Physics Core Course

1. Course overview

The course is intended to introduce the basic concepts of quantum physics at the graduate level. The course will consist of two parts, concentrated on the AMO/Quantum optics (taught by M. Lemeshko) and on Condensed matter physics (taught by M. Serbyn). The basic prerequisites for taking the course include the knowledge of Electricity and Magnetism (basic graduate/MS level, Jackson's "Classical Electrodynamics" or Landau&Lifshits "The Classical Theory of Fields") along with the Quantum mechanics (basic graduate/MS level, e.g. Griffiths "Introduction to Quantum Mechanics"), and second quantization.

The detailed curriculum is provided below. Overall, the goal of the core course is to provide the *basic* background so that student will be able to orient and understand subject of current research interest in the fields of quantum physics:

- *AMO* component will introduce the basics of atomic and molecular structure, interactions of quantum particles with electromagnetic fields, as well as the basics of atomic cooling and trapping.
- *Condensed matter* component will introduce the basics of electron theory in metals, including the band structures, effects of interactions, and phonons. Particular emphasis will be paid to topics of high current interest, including topological effect in solids.

2. Recommended Literature

The recommended books for this course are available on reserve at the IST library. The first two books on the list are mostly relevant for the AMO part, while the remaining ones are relevant for the Condensed Matter part:

- Pitaevskii&Stringari, Bose-Einstein Condensation and Superfluidity (2016)
- Bransden&Joachain, Physics of Atoms and Molecules (2003)
- Ashkroft&Mermin, Solid State Physics
- Grosso&Parravicini, Solid state physics AP, 2000; ISBN 012304460X

3. Curriculum

The two weekly lectures will have the blackboard format. In addition, there will be a designated time when TA will be available to answer the questions related to the problem sets and/or course contents. The lecture will cover following topics (see the more detailed weekly schedule below):

AMO curriculum:

1. Structure of atoms and molecules
2. Atoms and molecules in electromagnetic fields
3. Taming the motion of quantum particles: cooling and trapping
4. Bose-Einstein condensation and superfluidity

Condensed matter curriculum:

1. Free electrons: crystalline lattices, band structure
2. Spin-orbit coupling, topological effects in solids
3. Electrons in magnetic fields: semiclassic equations of motion, magneto-oscillations
4. Phonons and electron-phonon interactions
5. Brief overview of interaction effects on electrons: superconductivity, Mott insulators, magnetism

4. Schedule and Grading

Class will have weekly lectures on **Mondays** & **Wednesdays some time in the afternoon.** *Attendance and participation* make 50% of the grade. There will be between 8-10 problem sets that make up for remaining 50% of the grade. Typically the problem sets will be due one week after release date. One of the problem sets (with the worst grade or missed one) is excluded from counting.

Dates of planned lectures along with the release dates of problem sets are listed below.

Spring-I

Lemeshko's part lecture content

Spring-II

13 Free Electron Model
14 Crystalline Lattice. Point Group for Bravais Lattice
15 Bloch Theorem and Band Structure [PS5]
16 Tight Binding, van Hove Singularity
17 Semiclassical Dynamics of Electrons, Bloch Oscillation and Quantization of Orbits in a Uniform Magnetic Field [PS6]
18 de Haas-van Alphen Effect and Quantum Hall Effect
19 Quantum Hall Effect and Edge States; Topological insulators in 2d and 3d; [PS7]
20 Semiconductors: spin orbit coupling, k.p, donors, acceptors, excitons
21 Electron-electron Interaction: Hartree-Fock Approximation, Jellium [PS8]
22 Screening and Lindhard function; Hubbard Model, Plasmons
23 Phonons [PS9]
24 Electron-phonon Coupling; Attraction by Exchanging Phonons [PS10]
25 Superconductivity

5. Requests, feedback, ideas

It is important to keep the basic level of the course, so that it is accessible to students with different backgrounds. In addition, some subjects that would be nice to have covered:

- Numerical diagonalization of simple Hamiltonians, ideally including loss terms
- Connection to devices (simple electrical circuits, quantum dots) in the quantum description (Hamiltonian of a lossless electrical circuit)
- "Quantum optics without atoms" (e.g. statistics and definition of coherent / Fock / squeezed / thermal states and ways to show its properties with Wigner / Q functions and the like)
- Open systems, master equations, and something about input-output formalism
- Aspects of quantum electrodynamics (for example cavity QED)
- Basics of quantum info (e.g. via IBM quantum experience)