NIU Department of Physics Ph.D. Candidacy Examination Syllabi

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The Ph.D. candidacy examination tests students on their familiarity with fundamental physics concepts and their facility with applying these concepts to solving problems. These are the basic tools that a physicist brings to their research. The list of topics below is intended to help guide your preparation for the examination. However, it is important to realize that these lists of topics are necessarily coarse-grained and are not exhaustive or complete. The best and most important way to prepare for the examination is to practice problem-solving, and to study the concepts and techniques involved. Therefore, exam preparation should not center around these lists, but rather around actively working through problems given in the past, as found on the department website. Formulas related to spherical and cylindrical coordinates and certain integrals will be provided with each exam on which they might be relevant.

I. Classical Mechanics

• Newtonian mechanics: Newton's laws, forces, momentum, angular momentum, kinetic and potential energy, frames of reference, conserved quantities and conservation laws, friction, equilibrium

• Oscillations: Simple harmonic oscillator, damped, driven, and coupled oscillators, small oscillations, normal coordinates and normal modes, solutions of matrix eigenvalue equations, non-linear oscillations

• Hamilton's principle: variational calculus, Lagrangians and Hamiltonians, equations of motion from Lagrangian and Hamiltonian systems, phase space, conservation laws, Lagrange's equations with undetermined multipliers, generalized coordinates and forces

• Gravitation: gravitational force and potential, equipotential surfaces

• Central force motion: reduction to a 1-d problem, orbits, Kepler's Laws, planetary motion

• Dynamics of systems of particles: Center-of-mass, linear momentum, angular momentum, and energy of a system; elastic and inelastic collisions of two particles, scattering cross sections

• Dynamics of rigid bodies: Inertia tensor, principal axes of inertia, Euler's equations for a rigid body

• Dynamics of continuous media: Waves, loaded springs, wave equations, phase velocity and dispersion, group velocity and wave packets, fluids

II. Classical Mechanics

• Fundamentals of quantum mechanics: Quantum mechanical states, wavefunctions, probability amplitudes, operators, commutation relations, observables, Hilbert spaces, eigenstates, eigenvalues, expectation values, completeness relations, complete sets of commuting observables, Schrodinger and Heisenberg pictures, and their interpretations

• Position space and momentum space representations

• Uncertainty principles

• Schrodinger equation: time-dependent, time-independent, relation to Hamiltonian; time evolution of quantum states

• Two-state and few-state problems

• The harmonic oscillator: creation and annihilation operators

• Angular momentum: spin and orbital angular momentum, matrix representations, addition of angular momentum

• Symmetry transformations and unitary operators

• Bound states: square well problems

• Tunneling problems

• WKB approximation

• Scattering: scattering amplitudes and cross-sections, Born approximation, partial wave expansions, resonances

• Time-independent perturbation theory: non-degenerate, degenerate and almost-degenerate; up to 2nd order

• Time-dependent perturbation theory and Fermi's Golden Rule

• Variational techniques for estimating ground-state energies and wave-functions

• Hydrogen-like atoms: energy eigenvalues and eigenfunctions, multiplicity of states, Zeeman and Stark effects, spin-orbit and spin-spin couplings, fine and hyperfine structure, interaction with electromagnetic radiation

• Multi-particle systems: identical fermions and bosons, many-electron atoms, molecules, rotational and vibrational states

III. Electromagnetism

• Electrostatics: Coulomb's Law, Gauss' Law, electric potential, Poisson's equation, capacitance, method of images, electric dipoles and the multipole expansion

• Electric fields in matter: polarization, electric displacement, linear dielectrics, conductivity and conductors

• Magnetostatics: Ampere's Law, Biot-Savart Law, solenoids, magnetic vector potential, magnetic dipole moments

• Magnetic fields in matter: magnetization, H, paramagnetism, diamagnetism, ferromagnetism

• Behavior of charges in electromagnetic fields: the Lorentz force law, forces on objects carrying charges and currents

• Electrodynamics: Faraday's Law, EMF, self-inductance and mutual inductance, Maxwell's correction to Ampere's law, Maxwell's equations in vacuum and in materials, boundary conditions at interfaces, the Poynting vector, energy density, energy and momentum flow, charge conservation and the continuity equation, wave equations for electric and magnetic fields

• Solutions for electromagnetic problems using separation of variables in rectangular, spherical and cylindrical coordinate systems

• Electromagnetic waves: waves in vacuum, in linear media, and in conducting media; reflection, refraction and transmission at interfaces; waves in hollow and coaxial waveguides, dispersion

• Potentials for electrodynamics: gauge transformations, retarded potentials

• Radiation: electric and magnetic dipole radiation, radiation due to accelerated charges and Larmor's formula