Topics to be Covered in Qual-like Final Exams

I. CLASSICAL MECHANICS

- **Newtonian Mechanics:** Convervation laws, Central forces, Orbits and scattering, Rotating coordinate systems, Projectile motion, Foucault pendulum.
- **Lagrangian Dynamics:** Generalized coordinates, Constrained motion, Lagrange's equations, Lagrange multipliers and forces of constraint, Variational principle.
- **Small oscillations:** Normal modes, N-body problems in 1- and 2-d (string+masses) with fixed and continuum boundary conditions.
- **Continuum Mechanics:** Elasticity, Young's modulus,...
- **Hamiltonian Mechanics:** Derivation of Hamiltonian from Lagrangian, Hamilton's equations, Conservation of H
- **Rotational Motion:** Moment of inertia tensor, Projectile motion for symmetric objects, "sweet spots"

II. STATISTICAL MECHANICS

- **Thermodynamics:**

  First law of thermodynamics, Basic dilute gas processes, Reversible an irreversible cyclic processes, Engines and refrigerators, Second law of thermodynamics, Entropy, Thermodynamic potentials, Maxwell relations, Gibbs-Duhem relation. Examples: Clausius-Clapeyron equation, throttling process, ...

- **Kinetic theory of dilute gases:** Kinetic gas derivation of dilute gas equation of state, Mean free path, Boltzmann equation, Boltzmann factors. Examples: Maxwell Boltzmann distribution of speeds, Brownian motion, Perrin pollen distribution measurement of Boltzmann constant, Elementary transport theory (heat conduction, viscosity, diffusion coefficients).
- **Equilibrium statistical ensembles:** Probability distributions, Boltzmann-Shannon definition of entropy (information content, probability distribution functions), Principle of maximum entropy in thermal equilibrium for closed systems, Central limit theorem, Micro-canonical ensemble and its connection to thermodynamics, Gibbs paradox, Canonical and Grand Canonical ensembles from the micro-Canonical ensemble and reservoirs, Alternative derivation of the equilibrium ensembles using Lagrange multipliers. Examples: two level systems (paramagnets, lattice gases), dilute gases, equipartition theorem (rotational degrees of freedom, Law of Dulong-Petit), Langmuir absorption isotherm.
- **Quantum Statistical Mechanics:**

  Boltzmann, Fermi, and Bose statistics, Density of states. Examples: specific heat of diatomic molecules, Debye theory specific heat of solids, Fermion and Boson ideal gases, Sommerfeld description of metals, Stephan and Planck's law and black body radiation, Bose-Einstein condensation.

III. QUANTUM MECHANICS

- **Elementary Phenomenology:** Two-slit experiment, Stern-Gerlach experiment, Neutron interferometry.
- **Formalism of QM:** Linear vector spaces, Bras and kets, Operators and matrix representations, Measurement, Compatible and incompatible observables, Uncertainty principle, Position eigenkets, Momentum, Commutation Relations, Position-Momentum uncertainty, Projectors, Change of basis, Translation Operator, Wavefunctions, Gaussian wavepackets, Mixed states and density matrices.
- **Time evolution:** Spin-1/2 in B field, Schrödinger vs. Heisenberg picture, Time dependence of operators and matrix elements, Ehrenfest's theorem

- **1-d Wave Mechanics:** Step potentials, Infinite square well potentials, Finite square wells, Delta function potentials, 1-d simple harmonic oscillator, including raising and lowering operators, WKB approximation, Analytic structure of the scattering amplitude, Time delays and phase shifts, Coherent states.
- **Potentials in Quantum Mechanics:** Minimal substitution, Aharanov-Bohm effect.
- **Angular Momentum:** Orbital angular momentum, Spherical harmonics, Addition of angular momenta, Clebsch-Gordan coefficients. 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) and SU(2) in QM,
- **3-d Schrödinger equation:** Diatomic molecules, 3-d harmonic oscillator, Spinless hydrogen atom
- **Approximation methods and applications:** Time-independent PT (both non-degenerate and degenerate), Linear and quadratic Stark effects, Fine and hyperfine structure of H-atom, Variational approximation, Time dependent PT, Fermi's golden rule, Harmonic perturbations, Electron spin resonance.
- **Identical particles:** Fermions and bosons.
- **Time-Reversal:** Time-reversal invariance, Anti-unitary operators, Time-reversal for integer and half-integer spin systems, Electric dipole moments.

IV. ELECTRICITY AND MAGNETISM

- **Electrostatics:** Method of images, Multipole expansion of potential for bounded distribution, Multipole expansion of interaction energy, Electric stress tensor, Green functions in Cartesian, cylindrical and spherical coordinates.
- **Magnetostatics:** Magnetic scalar potential for current-free regions of space, Vector potential, Multipole expansion of bounded current distribution, Magnetic dipoles, Magnetic interaction energy, magnetic stress tensor.
- **Time-dependent fields:** Quasistatic 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, Reflection and refraction at boundaries, Imperfect conductors, skin depth and finite Q cavities,