Draft Proposal For the Comprehensive Examination

Last revised on: August 4, 2019

Contents

1   Preamble

The purpose of the Comprehensive Examination (CE) is to ensure that a student aspiring to undertake doctoral program has an adequate competence in the basic areas of physics.

2   Structure of the CE

The Comprehensive Examination will have two components: written and oral.

Successfully passing the CE is one of the requirements *before* proceeding to Doctoral research.

The proposed schedules for the Comprehensive exam has been designed keeping in mind student's convenience, time for preparation etc as well as the stipulation that

All requirements to formally proceed with doctoral work such as course work, clearing both components of the Comprehensive Examination, and signing-up with an advisor (formation of Doctoral Committee) must be completed within one year and six months of joining for the Ph.D. program students (2 years and six months for the Integrated Ph. D. program students).

The oral comprehensive exam must be completed within 2-3 months of completion of the course work – both for Ph.D. as well as I.Ph.D. students. The written comprehensive exam must be completed within one year (two years) of joining IMSc for Ph.D. (I.Ph.D.) students.

2.1   The Written Comprehensive Examination

1. Written comprehensive exams are currently being held (starting from 2018) three times a year (generally during the 1st Friday and the immediately next Monday of January, July, and October). In each time, examinations of four separate papers [on Classical Mechanics (CM), Electromagnetic Theory (EMT), Quantum Mechanics (QM), and Statistical Mechanics (SM)] are being held, with the exams on the papers on CM and EMT on the 1st day while the exams on the papers on QM and SM on the 2nd day – at different time slots of each day. Each student will get **two chances** to clear the exam of each of these four papers during the tenure of *one year* (*two years*) of joining IMSc as a Ph.D. (I.Ph.D.) student.

   A student is required to sign-up for a particular written comprehensive at least one week prior to the announced dates.

2. The duration of examination of each of the four papers is two hours, carrying, in total 30 marks. A student is considered clearing the paper if he/she would secure at least 12 marks in the exam of that paper.

3. The topics in each of the four areas (namely, CM, EMT, QM, and SM) along with the expected level is included separately below.

4. The 1st paper will cover Classical Mechanics, the 2nd paper will cover Electromagnetic Theory, the 3rd paper will cover Quantum Mechanics while the 4th will cover Statistical Mechanics. Each paper will consists of 3 - 4 problems requiring approximately 30 - 40 minutes each. The main aim being to test conceptual understanding and ability to apply them, details needed such as values of constants, specific integrals etc will be provided in the question paper.

   Evaluation will give partial credits and the result will be declared as pass/fail. Current practice regarding pass/fail: securing at least 12 marks (out of 30) corresponds to 'pass' in a paper. *But fixing this passing criterion each year is completely under the discretion of the concerned committee.*

5. **Dates of the Written Examination:**

   The examination in Classical Mechanics and Electromagnetic Theory will be held (with a gap of 15-30 minutes) on the first Friday of January (in case it is not an Institute holiday), July, and October while that in Quantum Mechanics and Statistical Mechanics will be held (with a gap of 15-30 minutes) on the following Monday in January, July, and October.

   Each of these examinations will have a maximum of two attempts and can be taken *separately* in January, July, and October or *jointly* in the same month.

2.2   The Oral Comprehensive Examination

Embarking on research requires more than competence in course work or core subjects. A student desirous of doing doctoral research will have to develop skill to read and understand research literature, recognise/formulate problem, acquire specialised skills needed etc. The objective of the Oral Comprehensive is to gauge if the student has acquired such skills to an adequate extent. The project work done during the course work provides a natural opportunity.

The Oral General Comprehensive Examination (OGCE) of a student – after successful completion of the coursework – can be conducted either under the supervision of the student's

Doctoral Committee members (in case the DC has already been formed) or under the supervision of the student's Monitoring Committee members.

In case the OGCE is to be conducted by the MC members, a three member Oral Examination Committee will be constituted by the M.Sc. project advisor – in consultation of the MC Chairman. The Oral Comprehensive will consists of a presentation based on the project, in the form of a seminar given to the committee. The committee will assess if the student has acquired adequate research skills and will arrive at a pass/fail decision.

Oral comprehensive exam must be conducted within 2-3 months *after* the completion of the course work. In case of unsatisfactory performance in the oral comprehensive exam, the same committee will examine the student a second time after one month *but no later than three months after the completion of the course work.* The student will be offered a choice of another presentation on the project material or presentation/discussion of one or two papers suggested by the committee.

3 Appendix I: Basic Topics

Following is the list of broad topics in each of the core subjects. To help identify approximate level of details, certain chapters/sections of standard reference books are also indicated. *This does not mean that questions will be confined only to this list, nor does it recommend the particular books for preparation.* You are free to choose any book/source for your preparation. For an orientation and practice purpose, some problem books are also mentioned.

A set of sample question papers are available on the Physical Sciences page of HBNI cell of IMSc.

3.1 Classical Mechanics

Indicative book is: *Classical mechanics*, Goldstein-Poole-Safko, 3rd edition. Chapter, sections refer to this book.

*For the first written comprehensive in January 2014, the topics marked * are omitted.*

1. **Variational Principles and Lagrangian formulation:** Generalised coordinates, configuration space, constraints, symmetries and conservation laws; [Chap. 2]

2. **Applications:** Central force problem, *Rigid bodies - kinematics and dynamics, small oscillations; [*Chap. 3, *4, *5, 6*]

3. **Special relativistic mechanics:** Lorentz transformations, velocity addition, basic relativistic kinematics and dynamics; [Chap. 7.1 - 7.4, 7.7, 7.9]

4. **Hamiltonian Mechanics:** Legendre transform, phase space, Poisson brackets, Hamilton's equations of motion, canonical transformations, Liouville theorem; [Chap. 8, 9]

5. ***Applications:** Hamilton-Jacobi theory, integrable systems; [Chap. 10]

3.2   Electromagnetism

Indicative book is: *Classical Electrodynamics*, J. D. Jackson, 3rd edition. Chapter, sections refer to this book.

For the first written comprehensive in January 2014, the topics marked ***** *are omitted.*

1. **Electrostatics and magnetostatics:** Boundary value problems using Green function techniques, special techniques for calculating potentials; electrostatics of dielectric media; magnetic vector potentials; magnetic dipole moments; magnetic susceptibility and permeability; [Chapters 1-5].

2. **Electrodynamics:** Maxwell's equations in vacuum and in a medium; energy-momentum of EM fields; Poynting's theorem; [Chapter 6, Sections 1, 4, 7, 8].

3. **Electromagnetic waves:** EM waves in vacua; linear and circular polarisations; their propagation through media; reflection, refraction, total internal reflection, lossy propagation; dispersions relations for a dielectric medium; [Chapter 7, Sections 1-5].

4. ***Radiating systems:** Radiation fields (near and far zones); electric dipole, magnetic dipole, electric quadrupole radiation; a few basics of antennae. [Chapter 9, Sections 1-4 and Sections 9, 12].

5. *****Motion of charges in uniform static electric and magnetic fields [Chapter 12, Sections 2, 3].

3.3   Quantum Mechanics

Indicative books are: *Quantum Mechanics, Vol I and II*, Cohen-Tannoudji et al; and *Quantum mechanics*, R. Shankar

For the first written comprehensive in January 2014, the topics marked ***** *are omitted.*

1. **Basics:** Wave-particle duality, Wave packets, Uncertainty Principle, Double slit experiment.

2. **Mathematical Formalism:** Hilbert Spaces, Linear operators, eigenvalues and eigenvectors, canonical commutation relations, position, momentum representation, $\delta-$function normalization;

3. **Postulates of QM:** Superposition, States and Operators, Observable, Measurement, Reduction of wave packet, Probabilistic Interpretation, Quantum dynamics, Schroedinger Equation, Stationary States, Relation to Classical Physics, Quantization and Commutation Relations, Density Matrix formalism

4. **Simple Applications:** one dimensional potentials, Probability Current, Transmission and Reflection Coefficients, Bound and Unbound states; Spin 1/2 particles, general two level system;

5. **Harmonic Oscillator:** spectrum, ladder operators $(a, a^{\dagger})$ method, Coupled harmonic oscillators, isotropic 3 dimensional harmonic oscillator, Oscillator at finite temperature;

6. **Symmetries and Angular Momentum in QM:** Discrete symmetries: P, T, Continuous Symmetries: Translation and Rotation Group $SU(2), SO(3)$, Pauli matrices, Commutation Relations for $\vec{J}$, Orbital $(\vec{L})$ and Spin $(\vec{S})$ angular momentum, Spherical harmonics $Y_{l,m}$, Addition of angular momenta, Clebsch Gordan, *Vector and Tensor Operators, *Wigner-Eckart theorem, *Electrical multipole moments and operators;

7. **Central Potential:** Hydrogen atom, stationary states, Orbitals, spectroscopic notation, Diatomic molecule - vibrational and rotational levels, *H atom in uniform magnetic field, *Zeeman effect;

8. **Approximation Methods:**

   - **Stationary Perturbation Theory:** Non degenerate and degenerate perturbation theory, applications to hydrogen atom- Fine structure, Hyperfine structure, Stark effect; Interaction of spins, Van der Waal's force, Variational Method;

   - ***Time Dependent Perturbation Theory:** Transition probability, Sinusoidal perturbation, Continuous states and Fermi Golden rule, Atom in an EM wave, Oscillation between two states and resonant perturbations.

   - ***Semi classical methods**: WKB, tunnelling through a barrier.

   - ***Other methods:** Sudden and adiabatic approximations;

9. **Identical Particles:** Identical Particles in CM and QM, Permutation operator, Symmetrization postulate, Bosons, Fermions, Pauli exclusion;

10. ***Scattering:** Stationary scattering states, method of partial waves, Born approximation, Unitarity and Optical Theorem.

3.4   Statistical Mechanics

Indicative book is: *Statistical Mechanics*, Kerson Huang, 2nd edition. Chapter, sections refer to this book.

For the first written comprehensive in January 2014, the topics marked * are omitted.

1. **Thermodynamics:** Laws of thermodynamics; entropy; thermodynamic potentials; the Carnot cycle; *Maxwell construction; *Gibbs-Duhem relation; *Clapeyron equation. [Chapters 1, 2]

2. **Classical Statistical Mechanics:** Micro-canonical, canonical and grand canonical ensembles; ideal gas; equipartition theorem; Maxwell-Boltzmann distribution; Gibbs paradox; Virial Expansion; van der Waal gas. [Chapters 6, 7, 10.1, 10.3, 10.5]

3. **Quantum Statistical Mechanics:** Fermi/Bose statistics; the degenerate electron gas; *the specific heat of the degenerate electron gas; *magnetism of an electron gas; the degenerate Bose gas; Bose-Einstein condensation; black body radiation. [Chapters 11, 12]

4. **Critical Phenomena:** one dimensional Ising model; Curie-Weiss mean field theory; Landau theory. [Chapters 16.1, 16.3, 17.1, 17.4]

3.5   Mathematical Methods:

The student is expected to be familiar with mathematical methods, roughly at the level of *Mathematical Methods for Physics*, by Mathews and Walker.

3.6   Some Reference Material

Here are some 'classic' references for practice with solving problems.

Chicago University Graduate problems in Physics with Solutions;

Princeton Problems in Physics with Solutions;

http://web.mit.edu/physics/refs/generals/ (MIT)

http://www.physics.orst.edu/comp_previous_years (Univ of Oregon);