Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	AY23/24	**Semester**	1
Course Coordinator	Asst Prof. Zhisong Qu and Assoc Prof. Elbert Chia		
Course Code	PH3103		
Course Title	Technological Applications of Quantum Mechanics		
Pre-requisites	PH2101 Quantum Mechanics 1		
Mutually Exclusive	Nil		
No of AUs	3 AU		
Contact Hours	Lectures: 26 hours; Tutorial: 12 hours		
Proposal Date	14 July 2023		

Course Aims

Quantum Mechanics is the foundation of many areas of physics and countless modern technologies. This course serves as an introduction to three main areas built on modern quantum mechanics: (1) atomic and molecular physics, (2) condensed matter physics and (3) nuclear physics. Students will be exposed to the basic concepts of each subject, supported by ample examples and applications. By the end of the course, students are expected to form a deeper understanding of both the theory of quantum mechanics and how it is connected to real life.

Intended Learning Outcomes (ILO)

By the end of this course, you (as a student) would be able to:

Basic quantum mechanics – a revision of QMI (B):
1. Solve the time-independent Schrodinger equation for the barrier potential.
2. Solve the time-independent Schrodinger equation for the square well potential.
3. Solve the time-independent Schrodinger equation for the hydrogen atom.

Atomic and molecular physics (A):
1. Explain the concept of electron spin and the spin-orbit interaction
2. Compute the split of atomic energy-level split in a magnetic field
3. Explain how electrons occupy their orbits in a many-electron atom
4. Illustrate the principle of lasers and their applications
5. Describe different types of molecular bonding and their properties
6. Identify different mechanisms of forming molecular energy levels
7. Discuss the applications of the molecular spectra

Condensed matter physics (C):
1. Write down the Maxwell-Boltzmann distribution; use it to derive the Maxwell distribution of molecular speeds, and use the Equipartition theorem to write down the average kinetic energy per molecule.
2. Use the Fermi-Dirac, Bose-Einstein and Maxwell-Boltzmann distribution functions, together with the density of states, to calculate average values of quantities such as particle number and energy.
3. Distinguish between ionic and covalent solids
4. Explain the classical theory of conduction
5. Using the free-electron gas in metals, explain the concept of Fermi energy and Fermi temperature, and the quantum theory of conduction.
6. Explain paramagnetism, diamagnetism, ferromagnetism.
7. Use the Kronig-Penny model to derive the band theory of solids.
8. Use the concept of band theory to distinguish between a metal, semiconductor and insulator.

9. Explain impurity semiconductors, and from it the Hall effect.
10. Explain the two properties of superconductors: (a) zero resistivity and (b) Meissner effect.
11. Explain applications of quantum mechanics behind components present in smartphones: (a) CCD camera, (b) transistors, (c) display, etc. Also explain the quantum mechanical principles of (d) scanning tunnelling microscope, (e) semiconductor junction diodes, (f) photovoltaic effect, (g) light-emitting diodes, (h) liquid Helium, (i) superconducting magnets, (j) Superconducting quantum interference device (SQUID), etc. A subset of the abovementioned applications will be discussed.

Nuclear physics (N):

1. Describe the composition of nucleus
2. Explain the concept and binding energy and nuclear stability
3. Discuss the different models of nucleus
4. Explain the principle of Nuclear Magnetic Resonance (NMR) and recognize its applications
5. Describe the concept of radioactivity and summarize different types of decays
6. Illustrate various applications of radioactivity
7. Explain nuclear fission and fusion, as well as the ways to use them as energy sources

Course Content

Basic quantum mechanics (B):

- Time-independent Schrodinger equation for the barrier potential
- Time-independent Schrodinger equation for the square well potential
- Time-independent Schrodinger equation for the hydrogen atom

Atomic and molecular physics (A):

- Electron spin, spin-orbit interaction, and Zeeman effects
- Exclusion principle
- Energy levels of many-electron atom
- Principle of lasers
- Ionic bonding and covalent bonding
- Molecular spectra and its applications

Condensed matter physics (C):

- Classical and quantum statistics
- Bose-Einstein condensation
- Photon gas
- Properties of a fermion gas
- Structure of solids
- Classical theory of conduction
- Free electron gas in metals
- Quantum theory of conduction
- Magnetism in solids
- Band theory of solids
- Impurity semiconductors
- Semiconductor junctions and devices
- Superconductivity

Nuclear physics (N):

- Composition of nucleus and their properties

- Binding energy, nuclear stability, and nuclear models
- Nuclear magnetic resonance and applications
- Radioactivity and applications
- Alpha, beta and gamma decay
- Nuclear fission and fusion, nuclear powerplant concept

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Weighting	Team/Individual	Assessment Rubrics
1. Mid-term Test 1	B, A	15%	Individual	Point-based marking, (not rubric based)
2. Mid-term Test 2	C	15%	Individual	Point-based marking, (not rubric based)
3. Mastering Physics Assignments Online	All	15%	Individual	Point-based marking, (not rubric based)
4. Final examination	All	55%	Individual	Point-based marking, (not rubric based)
Total		100%		

Formative feedback

Formative feedback is given through discussion within tutorial lessons. We will hold TA meeting regularly to discuss the progress and difficulty level of the course.

Feedback will be given after midterm tests to highlight the common mistakes and misunderstandings.

Past exam questions will be made available starting from the second year of offering.

The student can contact the lecturers after class or via email for individual questions and feedbacks.

Learning and Teaching approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Applications will be introduced first to motivate the topic. The fundamental concepts and the theory will then be introduced and discussed. Finally, the concepts are utilized to further explain the application.
Tutorial	Carry out step-by-step derivations of the equations introduced during the lectures. Review and discussion of key concepts from lectures with TAs, by working through problems. The TAs will monitor and provide timely feedback.

Mastering Physics Assignments	The Mastering Physics assignments will consolidate the learning outcomes by providing students with a chance to practice their knowledge.
Mid-term	Mid-term tests are used to motivate and assess your understandings regularly.

Reading and References

1. Tipler, P.A. and Llewellyn, R.A., 2012. *Modern physics*. WH Freeman and Co., ISBN 9781429250788.
2. Blatt, F. J., 1992. *Modern physics*, McGraw-Hill, Inc., ISBN 9780070058774.
3. Eisberg, R. and Resnick, R., 1985. *Quantum physics of atoms, molecules, solids, nuclei, and particles*, ISBN 9780471873730.
4. Beiser, A., 2003. *Concepts of modern physics*, ISBN 9780072448481.
5. More readings on individual topics will be suggested during the lectures.

Course Policies and Student Responsibilities

(1) General

You are expected to complete all assigned pre-class readings and activities, attend all tutorial classes punctually and take all scheduled assignments and tests by due dates. You are expected to participate in all tutorial discussions and activities.

(2) Absenteeism

Absence from the mid-term 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 are sick and unable to attend your class (particularly the mid-terms), you must:

1. Contact the lecturer to schedule an oral make-up exam within two weeks.
2. Submit the Medical Certificate* to administrator.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

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.

Use of Generative Artificial Intelligence (GAI) such as ChatGPT is allowed in the course but students need to adhere to NTU's prevailing guideline. i.e. **Give proper citations if you use any AI tool**. Extending the practice of correctly citing references in your work under NTU's policies on citation and plagiarism, the University requires students to **(i) identify any generative AI tools used** and **(ii) declare how the tools are used in submitted work**. Please note that even with acknowledgement, copying of output generated by AI tools (in part or whole) may still be regarded as plagiarism.

Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructors

Instructor	Office Location	Phone	Email
Assoc Prof Elbert Chia	SPMS-PAP-04-13	65138132	elbertchia@ntu.edu.sg
Asst Prof Zhisong Qu	SPMS-PAP-03-12	63167899	zhisong.qu@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Solution to 1D Schrödinger equation and the Hydrogen atom	**B1-B3**	Book 3, Chapter 6-7
2	Electron spin, Zeeman effect	**A1, A2**	Book 1, Chapter 7 Book 2, Chapter 9 Tutorial Mastering Physics Assignment 1
3	Lasers, many-electron atoms	**A3, A4**	Book 1, Chapter 7 and 9 Book 2, Chapter 9 Tutorial
4	Molecular structure	**A5-A7**	Book 1, Chapter 9 Book 2, Chapter 10 Tutorial Mastering Physics Assignment 2
5	Classical and quantum statistics	**C1**	Book 1, Chapter 8 Tutorial
6	Bose-Einstein condensation, photon gas, fermion gas	**C2**	Book 1, Chapter 8 Tutorial Mastering Physics Assignment 3 Mid-term Test 1
7	Structure of solids, classical theory of conduction, free-electron gas in metals	**C3, C4, C5**	Book 1, Chapter 10 Tutorial
8	Quantum theory of conduction, magnetism in solids, band theory of solids	**C6, C7, C8**	Book 1, Chapter 10 Tutorial Mastering Physics Assignment 4
9	Impurity semiconductors, semiconductor devices, superconductivity.	**C9, C10, C11**	Book 1, Chapter 10 Web articles Tutorial
10	Nuclear composition and properties, models of the nucleus	**N1-N3**	Book 1, Chapter 11 Book 2, Chapter 14 Tutorial Mastering Physics Assignment 5

11	Nuclear spin, nuclear magnetic resonance	**N4**	Book 1, Chapter 11 Book 2, Chapter 14 Tutorial Mid-term Test 2
12	Radioactivity and decay	**N5, N6**	Book 1, Chapter 11 Book 2, Chapter 15 Tutorial Mastering Physics Assignment 6
13	Nuclear reactions	**N7**	Book 1, Chapter 12 Book 2, Chapter 15 Tutorial

The above schedule is provided for illustrative purposes and may be subject to adjustments based on the progress of the course.