Placement Exam

Dates: Friday, Aug 28, 9:00-13:00 E&M I,II, Class Mech
Monday, Aug 31, 9:00-13:00 QM,I,II, Thermo/Stat Mech

Each day you will be given exams for the subjects listed. Part A for E&M, Classical Mech, Quantum Mech, and Thermo/Stat Mech will 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 repeat the appropriate undergraduate course or courses. Part B tests material at the graduate level. If you wish to place out of one of the core graduate courses you need to pass Part B of the appropriate exam. Astro students do need to complete Part A of Thermo/Stat Mech, but do not need to do Part B of either Thermo/Stat Mech or QM II, which are not taken in the astro sequence. The placement exam for astro courses will be offered at a later date.

You will be given both parts of the exams for the subjects covered each day. You may divide your time as needed, e.g. you might choose to spend 1 hour on Part A of E&M, and use the rest of the time to do Part B of Classical Mechanics. The exams will be closed book.

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

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 Mechanics

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 Coriolus 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

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

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

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

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

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

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

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

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

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

Astronomy

I. Basic
Parallactic distance
Apparent & absolute magnitude
Star colors and spectral types
Hertzsprung-Russell diagram - main seq.
Stefan-Boltzmann Law, WDs & red giants
Stellar masses from binaries and rough mass-luminosity relation
Hydrostatic balance in stars
Nuclear energy generation
Post-main sequence evolution (broad outline)
Basic differences between spiral & elliptical galaxies
Hubble expansion

II. Intermediate

Basic solar/stellar structure (radiative, convective zones)
Isochrones and age dating of star clusters
Stellar populations
Luminosity functions and mass-to-light ratios
Determining gas motions in disk galaxies
The Milky Way - problems getting R0, V0 and the rotation curve
Rotational balance & mass estimation in disk galaxies
Virial theorem and applications
Mass discrepancies in galaxies & galaxy clusters
Standard candles (Cepheid and SN1a) as distance indicators
The collisionless nature of stellar systems

III. Advanced

Eddington (limiting) luminosity
Stellar variability/pulsations
Degeneracy pressure & Chandrasekhar mass
Jeans instability and Jeans mass
Epicycle motion in galaxies
Distance estimation by Tully-Fisher, etc
Distribution functions & collisionless Boltzmann eq
Spiral arm theory
Mass estimation in pressure-supported systems
Gravitational lensing
Solar neutrinos, solar oscillations