

MSE8019: FUNCTIONAL PROPERTIES OF MATERIALS

Effective Term

Semester A 2025/26

Part I Course Overview

Course Title

Functional Properties of Materials

Subject Code

MSE - Materials Science and Engineering

Course Number

8019

Academic Unit

Materials Science and Engineering (MSE)

College/School

College of Engineering (EG)

Course Duration

One Semester

Credit Units

3

Level

R8 - Research Degree

Medium of Instruction

English

Medium of Assessment

English

Prerequisites

Nil

Precursors

Nil

Equivalent Courses

Nil

Exclusive Courses

Nil

Part II Course Details

Abstract

This course applies basic quantum mechanics principles (Schrödinger wave equation and perturbation theory, classical and quantum free-electron theories, band theory for solids) to understand the functional properties of materials (including electrical, optical, optoelectronic, magnetic and topological properties etc.). Topics in this course include single-particle Schrodinger wave equation and its applications in several typical quantum mechanical systems, realistic quantum materials and advanced characterization techniques; non-degenerate and degenerate (time-independent) perturbation theories and their applications in the ground state of helium atom, Stark effect, and Zeeman splitting; classical free-electron gas model, quantum free-electron theory, quantum density of states, Fermi-Dirac distribution, Maxwell Boltzmann distribution, Fermi energy, and Fermi surface; Bloch' s theorem, approaching band model through Schrödinger wave equation, nearly free-electron model, tight binding model, Kronig-Penney model for deriving the formation of discrete energy levels and band structures of crystalline solids; apply band structures to classify materials and understand electrical, optical, and topological properties of recently emerging materials systems (two-dimensional materials and topological insulators etc.).

Course Intended Learning Outcomes (CILOs)

CILOs		Weighting (if app.)	DEC-A1	DEC-A2	DEC-A3
1	Describe the fundamental concepts of quantum mechanics and single-particle Schrodinger wave equation and apply it in several typical quantum mechanical systems, realistic quantum materials and advanced characterization techniques	30	x	x	x
2	Apply Dirac notation, non-degenerate and degenerate (time-independent) perturbation theories to analyse typical quantum phenomena, such as the ground state of helium atom, Stark effect, and Zeeman splitting	10	x	x	x
3	Describe the classical free-electron gas model and the quantum free-electron theory; Introduce the quantum density of states, the Fermi-Dirac distribution function, and determine Fermi energy and Fermi surface	30	x	x	x
4	Describe the formation of discrete energy levels and the band structure of crystalline solids based on Bloch' s theorem, nearly free-electron model, tight-binding model, and Kronig-Penney model	20	x	x	
5	Apply band structures to classify materials and quantum theories to describe their electrical, optical (absorption, emission, and amplification of optically active materials), optoelectronic (devices), and topological properties	10	x	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	Students will gain knowledge about key quantum mechanics principles, single-particle Schrodinger wave equation, classical and quantum free-electron theories, statistical mechanics, solid-state band theories, and their applications in understanding the multi-physical properties of crystalline solids	1, 2, 3, 4, 5	2 hrs/wk
2	Tutorial	Students will engage in in-depth discussions on tutorial questions and assignments, and also be provided with course consultation	1, 2, 3, 4, 5	0.5 hrs/wk

Assessment Tasks / Activities (ATs)

ATs		CILO No.	Weighting (%)	Remarks ("- for nil entry)	Allow Use of GenAI?
1	Assignments	1, 2, 3, 4, 5	30	-	Yes
2	Midterm test	1, 2	20	-	No

Continuous Assessment (%)

50

Examination (%)

50

Examination Duration (Hours)

2

Assessment Rubrics (AR)

Assessment Task

Assignments (applicable to students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Understand basic theories and principles, be able to apply them to solve relevant questions and explain relevant physical phenomena

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

Midterm test (applicable to students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Demonstrate understanding of key quantum mechanics principles, single-particle Schrodinger wave equation, non-degenerate and degenerate (time-independent) perturbation theories, and be capable of solving relevant problems

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

Examination (applicable to students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Describe basic quantum mechanical theories and principles, explain experimentally observed quantum mechanical and solid-state physical phenomena, draw schematic diagrams and perform calculations, and understand the working principles of typical quantum materials, devices and instrument

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

Assignments (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion

Understand basic theories and principles, be able to apply them to solve relevant questions and explain relevant physical phenomena

Excellent

(A+, A, A-) High

Good

(B+, B) Moderate

Marginal

(B-, C+, C) Basic

Failure

(F) Not even reaching marginal levels

Assessment Task

Midterm test (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion

Demonstrate understanding of key quantum mechanics principles, single-particle Schrodinger wave equation non-degenerate and degenerate (time-independent) perturbation theories and be capable of solving relevant problems

Excellent

(A+, A, A-) High

Good

(B+, B) Moderate

Marginal

(B-, C+, C) Basic

Failure

(F) Not even reaching marginal levels

Assessment Task

Examination (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion

Describe basic quantum mechanical theories and principles, explain experimentally observed quantum mechanical and solid-state physical phenomena, draw schematic diagrams and perform calculations, and understand the working principles of typical quantum materials, devices and instrument

Excellent

(A+, A, A-) High

Good

(B+, B) Moderate

Marginal

(B-, C+, C) Basic

Failure

(F) Not even reaching marginal levels

Part III Other Information

Keyword Syllabus

- Quantum behaviours, wave-particle duality relationship;
- Heisenberg's uncertainty principle, quantum operators;
- Single-particle Schrodinger wave equations for typical quantum systems and realistic quantum materials;
- Dirac notation, non-degenerate and degenerate perturbation theories;
- Ground state of helium atom, Stark effect in hydrogen atom and Zeeman splitting
- Classical free-electron gas model quantum free-electron theory;
- Quantum density of states, Fermi-Dirac distribution Maxwell Boltzmann distribution;
- Fermi energy Fermi surface;
- Three approximations for approaching band model through Schrodinger equation;
- Bloch's theorem;
- Nearly free-electron model;
- Tight-binding model;
- Kronig-Penny model;
- Formation of discrete energy levels;
- Band structures of typical crystalline solids (metals, insulators and semiconductors);
- Band model interpretation of electrical conduction in solids, and crystal momentum and effective mass;
- Band structures for understanding optical absorption, emission, and amplification of optical materials;
- Emerging two-dimensional materials (graphene and TMDCs) and topological insulators

Reading List

Compulsory Readings

Title	
1	Nil

Additional Readings

Title	
1	Richard P. Feynman, "The Feynman Lecture Notes on Physics, Vol. III: Quantum Mechanics", Ingram Publisher Service, New York, US, 1971
2	Hasse Fredriksson, Ulla Åkerlind, "Physics of Functional Materials", John Wiley & Sons Inc., 2008 (QC21.3.F74, 2008)
3	Neil W. Ashcroft, N. David Mermin, "Solid State Physics", Saunders College Publishing, 1976 (QC176.A83, 1976)
4	Charles Kittel, "Introduction to Solid State Physics", 8th Edition, John Wiley & Sons Inc. 1996/2005 (QC176.K57, 1996/2005).
5	(E-Book) Rolf E. Hummel, "Electronic Properties of Materials", 4th Edition, Springer, New York, 2011 (QC176.H86, 2011)

6	Robert Eisberg and Robert Resnick, "Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles", 2nd Edition, Wiley, 1985 (QC174.12.E34, 1985)
7	Safa O. Kasap, "Principles of Electronic Materials and Devices", 3rd Edition, McGraw-Hill, 2006 (TK453.K26, 2006)
8	Sara M. McMurry, "Quantum Mechanics", Addison-Wesley, Wokingham c1994 (QC174.12.M38, 1996)