MSE-494

Quantum materials: fundamentals and applications

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Cursus	Sem.	Type
Materials Science and Engineering		Obl.
Materials Science and Engineering	MA2, MA4	Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

Introduces the exceptional electromagnetic and optical properties of low-dimensional, Dirac and superconducting materials - the quantum-mechanical models that explain them, and experimental techniques to probe them. Surveys new applications in information processing, sensing, energy technologies..

Content

- Review of the quantum-mechanical description of two-level systems and tight-binding models
- Exploring fundamental tight binding models through simulation
- The Dirac Hamiltonian, Berry phases, Berry curvatures
- Non-trivial topology in band structures
- The (anomalous) Quantum Hall Effect
- Graphene and other two-dimensional materials
- Experimental techniques to probe Quantum Materials
- Coherent Dynamics of Electrons and the superconducting wavefunctions
- Key electromagnetic properties of superconductors
- Josephson junctions and SQUIDS
- Applications of superconductors including quantum sensing and quantum computing

Keywords

Tight-binding models, Dirac Hamiltonian, Berry phases, Berry curvatures, Band Topology, Quantum Hall Effect, Graphene, 2D Materials, Coherent electron dynamics,
superconductivity, Meissner effect, Josephson junction, SQUID, quantum sensing, quantum computing

Learning Prerequisites

Required courses

Electromagnetism, General Physics III, or equivalent.
A course about fundamentals of solid matter, e.g. MSE-423 Fundamentals of solid-state materials, Solid state physics, Theory of materials: from structures to properties, or equivalent

Important concepts to start the course

Basic quantum mecanics, electromagnetism, Fourier transforms, band structures.

Learning Outcomes

By the end of the course, the student must be able to:

- Construct complex tight-binding models

- Implement Dirac Hamiltonians
- Interpret quantum-mechanical effects in materials
- Examine the electromagnetic properties of superconductors
- Propose appropriate methods to characterize quantum materials
- Reason about applications of 2D materials and superconductors

Transversal skills

- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Demonstrate the capacity for critical thinking
- Use both general and domain specific IT resources and tools
- Access and evaluate appropriate sources of information.
- Collect data.
- Write a scientific or technical report.

Teaching methods

Ex cathedra, exercises, simulations, basic experiments, lab visit

Expected student activities

Attend lectures and exercises, complete problem sets, perform siumlations and basic experiments, partake in a lab visit

Assessment methods

Brief report on a measurement (25%)
Brief report on an experiment (25%)
Oral exam (50%)

Resources

Moodle Link

- https://go.epfl.ch/MSE-494