Incoming graduate students will take Placement / Challenge Exams, generally scheduled for the week before the start of the fall and spring terms. The Exams come in two parts.

Exam Part A - the placement exam - for Quantum Mechanics, Electricity & Magnetism, and Classical Mechanics in the fall term and statistical mechanics / thermodynamics in the spring term. These exams cover material at the undergraduate level. The purpose is to determine your understanding of the essential physics required to begin the graduate courses and to identify weaknesses in your preparation. Depending on your performance, you may be advised to take the appropriate undergraduate course or courses.

Exam Part B - the challenge exam - for Quantum Mechanics I, Electricity & Magnetism I, and Classical Mechanics will cover material at the graduate level, corresponding to Rutgers Physics & Astronomy graduate classes 501, 503, and 507. If you have taken graduate level course(s) and wish to place out of one or more of the core graduate courses, you need to pass Part B of the appropriate exam. You must have permission in advance to take the Part B exams. Please email a request to Prof. Gilman *and* Shirley Hinds (rgilman@physics.rutgers.edu and shinds@physics.rutgers.edu). Your request should indicate the equivalent class you already took and university, and provide a class description, the name of your textbook, and your grade.

Astronomy-option students take the same courses in the fall, and also need to take the fall placement exams.

Placement exam Part A for Thermodynamics and Part B challenge exams for Quantum Mechanics II (502), Electricity & Magnetism II (504) and Statistical Mechanics (611) are offered in January.

The exams will be closed book, but you may bring one 8.5 x 11 inch sheet of paper with whatever you want written on it for each topic. You may use both sides. You will be given a formula sheet with integrals, physical constants, Clebsch-Gordon coefficients, spherical harmonics, etc. that may be needed on the exam.

The following pages outline the material to be covered by the exams.

For undergraduate courses, the material has been divided into very basic, intermediate, and advanced. Basic topics are those that are generally covered in an introductory sequence (or sophomore/junior level “modern physics” type course for QM), and we would expect you to know well. Intermediate topics are those covered in typical sophomore/junior level courses and we would expect you to know well and be able to work reasonable problems on those topics. Advanced topics are those that you should have familiarity with, and we would expect you to be able to answer some questions. For graduate courses we would expect you to have good familiarity with the advanced undergraduate topics as well as the additional topics listed.

Undergraduate Classical Mechanics – Suggested text: Classical Mechanics, Taylor

I. Basic

Vector algebra: addition, dot and cross products, scalar multiplication, components
Kinematics: displacement, velocity, acceleration, units, Newton's laws.
Rolling, angular velocity and acceleration.
Static equilibrium, forces and torques.
Force and torque balance in compound problems, and with constant
(linear and circular) acceleration. Free body diagrams.
Momentum, impulse. Collisions, elastic and inelastic.
Work and Energy, integral along path, conservative forces. Potential energy, power.
Determine motion: ballistic, constant forces with friction,
Apply conservation laws: momentum, angular momentum, energy
Newton's law of gravity, Kepler's laws
Rotational motion about a fixed axis. Center of mass, Torque, moment
of inertia. Rolling motion. Angular momentum of particles and rigid bodies.
Simple harmonic motion, including damping and driven oscillations
The pendulum (small oscillations)
Wave motion on string, boundary conditions, wave number, phase. Wave
fronts, power and intensity. Standing waves, reflection and transmission
Fluids: pressure, density, buoyancy, equation of continuity,
Bernoulli's eq. Young's modulus and Bulk modulus
Springs, Hooke's law.
Doppler effect

II. Intermediate

Vectors and their derivatives in polar and spherical coords.
Projectile motion with air resistance.
Charged particle motion in constant B field.
Rocket equation of motion. Systems of particles.
Potential and its gradient.
Momentum and Angular momentum and angular velocity as vectors, Moment of inertia tensor
and center of mass from integrals.
Solution of general 1-D potential problems. Two-body central force
problem. Kepler's laws, including ellipse.
Oscillations, including damped driven harmonic oscillator, Q, Fourier
series, Parseval's theorem.
Non-inertial reference frames --- linearly accelerating; rotating.
Centrifugal and Coriolis forces. Foucault pendulum. Accel in rotating
frame.
Calculus of variations, shortest path, Fermat's principle, Euler-Lagrange equations, Hamilton's
princ. generalized forces and momentum,
Constrained systems, Lagrange multipliers.
Rigid body motion: inertia tensor and principle axes, Euler's
equations, torque-free motion near principle axes, or for axially symmetric body. Euler angles,
spinning top.
Kinematics of elastic and inelastic collisions

Small oscillations about static equilibrium, general case
Relativity: Galelean. Special Rel postulates. events. simultaneity,
time dilation, length contraction, 1-D velocity addition. momentum,
relativistic energy, mass-energy conversion

III. Advanced

Hamiltonian Mechanics. state space, generalized momentum, phase space
hamilton's equations, ignorable coords, phase space orbits, Liouville's
theorem
Collision theory: scattering angle, impact parameter, cross section
$D\sigma/d\Omega$, Rutherford scat. CM vs lab.
Special relativity: twin paradox, Lorentz transformations, space-time, 4-vectors, scalar product,
light cone, light- and time-like vectors,
Doppler shift, mass, 4-velocity, momentum and energy. Threshold
energies. tensors and $F^{\mu\nu}$ transform of E, B.

Undergraduate E&M – Suggested text: Introduction to Electrodynamics, Griffiths

I. Basic

Coulomb's law
Continuous charge distributions
Electric fields and electrostatic potentials
Gauss's law
Work and energy
Capacitors
Electric dipoles
Magnetostatics and Lorentz force
Biot-Savart law
Ampere's law
Ohm's law
Electromagnetic induction
Electromotive force, motional emf
Faraday's law
Induced charges, surface charges on conductors
Fields inside cavities in conductors
EM waves in vacuum
Basic electrical circuits

II. Intermediate

Laplace's equation
Method of images
Separation of variables
Multipole expansion
Electric fields in matter
P, D, and linear dielectrics
Continuity equation

Curl and divergence of B
Mutual inductance, self-inductance
The vector potential
Magnetic dipoles
Magnetic fields in matter
Maxwell's equations, displacement current
Maxwell's equations in matter
EM waves in matter
EM waves in conductors
Absorption, reflection, and dispersion of EM waves
Wave guides
Dipole radiation

III. Advanced

Energy, momentum, and angular momentum of EM field
Poynting's theorem
Maxwell stress tensor
Conservation laws
Potentials and gauge transformations
Electric and magnetic dipole radiation
Retarded potentials
Radiation from accelerating charges
Relativistic electrodynamics
Tensor formulation of electrodynamics

Undergraduate QM – Suggested text: Introduction to Quantum Mechanics, Griffiths

I. Basic

Interpretation of wave functions (normalization, expectation
values, probabilities, stationary vs. non-stationary states)
Position and momentum operators
Uncertainty principles: position and momentum; time and energy
Eigenvalues and eigenfunctions of an operator given as a matrix
Solving the time-independent Schroedinger equations in 1D
-- Free particles; de Broglie wavelength
-- Infinite square potential well
-- Transmission and reflection from a step potential
Gaussian wavepackets

II. Intermediate

Solving 1D Schroedinger equation for
-- Delta function potential and barrier
-- Finite square well
-- Harmonic oscillator using wavefunction approach
Harmonic oscillator using raising and lowering operators
Separation of variables for 3D Schrodinger equation for radial potentials

-- Spherical harmonics
-- Particle in a spherical box
-- Hydrogen atom
Angular momentum
Spin, spin-1/2, Pauli matrices, magnetic moment, Stern-Gerlach
Indistinguishable particles (bosons and fermions)
Bose-Einstein, Fermi-Dirac and Maxwell-Boltzmann statistics
Time-independent perturbation theory (elementary)
Stark effect
Variational principle
WKB approximation for tunneling
Free-electron gas model for solids

III. Advanced

Generalized uncertainty principle
Angular momentum addition and Clebsh-Gordon coefficients
Selection rules
Electron configurations of atoms based on Hund's rules
WKB approximation for a bound state
Time-independent perturbation theory (2nd order, degenerate)
Time-dependent perturbation theory
Charged particle in an electromagnetic field
Scattering theory and Born approximation
Optical theorem

Undergraduate Thermodynamics (spring term, given in January) – Suggested Text: Intro to Thermal Physics, Schroeder

I. Basic

Laws of thermodynamics –definitions
Temperature scales
Heat transfer by conduction
Properties of ideal gas
Relation between temperature and kinetic energy
Maxwell distribution
Work and PV diagrams
Carnot cycle

II Intermediate

Thermodynamic variables
Macro and micro states
Heat Engines and refrigerators
Thermodynamic potentials
Kinetic theory
Phase transititions
Transport phenomena

Van der Waals gas

III Advanced

Boltzmann distribution
Phase transformations in binary mixtures
Statistics of ideal quantum systems
Black body radiation
Bose-Einstein condensation

Graduate Classical Mechanics (507, fall term) - Suggested text: Classical Mechanics, Goldstein

Lagrangian mechanics, invariance under point transformations,
generalized coordinates and momenta, curved configuration space,
Phase space, dynamical systems, orbits in phase space, phase space flows, fixed points, stable and unstable,
Canonical transformations, poisson brackets, differential forms,
Liouville's theorem, the natural symplectic 2-form and generating
functions, Hamilton-Jacobi theory.
Integrable systems, adiabatic invariants,

Continuum mechanics: taut string and lattice of point masses. 1-D wave equation. boundary conditions, 3-D wave equation, ∇^2, plane waves, spherical waves, volume and surface forces, stress and strain, elastic moduli (bulk, shear, Young) stress tensor. Strain tensor. longitudinal and transverse waves in solid. Fluids. "material derivative", inviscid fluid, Bernoulli, eq of continuity. Waves.

field theory: Lagrangian density, Hamilton's principle for fields, cyclic coordinates, Noether's theorem. Lagrangian formulation of electromagnetism.

Graduate E&M I (503, fall term) - Suggested Text: Electrodynamics, Jackson

Gauss Law – differential and integral form
Poisson and Lapace Equations
Green's Theorem
Dirichlet and Neumann boundary conditions
Boundary value problems with cylindrical and spherical symmetry
Laplace equation in cylindrical and spherical coordinates
Magnetostatics
Vector and scalar potentials
Maxwell's equations
Plane electromagnetic waves
Linear and circular polarization

Graduate E&M II (504, spring term, given in January)

Dipole radiation
Special Relativity
Relativistic charged particles in and external magnetic field
Electromagnetic waves in conducting and dissipative media
Wave guides and resonant cavities
Motion in static fields, adiabatic flux invariance
Lagrangian for the electromagnetic field
Cherenkov radiation
Radiation of accelerating point charges, Lienard-Wiechert potentials
Thomson scattering
Radiation emitted during collisions, bremsstrahlung

Graduate QM I (501, fall term) - Suggested texts: Principles of Quantum Mechanics, Shankar, and Modern Quantum Mechanics, Sakurai

Vector spaces
Eigenvalues and eigenvectors
Position and momentum operators
Schroedinger equation
One dimensional potentials
Harmonic oscillator
Symmetries in quantum mechanics
Identical particles
Translations and rotations in two dimensions
Hydrogen atom, energy levels, degeneracy
Spin, Pauli matrices

Graduate QM II (502, spring term, given in January)

Variational methods
WKB approximation
Tunneling
Time independent perturbation theory
Degenerate perturbation theory
Scattering theory
Born approximation
Partial wave expansion
Time dependent perturbation theory
Electromagnetic interactions
Dirac equation

Graduate Statistical Mechanics (611, spring term, given in January) - Suggested text: Statistical Physics of Particles, Kardar

The problem of kinetic theory binary collisions, boltzmann transport, gibbsian ensemble
Postulate of class. stat mech, microcanonical ensemble, derivation of thermodynamics, equipartition theorem, classical ideal gas, Gibbs paradox
Canonical Ensemble and Grand Canonical Ensemble -Canonical ensemble, energy fluctuations in the ensemble, Grand Canonical ensemble, density fluctuation in the GCE, chemical potential
Postulates of Quantum Stat Mech, density matrix, ensembles in QSM, 3rd law, ideal gas - microcanonical ensemble, grand canon. ens., of statis. mech.
Fermi systems equat. of state of an ideal fermi gas, theory of white dwarf stars, Landau diamagnetism, De Haas-Van Alpen effect, quantized hall effect, Pauli paramagnetism, magnetic properties of an imperfect gas
Bose systems –photons, black body radiation, phonons in solids, bose-einstein condensate, imperfect bose gas, superfluid order parameter.
Fluctuation-Dissipation theorem, phase transitions of first and second order