Course Requisites (if applicable)

Pre-requisites	PH3101 Quantum Mechanics or equivalent and PH3102 Condensed Matter Physics I or equivalent and PHY (PPHY) or PHY (APHY) programme and CGPA 4.0 or higher
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course aims to equip you with the advanced concepts and problem solving skills in condensed matter physics. Condensed matter systems can display a very wide variety of phenomena. As a result, condensed matter physics is characterized by a patchwork of effective models and theories that capture the behavior of electronic and lattice systems. While each effective theory provides key insight in a particular setting, together the set of model descriptions --- phenomenology --- form the core structure of the modern day understanding of electrons in solids.

This course surveys foundational phenomenology of solid state systems with an emphasis on the origin and basic techniques used to describe how electrons behave in crystals, and material responses to electric and magnetic fields. The course will provide you with an essential conceptual framework to parse fundamental electronic phenomena in crystalline materials, as well as a toolkit of effective models and approximations to perform calculations for materials.

In the second part of the course, some topics in topological band theory of electrons will be covered as a natural extension of the more fundamental contents. This will equip you with the necessary background to make a seamless transition to research in Condensed Matter Physics.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Describe and analyze quantum many body systems in the occupation number representation.
ILO 2	Construct the wavefunctions for systems of identical particles – understand the difference between fermionic and bosonic wavefunctions.
ILO 3	Explain the significance and calculate the attributes of electrons in crystals (such as velocity, effective mass, quasi-momentum and energy bands)
ILO 4	Compute electronic band structure for crystals and explain the significance of bands using perturbation theory
ILO 5	Construct effective models for electronic structure using methods such as tight-binding methods and k.p theory and solve simple effective models for electronic structure (e.g., graphene)
ILO 6	Apply MFT to study spontaneously broken phases in magnetism
ILO 7	Understand Bardeen Cooper Schrieffer theory of superconductivity as an example of MFT.
ILO 8	Analyze the response of a quantum many body system to an external field.
ILO 9	Calculate electrical conductivity using Kubo formula.
ILO 10	Calculate Berry phase of an isolated band.
ILO 11	Analyze the role of symmetries in determining electronic properties.
ILO 12	Calculate topological band structure for Haldane model; evaluate Berry phase and chiral edges states.

Course Content

Second Quantization (Bruus and Flensberg)

Second quantization – creation and annihilation operators

Quantum many body wavefunction – bosons and fermions

Fock space – Occupation number representation

Electrons in a lattice (Ashcroft and Mermin)

Bloch theorem

Tight binding model

Low-energy effective theories

Graphene

Mean Field Theory (Bruus and Flensberg)

Fluctuation from equilibrium

Hartree-Fock theory

Heisenberg model of ferromagnetism

Stoner model of metallic magnet

BCS theory of superconductivity

Linear Response Theory (Bruus and Flensberg)

Time evolution in quantum mechanics

General Kubo formula

Kubo formula for conductivity

Kubo formula for dielectric function

Topology in condensed matter (Shankar, Bernevig)

Scalar and vector potentials

Berry phase

Time reversal symmetry

Su-Schrieffer-Heeger model

Chern bands

Quantum Hall state

Haldane model

Kane-Mele model

Reading and References (if applicable)

1. Many-Body Quantum Theory in Condensed Matter Physics: An Introduction (Oxford Graduate Texts) by Henrik Bruus and Karsten Flensberg, Oxford University Press, 2004. ISBN-10: 0198566336
2. Solid State Physics by Neil W. Ashcroft and N.D. Mermin, Brooks Cole, 1976. ISBN-10: 8131500527
3. Topological Insulators and Topological Superconductors by Andrei Bernevig and Taylor Hughes, Princeton University Press, 2013. ISBN-10: 069115175X
4. Topological Insulators – a review by R. Shankar, arXiv.org:1804.06471

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Second quantization	ILO1 , ILO2	Lecture Sets	In-person	Problem sets
2	Second quantization	ILO1 , ILO2	Lecture sets	In-person	Problem sets
3	Electrons in a lattice	ILO3 , ILO4 , ILO5	Lecture sets	In-person	Problem sets
4	Mean Field Theory	ILO6	Lecture Sets	In-person	Problem Sets
5	Mean Field Theory	ILO6 , ILO7	Lecture sets	In-person	Problem sets
6	Linear Response Theory	ILO8 , ILO9	Lecture notes	In-person	Mid-Term Test
7	Review of Ch. 1-3 , Mid-Term Test	ILO1 -7	Lecture sets	In-person	Problem sets
8	Linear Response Theory	ILO8 , ILO9	Lecture sets	In-person	Problem sets
9	Topological band theory	ILO10	Lecture sets	In-person	Problem sets
10	Topological band theory	ILO10, ILO11	Lecture sets	In-person	Problem sets
11	Topological band theory	ILO11, ILO12	Lecture sets	In-person	Problem sets

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
12	Topological band theory	ILO12	Lecture sets	In-person	Problem sets
13	Topological band theory	ILO12	Lecture sets	In-person	Problem sets

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Acquire knowledge through interactive lecture sessions
Tutorials	Practise problem solving skills
Technology enhanced learning: Embedded animations	Illustrate crystal symmetries, electronic band structures
Technology enhanced learning: Numerical simulations	Illustrate topological bands, calculate Berry phase

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Summative Assessment (EXAM): Final exam(Final Examination)	ILO 1-12	Competency (1,4,5), Communication (1,2)	50	Individual	Analytic	Extended Abstract
2	Continuous Assessment (CA): Test/Quiz(Mid-term test)	ILO1-7	Competency (1,4,5), Communication (1,2)	30	Individual	Analytic	Extended Abstract
3	Continuous Assessment (CA): Assignment(Continuous Assessment: Homework Sets)	ILO 1-12	Competency (1,3,4,5,6), Creativity, Communication (1,2)	20	Individual	Analytic	Extended Abstract

Description of Assessment Components (if applicable)

Formative Feedback

You will receive formative feedback is given through discussion during tutorials as well as comments on your homework assignments. Further, feedback will also be provided after the midterm exam on common mistakes and difficulties in understanding core concepts.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Curiosity	Advanced
Learning Agility	Intermediate
Critical Thinking	Advanced

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned pre-class readings and activities, attend all seminar classes punctually and take all scheduled assignments and tests by due dates. You are expected to take responsibility to follow up with course notes, assignments and course related announcements for seminar sessions they have missed. You are expected to participate in all seminar discussions and activities.

Policy (Absenteeism)

Absence from class without a valid reason will affect your overall course grade. Valid reasons include falling sick supported by a medical certificate and participation in NTU's approved activities supported by an excuse letter from the relevant bodies.

If you miss a lecture, you must inform the course instructor via email prior to the start of the class.

Policy (Others, if applicable)

Last Updated Date: 25-07-2024 06:03:35