MSE2106: QUANTUM PROPERTIES OF MATERIALS

Effective Term
Semester A 2025/26

Part I Course Overview

Course Title
Quantum Properties of Materials

Subject Code
MSE - Materials Science and Engineering
Course Number
2106

Academic Unit
Materials Science and Engineering (MSE)

College/School
College of Engineering (EG)

Course Duration
One Semester

Credit Units
3

Level
B1, B2, B3, B4 - Bachelor's Degree

Medium of Instruction
English

Medium of Assessment
English

Prerequisites
PHY1201 General Physics I
PHY1202 General Physics II

Precursors
Nil

Equivalent Courses
Nil

Exclusive Courses
Nil

Part II Course Details

Abstract

This course introduces the electrical, magnetic, optical and thermal properties of materials using basic quantum mechanics. It covers three main topics: (i) the fundamental postulates and concepts of quantum mechanics; (ii) the quantum mechanical models and behaviours of electrons and atoms in metals, semiconductors and magnetic materials; and (iii) the electronic band structure and theory in crystalline solids.

Course Intended Learning Outcomes (CILOs)

	CILOs	Weighting (if app.)	DEC-A1	DEC-A2	DEC-A3
1	Describe the phenomena of quantum mechanics, its key concepts, and their associations with classical mechanis.	20	x	x	
2	Explain the solutions to Schrödinger's equation for simple quantum mechanical systems and demonstrate their applications in quantum dots and quantum wells.	20	x	x	x
3	Describe and analyse atomic and molecular orbitals, quantum statistics, and the classical and quantum free-electron theories of metals.	20	x	x	x
4	Explain the band theory of crystalline solids and its applications in metals, superconductors, and semiconductors.	20	x	x	x
5	Discuss the basic operating principles of transistors, lasers, electron microscopes, and magnetic resonance imaging.	20	x	x	

A1: Attitude
Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: Ability
Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to real-life problems.

A3: Accomplishments
Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

Learning and Teaching Activities (LTAs)

	LTAs	Brief Description	CILO No.	Hours/week (if applicable)
1	Lecture	Stduents will engage in discussing key concepts, theories and applications.	1, 2, 3, 4, 5	3

2	Tutorial	Students will consolidate their knowledge by engaging with assigned readings and questions and then expressing their thoughts in the discussion.	2, 3, 4, 5	1

Assessment Tasks / Activities (ATs)

	ATs	CILO No.	Weighting (%)	Remarks ("-" for nil entry)	Allow Use of GenAI?
1	Assignments	1, 2, 3, 4, 5	20	-	Yes
2	Midterm test	1, 2, 3, 4	20	-	No

Continuous Assessment (%)

40

Examination (%)

60

Examination Duration (Hours)

2

Minimum Examination Passing Requirement (%)

30

Additional Information for ATs

For a student to pass the course, at least 30% of the maximum mark for the examination must be obtained.

Assessment Rubrics (AR)

Assessment Task

1. Assignments

Criterion

Justify and apply basic theory and principles, explain experimental observations using theory and simple calculations, describe atomic structures, calculate basic materials properties.

Excellent (A+, A, A-)

High

Good (B+, B, B-)

Significant

Fair (C+, C, C-)

Moderate

Marginal (D)

Basic

Failure (F)

Not even reaching marginal levels

Assessment Task
2. Midterm test

Criterion
Justify and apply basic theory, explain experimental phenomena and materials properties using calculations.

Excellent (A+, A, A-)
High

Good (B+, B, B-)
Significant

Fair (C+, C, C-)
Moderate

Marginal (D)
Basic

Failure (F)
Not even reaching marginal levels

Assessment Task
3. Final Exam

Criterion
Describe basic theory and principles, explain observed materials phenomena, draw schematic diagrams and calculate basic materials properties, explain materials/devices working principles

Excellent (A+, A, A-)
High

Good (B+, B, B-)
Significant

Fair (C+, C, C-)
Moderate

Marginal (D)
Basic

Failure (F)
Not even reaching marginal levels

Part III Other Information

Keyword Syllabus

- Quantum phenomena and history of quantum mechanics: double-slit experiment and wave-particle duality, thermal radiation, emission of light by hydrogen atoms;
- Planck’ s constants and postulate: energy quantization, quantum numbers and quantum states;
- Photoelectric effect and Einstein’ s hypothesis: light, electromagnetic radiation, photon;

- Waves and electromagnetic radiation: wavelength, frequency and energy, standing waves and superposition principles, electromagnetic spectrum, Heisenberg uncertainty principle;
- Models and structure of the atom: Bohr model and atomic orbitals: energy levels and atomic spectra, Aufbau principle;
- The Schrödinger theory of quantum mechanics: de Broglie postulate, wave functions, Schrödinger equation, eigenvalues and eigenfunctions, Born's probability postulate, probability density and expectation values;
- Solutions of time-independent Schrödinger equation in zero, step, square well, harmonic and lattice periodic potentials, tunnelling, electron-atom scattering;
- One-electron atoms: three-dimensional Schrödinger equation, spherical polar coordinates, eigenvalues, quantum numbers and degeneracy, orbital angular momentum;
- Magnetic dipole moments and spin, spin-orbit interaction;
- Quantum statistics: quantum distribution function, work function and Fermi energies, specific heat of crystalline solids, laser, photon gas, the free electron gas;
- Band theory of solids: molecular orbitals, band structure in metals, semiconductors and insulators, density of states, Fermi-Dirac distribution, thermal and photoexcitation;
- Introduction to metals: electrical conductivity, Hall effect, classical and quantum free-electron model, energy distribution, thermoelectric phenomena;
- Introduction to semiconductors: band gap, charge carrier, conductivity, intrinsic and extrinsic semiconductors, free holes and electrons, doping and gating, transistor, light-emitting diodes, solar cells;
- Introduction to magnetic properties of solids: paramagnetism, ferromagnetism, antiferromagnetism and ferrimagnetism.

Reading List

Compulsory Readings

	Title
1	Nil

Additional Readings

	Title
1	Robert Eisberg and Robert Resnick, "Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles", 2nd Edition, Wiley, 1985 (QC174.12 .E34, 1985).
2	Charles Kittel, "Introduction to Solid State Physics", John Wiley & Sons Inc., 1996/2005 (QC176 .K57, 1996/2005).
3	(E-Book) Rolf E. Hummel, "Electronic Properties of Materials", 4rd Edition, Springer, New York, 2011 (QC176.H86, 2011).
4	Neil W. Ashcroft, N. David Mermin, Solid State Physics 1st Edition, "Solid State Physics", 1st Edition, Cengage Learning, 1976 (QC176.A83).