City University of Hong Kong
Course Syllabus

offered by Department of Materials Science and Engineering
with effect from Semester A 2021/22

Part I Course Overview

Course Title:	**Electronic Properties of Crystalline Solids**
Course Code:	**MSE8012**
Course Duration:	**One semester**
Credit Units:	**3**
Level:	**R8**
Medium of Instruction:	**English**
Medium of Assessment:	**English**
Prerequisites: *(Course Code and Title)*	**Nil**
Precursors: *(Course Code and Title)*	**Nil**
Equivalent Courses: *(Course Code and Title)*	**Nil**
Exclusive Courses: *(Course Code and Title)*	**Nil**

Part II Course Details

1. Abstract

This course applies basic quantum mechanics principles (Schrödinger equation and perturbation theory) to derive the band structure theories of crystalline solids and understand the multiphysics nature of materials (including electrical, optical, optoelectronic, and topological properties). Topics in this course include single-particle Schrodinger equation and its application in several quantum mechanical systems; Dirac notation, non-degenerate and degenerate perturbation theories and their applications in hydrogen and helium atoms; 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 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.).

2. Course Intended Learning Outcomes (CILOs)

No.	CILOs#	Weighting* (if applicable)	Discovery-enriched curriculum related learning outcomes (please tick where appropriate)		
			A1	*A2*	*A3*
1.	Describe the fundamental concepts of quantum mechanics; Describe single-particle Schrodinger equation and its application in several quantum mechanical systems	20%	✓	✓	✓
2.	Introduce Dirac notation, non-degenerate and degenerate perturbation theories and their applications in hydrogen and helium atoms	10%	✓	✓	
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%	✓	✓	✓
4.	Describe the formation of discrete energy levels and the band structure of crystalline solids based on Bloch's theorem, Schrödinger equation, nearly free-electron model, tight-binding model, and Kronig-Penney model	20%	✓	✓	✓
5.	Apply band structure to classify materials and understand their electrical, optical (absorption, emission, and amplification of optically active materials), optoelectronic (devices), and topological properties	20%	✓		✓
		100%			

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 self-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.

3. Teaching and Learning Activities (TLAs)

TLA	Brief Description	CILO No.					Hours/week (if applicable)
		1	2	3	4	5	
Lecture	Explain key quantum mechanics principles, statistical mechanics, solid-state band theories, and their applications in understanding the physical properties of crystalline solids	✓	✓	✓	✓	✓	2 hrs/wk
Tutorial	Discuss tutorial questions and assignments, and provide consultation	✓	✓	✓	✓	✓	0.5 hrs/wk

4. Assessment Tasks/Activities (ATs)

Assessment Tasks/Activities	CILO No.					Weighting*	Remarks
	1	2	3	4	5		
Continuous Assessment: 50%							
Assignments	✓	✓	✓	✓		30%	
Midterm test	✓	✓	✓			20%	
Examination: (duration: 2 hours)	✓	✓	✓	✓	✓	50%	
						100%	

5. Assessment Rubrics

Assessment Task	Criterion	Excellent (A+, A, A-)	Good (B+, B, B-)	Fair (C+, C, C-)	Marginal (D)	Failure (F)
1. Assignments	Understand basic theory and principles, be able to apply them to solve relevant questions and explain relevant physical phenomena.	High	Significant	Moderate	Basic	Not even reaching marginal levels
2. Midterm test	Demonstrate understanding of key quantum mechanics principles, classical free-electron gas model, quantum free-electron theory, quantum density of states, Fermi-Dirac distribution, Fermi energy and Fermi surfaces, and be capable of solving relevant problems	High	Significant	Moderate	Basic	Not even reaching marginal levels
3. Examination	Describe basic theories and principles, explain observed quantum mechanics and solid-state structure phenomena, draw schematic diagrams and perform calculations, explain materials/devices working principles	High	Significant	Moderate	Basic	Not even reaching marginal levels

Part III Other Information (more details can be provided separately in the teaching plan)

1. Keyword Syllabus

- Quantum behaviours, wave-particle duality relationship;
- Heisenberg's uncertainty principle, quantum operators;
- Single-particle Schrodinger equation in example quantum systems;
- Dirac notation, non-degenerate and degenerate perturbation theories;
- Ground state of helium atom, and Stark effect in hydrogen atom;
- 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;
- Laser diodes, optical modulators, and solar cells;

2. Reading List
2.1 Compulsory Readings

1.	Nil

2.2 Additional Readings

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)