SPRING 2023: Solid State Physics/Applications - PHYS 512

CRN 19488. 3 credits.

Duration: 01/27/2023 - 05/12/2023.

Location: Planetary Hall 112

Time: 10:30 am - 1:10 pm, Friday

Instructor: Igor Mazin, imazin2@gmu.edu. Online office hours by arrangement, please send me an email. I usually respond within a few hours.

TEXTS: *Required*: J. Ziman, Principles of the Theory of Solids. Any edition (a used book OK); *Recommended*: D. Khomskii, Basic Aspects of the Quantum Theory of Solids; *Reference material*: N. W. Ashcroft and D. Mermin, Solid State Physics.

You are welcome to use, in addition, any other textbook in condensed matter theory; there are many that I know of and many I don't. Different people like different books.

Course philosophy and class format

- *The broad goal of this class is to familiarize the students with the fundamentals (most basic notions) of the modern condensed matter theory. There is no way one can apprehend the entire CMT in one semester; I am still learning something new every year. The general idea is to teach the students how to look up, digest and understand information on any specific subject that one may need in their future research using books, internet, and consultation with more experienced colleagues.*
- First and foremost, this will be an experimental class: instead of giving me lectures, you will be presenting to each other. I will assign a subtopic to each of you, and each will give a 15 minutes presentation in the class, following by 15 min discussion and questions. Besides, I expect everybody to read in advance about all subtopics, not only the one you personally present.
- YOUR GRADES WILL MOSTLY DEPEND ON THE QUALITY OF YOUR PRESENTATIONS AND PARTICIPATION IN DISCUSSIONS. You may use electronic presentations on screen, or just use the white board.
- After the first class, there will be small homework about the material studied in the class
- Making a good presentation, useful to your classmates, will be a challenge, especially in the beginning. Therefore *you are welcome to ask me for help*, particularly if do not understand some part of the material, and/or are in doubt about what should be included. Email me and we shall arrange a zoom or face-to-face meeting. Be proactive, do not hesitate to ask questions!

Exams, tests and grading.

- Grading will mostly depend on the quality of your presentations and your activity in the classroom (~50% of the grade). Homework assignments will count as another 20%
- Midterm exam (~15%): 10:30 am - 1:10 pm March, 10, 2023.

- Final exam (~15%): 10:30 am - 1:10 pm May 5 or 12 (TBD), 2023.
- Students can use lecture notes, textbooks and Mathematica/Matlab during the tests. As in the homework, a right answer without proper derivation (which no software will be able to provide) counts as nil.

Syllabus

1. Fundamentals of physical crystallography. Crystal symmetry. Crystal systems. Symmetry operations. Space groups. Magnetic symmetry. Centrosymmetric groups. Symmorphic groups. Tensorial physical quantities in most important applications.

2. One-electron Schrödinger equation in periodic potential. Bloch theorem. Plane wave expansion. Bloch functions and Wannier functions. Localization and orthogonality of the Wannier functions.

3. Fundamentals of the band structure. Metals, insulators, semimetals and semiconductors. Density of states. Specific heat of free electrons. Fermi surface and Fermi velocity.

4. Solving Schrödinger equation. Pseudopotentials. Different bases. Plane waves, augmented plane wave, local orbitals.

5. Interacting vs. noninteracting electrons. Landau's Fermi liquid theory. Hohenberg-Kohn-Sham density functional theory (DFT). Self-consistent DFT calculations. Andersen's force theorem. Ground state properties vs. excitation properties.

6. Linear response theory. Lindhard dielectric functions. Random phase approximation. Dielectric function of a semiconductor. Penn's dielectric function. Plasma frequency.

7. Lattice properties. Force constants. Dynamical matrix. Phonons. Electron-phonon interaction. Anharmonic phonon-phonon interactions. Visual understanding of Feynman diagrams.

8. Transport properties. Drude formula and its relation to the Lindhard susceptibility. Defect scattering. Phonon scattering. Bloch-Grüneisen formula. Optical properties. Transport in semiconductors. Hall effect. Thermoelectric power.

9.Magnetism. Ising model. Heisenberg model. Itinerant magnetism. Spin-DFT. Pauli susceptibility. Stoner criterion. Curie and Curie-Weiss laws.

10.Spin-orbit coupling. Single-site anisotropy. Anisotropic exchange. Heisenberg ferromagnetic exchange. Antiferromagnetic exchange. Superexchange. Double exchange.

11.Electron-electron interaction. Exchange and correlations. Wigner localization. Hubbard model.

12.Superconductivity. Pairing approximation. Sources for pairing interaction. BCS formula.