Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2020/21	**Semester**	2
Course Coordinator	Asst. Prof. Tomasz Paterek		
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	17 March 2020		

Course Aims

The overarching aim of the course is to enable you to predict outcomes of simple quantum experiments and to provide working knowledge necessary for more advanced topics in quantum physics. We will gradually develop formalism of quantum mechanics in terms of matrices and wave functions. Many experiments fundamental to physics will be discussed on the way as well as real-life applications.

Intended Learning Outcomes (ILO)

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

Review (R) :

1. discuss experimental results related to quantum mechanics (such as blackbody radiation, photoelectric effect, spectral lines, Compton scattering, matter waves.)
2. discuss existence of spin and cite examples of its occurrence and applications.

Spin ½ and Formalism (SnF) :

3. analyse simple experiments involving spin ½ particles.
4. use Bloch vector to solve problems involving two level system.
5. use Dirac notation to solve problems in quantum mechanics.
6. perform matrices and vectors operations in quantum mechanics (such as normalization of vectors, calculation of eigenvalues and eigenvectors, determining whether a matrix is Hermitian or Unitary and calculation of trace).
7. analyse the possible outcomes of the measurements in quantum systems (such as determining expectation values and variances).
8. distinguish between pure and mixed states and determine various quantum mechanical quantities (such as probabilities, expectation values and variances given a mixed state.)
9. analyse the time evolution of quantum states.
10. discuss the postulates of quantum mechanics and their applications.

Wave mechanics (WM) :

11. derive quantum states and operators in position and momentum representation.
12. analyse the behaviour of a quantum particle in a region of space and momentum given its wave function.
13. verify that uncertainty relations hold.
14. analyse and solve 1d quantum dynamics (such as free particle, harmonic oscillator and potential well).

Course Content

Review (R)
- History of QM

Spin ½ and Formalism (SnF)
- Matrix and vector operations
- Stern Gerlach experiment and its Mathematisation (matrix representation of simple apparatus in Stern Gerlach set up, etc).
- Born rule in the context of spin ½ or two level system.
- Quantum Zeno effect and interaction free measurement.
- Dirac notation (bra-ket)
- Representation of operator and vector with respect to a given basis.
- Observables, pure, mixed states, and density matrix.
- Quantum statistics (Born's rule, expectation value) for pure and mixed state.
- Bloch vector of a two level system.
- Properties of a Hermitian operator.
- Quantum formalism (discrete and continuous measurement outcomes).
- Robertson uncertainty relation
- Time evolution of a quantum system (Schrodinger equation)

Wave mechanics (WM)
- Position, and momentum operator.
- Wave function in position and momentum representation
- Expectation of position, momentum operator.
- Quantum harmonic oscillator, annihilation, creation operator, and coherent state.
- Infinite square well, and free particle.

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: Homework	Range (1-14)	Competency 1,2,3,4,5 Creativity 1,2 Communication 1,3	20%	Team	Point-based marking, Open-ended marking scheme*
3. CA2: Mid-term Test 1	Range (3-8)	Competency 1,2,3,4,5 Creativity 1,2 Communication 1	15%	Individual	Point-based marking, Open-ended marking scheme*
4. CA3: Mid-term Test 2	Range (3-14)	Competency 1,2,3,4,5 Creativity 1,2 Communication	15%	Individual	Point-based marking,

		1			Open-ended marking scheme*
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 Learning Catalytics where you are required to answer on your mobile devices questions posted during lecture/tutorial.
Feedback is always provided for your response to each question.
Feedback is also given after each midterm on the common mistakes and level of difficulty of the problems. Past exam questions and examiner's report are made available for you.

Learning and Teaching approach

Approach	**How does this approach support students in achieving the learning outcomes?**
Use of Learning Catalytics (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 require more time as well as computational problems that have to be solved using computers. It is also expected that solutions are prepared using computers.

Reading and References

1. B.-G. Englert "Lectures on Quantum Mechanics: Basic Matters", World Scientific 2006. ISBN-13: 978-9812569707

2. B. H. Bransden, C. J. Joachain "Quantum Mechanics", Pearson Education Limited 2000. ISBN-13: 9780582356917

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class / Mid-terms, you have to:

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

* 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
Asst. Prof. Tomasz Paterek	SPMS-PAP-04-08	+65 6592 1843	tomasz.paterek@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	History of Quantum Mechanics	Which evidence requires quantum mechanics? (**R**1)	Book 2, Chapter 1. Videos, Learning Catalytics (LC), Demos, Problems to be solved during the lecture (P)
2	Stern-Gerlach experiment	Physical motivation for quantum formalism (R2,SnF3,6)	Book 1, Sec. 2.1-2.14 Book 2, Sec. 1.5 LC, P
3	Born rule	Quantum mechanics gives statistical predictions (SnF3,6,7)	Book 1, Sec. 2.4-2.5 P, LC
4	Quantum Zeno effect	Measurement typically disturbs measured object (SnF3,6,7)	Book 1, Sec. 2.6 P, LC, Demo

5	Quantum statistics	Tools to calculate statistics of measurement results obtained in quantum experiments (SnF4-8)	Book 1, Sec. 2.7-2.15 LC, P
6	Quantum statistics	Tools to calculate statistics of measurement results obtained in quantum experiments (SnF4-8)	Book 1, Sec. 2.7-2.15 LC, P
7	Topics in Week 1-5	Review and practice of problem-solving skills.	Midterm Test 1
8	Recess week		
9	Multilevel systems	General quantum formalism (SnF6,7,10, WM11,12)	Book 1, Sec. 2.20-2.22 and 4.1-4.6 P, LC
10	Uncertainty relations	Observables that cannot be measured simultaneously and applications (WM12,13)	Book 1, Sec. 4.7 Book 2, Sec. 2.5 and 5.4 P, Video
11	Schrodinger equation	Time evolution of a quantum system (SnF9)	Book 2, Sec. 3.1,3.2,3.4,3.5,3.7,3.8 Notes with derivations, P, LC
12	Topics in Week 1-10, with increased weightage on Week 6-10 content.	Review and practice of problem-solving skills.	Midterm Test 2
13	Quantum dynamics	Quantum harmonic oscillator (WM14)	Book 1, Sec. 5.3 Book 2, Sec. 4.7 LC, P, Mathematica illustrations
14	Quantum dynamics	Free particle, potential wells (WM14)	Book 1, Sec. 5.1, 5.5 Book 2, Sec. 4.2, 4.5, 4.6 P, Mathematica illustrations

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

Upon the successful completion of the PHY, APHY and PHMA 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.