

Electronic, optical and magnetic properties of materials (MAT 204)

This course aims to give an understanding of the electronic, optical, electrothermal and magnetic properties from a materials perspective. A major portion of the topics are covered in solid state physics textbooks. In addition to fundamentals such as electronic conduction, optical response of materials, why certain materials have magnetic properties and alike, part of the focus will be on the material physics and how material properties can be engineered. Examples include and are not limited to applications such as p-n junctions, power amplification via transistors, Schottky diodes, solar cells, thermoelectric energy harvesting, magnetic data storage and alike. In the course, a number of fundamental relations will also be studied in preparation for developing the understanding needed to link physics to materials.

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Date and classroom: N/A yet

Grading: % 20 Homeworks, %35 Midterm, %10 Recitation quizzes, % 35 Final. There will be around one homework every two weeks.

Important: Late homeworks and assignments WILL NOT BE accepted and will receive zero. Students are allowed to skip a max. of 3 lecture hours. More than that will be considered as a sign of lack of interest unless a specific medical report and similar is provided.

Textbook: There is no textbook requirement for this class and I compile the notes from a variety of books that are also available at the IC. Recommended references at the IC (the ones much of the course notes are compiled from are highlighted):

- a. Electronic Properties of Materials, 3rd Edition, Rolf Hummel (2001).
- b. Electronic Properties of Engineering Materials, James D. Livingston (1999).
- c. Introduction to Solid State Physics, 8th International addition, Charles Kittel (2005).
- d. Electrons in Solids – An Introductory Survey, 3rd Edition, Richard H. Bubbe.
- e. Band Theory and Electronic Properties of Solids, Oxford Master Series in Condensed Matter Physics, John Singleton, (2004).
- f. Solid state physics / J.R. Hook, H.E. Hall. Hook, J. R. (John R.) Chichester
- g. Solid state physics for engineering and materials science / John P. McKelvey. McKelvey, John Philip.

Subjects to be covered in the course (Note that there might be some slight modifications to the content during the course of the semester) :

1. An introduction to waves and oscillations (weeks 1-2)

- 1.1. Vibrations on a string: Classical mechanics.
- 1.2. Electromagnetic wave equation and the black body radiation.

2. Optical and electrical properties in solids – classical mechanics (week 2-4)

- 2.1. Electromagnetic wave equation and index of refraction.
- 2.2. Continuum approach to explain optical properties of solids (harmonic oscillator treatment of electrons as dipoles).
- 2.3. Atomistic approach (Classical dynamics using eqn. of motion of an electron under an oscillating electric field).

2.4. Classical approach to electrical conduction in metals (Drude model).

2.5. Capacitors and materials.

3. Electrons in Solids and Band Theory – Quantum view (week 4-7)

3.1. Wave-particle duality: An overview on the quantum mechanical nature of the electron

3.2. The Schrödinger Equation.

3.3. Electron in an atom and electron in a crystal: Why bands form?

3.3. A few case studies of the Schrödinger equation.

3.4. Electron tunnelling: An overview.

3.5. Schrödinger equation for a periodic potential (Bloch approach, Krönig-Penney model).

3.6. Energy bands in ordered solids, crystals, construction of free electron energy-wave vector diagrams.

3.7. Density of states of electrons and population density (Fermi-Dirac statistics).

4. Electrical Properties of Certain Materials and Applications (week 7-9)

4.2. Quantum mechanical approach to electrical conduction in metals (Sommerfeld model).

4.3. Semiconductors, Schottky junctions, Ohmic junctions, current flow at a junction.

5. Thermal Properties of Materials (week 10)

5.1. Lattice oscillations: Phonons

5.2. Thermal properties: (Phonon and electronic contribution), heat capacity (Einstein model, Debye Model, discussion of the Dulong-Petite Law), thermal conductivity and its relation to phonon population and free electron density (population density in the conduction band) in a crystal.

6. Optical properties of solids – Quantum view (week 11-12)

6.4. Quantum approach, inter-band, direct/indirect gap transitions in semiconductors and insulators, absorption of radiation by materials.

6.5. Lasers, some other optical phenomena.

7. Magnetism in solids, dielectrics and ferroelectrics (week 12-13)

7.1. Theories to explain magnetism in materials.

7.2. Paramagnetism, ferromagnetism, antiferromagnetism, diamagnetism, ferrimagnetism.

7.3. Origin of dielectric behavior.

7.4. Piezoelectrics, ferroelectric phenomena.

8. Case studies - as long as time avails (week 13-14)