Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2021/22	**Semester**	2
Course Coordinator	Assoc. Prof. Rainer Helmut Dumke Research. Prof. Christos Panagopoulos		
Course Code	PH2101		
Course Title	Quantum Mechanics 1		
Pre-requisites	(MH1801 and PH1107) OR (MH1801 and CY1307) OR (MH1802 & MH1803 & PH1107) OR (CY1307, CY1601 & CY1602) OR (MH1101 & MH1200 & PH1107)		
No of AUs	3 AU		
Contact Hours	Lecture: 26 hours (2 hours per week); Tutorial: 12 hours (1 hour per week)		
Proposal Date	18 Sep 2021		

Course Aims

This course aims to introduce major physical phenomena that led to the development of quantum mechanics. Many experiments fundamental to physics will be discussed, along with real-life applications. Moreover, this course also discusses the limitation of old quantum theory and hence the necessity of modern quantum theory, i.e. Schrodinger approach. We will also provide a basic introduction to the matrix formalism to bridge the gap between QM1 and QM2.

Intended Learning Outcomes (ILO)

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

Classical physics and old quantum theory (C):

1. Derive classical Rayleigh-Jeans Law.
2. Use quantization of light energy to derive Planck's spectrum of blackbody radiation.
3. Use Einstein's photon postulate to explain photoelectric effect.
4. Analyse Compton shift and pair production/ annihilation via photon (particle) perspective.
5. Understand wave-particle duality and distinguish between microscopic and macroscopic behaviours of physical objects.
6. Use de Broglie's relation to investigate matter waves.
7. Understand origin and consequences of Heisenberg uncertainty principle.
8. Discuss the various model of atoms (Thomson, Rutherford, Bohr).
9. Discuss the limitations of old quantum theory.

Modern Quantum Theory (M):

10. Understand the interpretation of wave functions as states, and Hermitian operators as physical measurements in quantum mechanics.
11. Understand the probabilistic interpretation associated with linear superpositions of wave functions.
12. Be able to compute the expectation and variance of physical measurements, from the wave function of a system.
13. Solve the eigenvalue problem given by the time-independent Schrodinger equation for the given potential function.
14. Understand the solution of the harmonic oscillator.
15. Understand the solution of hydrogen atom.
16. Understand the concept and consequence of "spin" via Stern-Gerlach experiment.
17. Analyse the spin-orbit interaction and the hydrogen energy levels.
18. Understand Dirac notation of quantum mechanics.
19. Perform matrices and vectors operations in quantum mechanics, eg: normalization of vectors, calculation of eigenvalues and eigenvectors.
20. Understand the matrix formalism of quantum mechanics and how it is related to wavefunction approach of quantum mechanics.

Course Content

Classical physics and old quantum theory:

- Classical Rayleigh-Jeans Law of blackbody radiation
- Planck's spectrum of blackbody radiation
- Photoelectric effect
- Compton shift and pair production/ annihilation
- Wave-particle duality
- De Broglie's relation of matter waves
- Heisenberg uncertainty principle
- Various model of atoms (Thomson, Rutherford, Bohr)
- Limitations of old quantum theory

Modern Quantum Theory:

- Wavefunction
- Expectation, variance, and probability of measured physical outcomes
- Schrodinger equation
- Solution of Harmonic Oscillator
- Solution of hydrogen atom
- Orbital magnetic dipole moment
- Stern-Gerlach experiment
- Spin
- Spin-orbit interaction and the hydrogen energy levels
- Dirac notation of quantum mechanics
- Matrix formalism and wave formalism of quantum mechanics

Assessment (includes both continuous and summative assessment)

Component	**Course LO Tested**	**Related Programme LO or Graduate Attributes**	**Weighting**	**Team / Individual**	**Assessment Rubrics**
1. Final Examination	All	Competency 1,2,3,4,5 Creativity 1,2 Communication 1	50%	Individual	Point-based marking, Open-ended marking scheme*
2. CA1: Assignment 1	Range (1-14)	Competency 1,2,3,4,5 Creativity 1,2 Communication 1,3	10%	Individual	Point-based marking, Open-ended marking scheme*
3. CA2: Assignment 2	Range (1-14)	Competency 1,2,3,4,5 Creativity 1,2 Communication 1,3	10%	Individual	Point-based marking, Open-ended marking scheme*
4. CA3: Mid-term Test	Range (3-14)	Competency 1,2,3,4,5 Creativity 1,2 Communication 1	30%	Individual	Point-based marking,

Total	100%	

*You would be expected to synthesise the physics concepts learnt in the course to propose scientifically valid approaches to given situations or problems.

Formative feedback

Formative feedback is given through discussion within tutorial lessons.
Formative feedback is given via the student response application Wooclap where you are required to answer on your mobile devices questions posted during lecture/tutorial.
Feedback will be provided in case students have a serious misconception on a provided problem.
Feedback is also given after each midterm on the common mistakes and level of difficulty of the problems.
Past exam questions are made available for you via the library, but the solutions will not be provided.

Learning and Teaching approach

Approach	**How does this approach support students in achieving the learning outcomes?**
Use of Wooclap (lecture)	It is used to set you out of your comfort zone, to stimulate your thinking and compare your understanding with others.
Lectures	Warm-up questions will be raised first, followed by lectures that further explain the physics based on the questions. Then wrap-up questions will also be provided.
Tutorial	You will review main concepts learned in lectures with TAs. This helps you to digest and understand better.
Homework	The homework comprises more difficult problems that may require more time to solve.

Reading and References

1. Eisberg, R.M., & Resnick, R. (1985). “Quantum physics of atoms, molecules, solids, nuclei, and particles (2nd ed.)”Wiley. ISBN 978-0471873730
2. J.J. Sakurai, Jim Napolitano (2011), “Modern Quantum Mechanics (2nd ed.)”, Addison-Wesley, U.S.A. ISBN 978-0201539295

Course Policies and Student Responsibilities

Students are strongly advised to attend tutorials and lectures. Announcements made during the lectures/tutorials may not be repeated on NTU learn or other channels.

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class.
2. Submit the original Medical Certificate* or official letter of excuse to administrator.
3. Attend the assigned replacement class (*subject to availability*).

If you are sick and unable to attend your midterm test, it is your responsibility to arrange with the instructor for an oral make-up test within two weeks of the midterm test.

* 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. 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. Rainer Helmut Dumke	SPMS-PAP-04-15	+65 6316 2969	rdumke@ntu.edu.sg
Research.Prof. Christos Panagopoulos	SPMS-PAP-04-11	+65 6513 7412	christos@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Blackbody radiation	Which evidence requires quantum mechanics? **(C1-C2)**	Book 1, Sec.1.1-1.4 Wooclap Questions
2	Photoelectric effect, Compton shift	Light has particle properties **(C3-C4)**	Book 1, Sec.1.5 & Sec 2.1-2.4 Wooclap Questions Tutorial 1
3	X-Ray, Pair production/Annihilation	More particle behaviors of light **(C4-C5)**	Book 1, Sec 2.5-2.7 Wooclap Questions Tutorial 2
4	Matter wave, Uncertainty principle	Matter has wave properties Origin and consequence of uncertainty principle **(C6-C7)**	Book 1, Sec.3.1-3.5 Wooclap Questions Tutorial 3
5	Atom Model	Various model of atom **(C8-C9)**	Book 1, Sec.4.1-4.7 Wooclap Questions Tutorial 4

6	Atom Model & Schrodinger Equation	Various model of atom and Schrodinger equation **(C8-C9, M10)**	Book 1, Sec. 4.8-4.12 & 5.1-5.3 Wooclap Questions Tutorial 5
7	Schrodinger Equation	Calculate various quantum physical quantities of some systems**(M10-M11)**	Book 1, Sec.5.4-5.8 Wooclap Questions Homework 1 Tutorial 6
8	Recess week		
9	Schrodinger Equation (Potential Problem)	Solving the eigenfunction problem in various potentials **(M12)**	Book 1, Sec. 6.1-6.8 Midterm Test 1 Wooclap Questions Tutorial 7
10	Harmonic Oscillator atom	Solving the eigenfunction problem for the harmonic oscillator **(M12)**	Book 1, Sec. 6.8-6.9 Wooclap Questions Tutorial 8
11	Hydrogen atom	Solving the eigenfunction problem in various potentials; Understand solution of hydrogen atom **(M12-M13)**	Book 1, Sec. 7.1-7.8 Wooclap Questions Tutorial 9
12	Stern-Gerlach Experiment, Spin	Understand “spin” and total angular momentum **(M14-M15)**	Book 1, Sec.8.1-8.6 Wooclap Questions Tutorial 10
13	Dirac notation	Understand Dirac Notation of quantum mechanics **(M16-M17)**	Book 2, Sec.1.1-1.2 Wooclap Questions Tutorial 11
14	Matrix operations	Perform matrix/vector operations to solve quantum problems **(M17)**	Book 2, Sec.1.2-1.3 Wooclap Questions Tutorial 12

Graduate Attributes
What we want our graduates from Physics and Applied Physics to be able to do:

Upon the successful completion of the PHY, APHYPHMA, PHME and PHMS programs, graduates should be able to:

Competency	1	demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics [PHMA only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis
	2	read and understand undergraduate level physics content independently;
	3	make educated guesses / estimations of physical quantities in general;
	4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.

Creativity	1	propose valid approaches to tackle open-ended problems in unexplored domains;
	2	

		offer valid alternative perspectives/approaches to a given situation or problem.

Communication	1	describe physical phenomena with scientifically sound principles;
	2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	3	communicate effectively with team members when working in a group.

Character	1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	3	contribute as a valued team member when working in a group.

Civic Mindedness	1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.