
2-d harmonic oscillator, SU(2) and SO(2) symmetry
Spinless hydrogen atom, energy levels, degeneracy, etc.
Runge-Lenz Vector
Creation, Annihilation Operators for H-atom

Time-Dependent and Time-Independent Perturbation Theory

Time-Independent, Non-Degenerate and Degenerate Perturbation Theory
Linear and Quadratic Stark Effects
Fine structure of H-atom, spin-orbit and relativistic effects, hyperfine structure
Variational procedures, Feynman-Hellman theorem
Time-dependent perturbation theory

Quantum Mechanics, continued

Electron Spin Resonance
Fermi's Golden Rule
Harmonic Perturbations
Cross section for the absorption of EM quanta, Dipole approximation, E1 sum-rule, Photo-Electric Cross section

Identical Particles

Fermions and bosons
Slater determinant
Ground state energy of helium
Excited states of helium
Screening, variational approach
Thomas-Fermi model
Fermi levels

Scattering

Lippmann-Schwinger Equation
First Born approximation and higher order terms
The T-operator
Optical theorem
Partial waves
Hard sphere scattering, finite square well scattering
Ramsauer-Townsend effect
Effective range theory, low-lying bound states
Resonances
Dispersion Relations
Coulomb Scattering
Scattering of Identical Particles
Inelastic Scattering, electron-atom scattering
Neutron-proton scattering, neutron- H2 scattering

Time-Reversal

Time-reversal invariance
Anti-unitary operators
Time-reversal for integer and half-integer systems
Electric dipole moments

Electricity and Magnetism

This section covers material typically included in the first-year graduate course in Electricity and Magnetism (513, 514, 515), <u>including at least 50% Electrodynamics.</u>

Electrostatics

Method of images
Green's functions in Cartesian, cylindrical, spherical coordinates
Multipole expansion of potential bounded distribution
Multipole expansion of interaction energy
Electric stress tensor

Magnetostatics

Magnetic scalar potential for current-free region of space

Electricity and Magnetism, continued

Vector potential
Multipole expansion of bounded current distribution
Magnetic dipoles
Magnetic interaction energy
Magnetic stress tensor

Time-dependent fields

Quasi-static fields: near-zone vs. radiation zone
Induced fields for slowly varying sources
Maxwell's equations in covariant or non-covariant form
Lorentz force in covariant or non-covariant form
Gauge transformations
Electromagnetic stress-energy tensor
Plane waves in free space, polarization
Waveguides and cavities

Materials

Linear dielectric and diamagnetic response
Macroscopic Maxwell's equations
Waves in dispersive and dissipative media
Phase vs. group vs. signal velocities
Causality and Kramers-Kronig relations
Reflection and refraction at boundaries
Imperfect conductors: skin depth, finite Q cavities
Very basic MHD (plasma waves, magnetic diffusion)

Radiation

Radiation zone (retarded) fields
Radiation of accelerating point charge (Relativistic or non-relativistic)
Total power radiated
Angular distribution of radiated power from compact source
Frequency distribution of radiation
Special cases such as oscillating dipoles
Cyclotron motion and synchrotron radiation
Thomson scattering
Cerenkov radiation
Radiation reaction

Exam Day

On the day of the qualifying exam, students should arrive 10 minutes before the exam begins. The proctor will open the door and let students find a seat and get settled. Students should leave one seat between them and other test takers. Then the proctor will distribute an envelope to each student which contains detailed instructions and paper tablets coded to protect anonymity in grading.

Students should sign the first sheet of the coded tablet each day so that the Graduate Program Assistant can make sure that they are using the code that has been assigned to them. Students should not write anything else on the first sheet. This code verification sheet should be the top sheet in the envelope returned at the end of the day.

Students should label and number the pages of each section in the upper right hand corner and staple them together before handing them in to the proctor. For example, if students have six pages of answers for the Basic Physics section, they should label the first page BP 1/6. The last page would be labeled BP 6/6. Answers to all sections should be labeled and numbered in this way. These procedures help the Graduate Program Assistant sort exams and avoid mistakes.

Exam Grading

The Qualifying Exam Committee grades exams. At no time does the committee ever see names associated with exams or scores. All grading and discussion of grades is done using only the coded numbers. Exams are first scored numerically and then given a grade of A, B, or C. Additionally, +/- can be added to the letter grades. The committee reviews the distribution of grades on each problem, and in particular will carefully review a problem with a significant number of C grades. Such a review sometimes results in additional committee members independently determining grades, and then checking for consistency.

Students are strongly urged to consider carefully and remark on the physical meaning of their calculations and results. Simple mathematical errors will not lead to a significant reduction in the points awarded unless such errors produce a result which is both obviously unphysical and not noted as such by the student. The Exam Committee makes every effort to award partial credit consistently.

The sole criterion in awarding the letter grade for a section of the exam is the degree of demonstrated understanding of the relevant physics. In rare instances, this could lead to a paper with a lower numerical score being assigned a higher letter grade than a paper with a slightly higher numerical score. The letter grade alone determines whether a student is recommended to pass a particular section of the exam.

Qualification

The Qualifying Exam Review Committee[3] is a separate and independent committee from the Qualifying Exam Committee. This committee reviews the exam results submitted to them by the Qualifying Exam Committee, and makes final decisions on which students shall be deemed to have passed the qualifying exam. The committee discusses students individually and sees the names associated with the exam grades and scores.

A student who has received a passing grade of an A or B in each section of the qualifying exam is deemed to have passed the exam and is automatically qualified for the Ph.D.

[3] The qualifying exam review committee is composed of the graduate program coordinator, department chair, department associate chairs, graduate committee chair, and qualifying exam committee chair. Occasionally, one of the department associate chairs and the graduate committee chair may be the same person.

program. Further, once a student has received a passing grade on a particular section of the exam, the student will not be ever be required to retake that section.

A student taking the exam for the first time who has received passing grades for all except one section of the exam, and a borderline grade of C+ for that section, will usually be deemed to have passed the exam and qualified for the Ph.D. program. While making this decision, the committee will review the student's exam papers and will take into account the student's overall level of performance on the exam and in the Ph.D. program.

The committee carefully reviews the exams of all other students and also takes into account their entire record. Factors considered include: performance on previous attempts at the qualifying exam, course grades, and letters from faculty attesting to their research promise and accomplishments. For this reason, second and third time test takers are required to provide letters. In second or third tries, there is no presumption that one borderline grade is acceptable. Only under very exceptional circumstances will students be deemed qualified who received C grades in more than one section of the exam. Students who do not qualify on the second try may petition the Qualifying Exam Review Committee to take the exam a third time. (See "Satisfactory Progress" and "Appeals")

Graded Exam Papers

The University of Washington and the Physics Department retain possession of all exam papers. Students cannot make photocopies or duplicate in any other way their graded exams. Students may look at their graded exams as permitted by the Graduate Program Assistant. Students are free to make notes, but graded exams must remain in the room in which they are stored.

The qualifying exam is written jointly by all members of the Qualifying Exam Committee. As such there is not one committee member who is solely responsible for any one question.

Appeals

Students may appeal the decision of the Qualifying Exam Review Committee within seven days of being notified of the outcome by submitting an appeal letter to the Graduate Program Assistant. The appeal may concern the grading of one or more questions, the overall pass/fail decision, or a request for a third attempt. The Qualifying Exam Review Committee will consider the appeal and students will be formally notified of its decision within seven days. No further appeals will be considered.

Master's Degree

After students pass the qualifying exam, they are eligible to receive their Master's degree provided that course credit and grade point average requirements have been satisfied. Students should apply for their non-thesis Master's degree on the Graduate School's Master's Degree Application web page. The request period begins on Monday of the third week of each quarter and closes on Friday at midnight in the second week of the subsequent quarter.

Contact Information

Students are encouraged to contact one of the following persons if they have questions or need support and guidance.

Alejandro Garcia, Exam Committee Chair – 616-2875, agarcia3@u., C529
Steve Sharpe, Graduate Program Coordinator – 685-2395, sharpe@phys., B406
Jennifer Lehner, Graduate Program Assistant – 543-2488, grad@phys., C139B