Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2019/20	**Semester**	1
Course Coordinator	Dr. Leek Meng Lee		
Course Code	PH3101		
Course Title	Quantum Mechanics II		
Pre-requisites	PH2101 and MH2801		
No of AUs	4 AU		
Contact Hours	3 hr – lecture 1 hr – tutorial		
Proposal Date	21 January 2019		

Course Aims

Most introductory courses or books in QM start off with special systems (for example infinite square well) and derive its wave function in position representation from the Schrodinger's equation. Although this approach may be intuitive due to its physical setup, it tends to give the wrong impression that wave functions are fundamental objects in QM. In actual fact, wave functions are just the different representations of the state (ket in Dirac notation) of the system. One can always choose other representations or even not choose a representation.

This course aims to unteach wave mechanics and free you of particular representations and work with the formalism directly. You will explore the logical development of Quantum Mechanics (QM) formalism and develop QM systematically from finite to infinite dimensions in three parts.

Part 1 aims to give a complete and systematic run-down of basic quantum kinematics and quantum dynamics so that you have a working understanding of quantum mechanics for finite-dimensional and infinite dimensional systems. The concept of measurement will also be covered. This provides probabilistic results for experiments.

Part 2 aims to discuss symmetry within QM. Rotational symmetry (angular momentum is the generator of rotations) is the main and very important example. The rotational symmetry in Hydrogenic atoms will also be discussed, which will also introduce you to 3D QM.

Part 3 adds on to the formalism for systems that cannot be solved exactly. These are real-life QM examples and the standard method to solve these systems is via perturbation for time-independent/dependent and non-degenerate/degenerate systems.

Intended Learning Outcomes (ILO)

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

Part 1: Basic Formalism – Kinematics and Dynamics

1. Apply kinematical formalism of quantum mechanics to analyse quantum systems with discrete and continuous eigenvalues and eigenstates.
2. Apply dynamical formalism of quantum mechanics using either Schrodinger, Heisenberg or Interaction picture to determine the time evolution of a quantum operator or state.
3. Demonstrate correspondence between classical mechanics and quantum mechanics in simple examples.

Part 2: More Formalism – Symmetry, Angular Momenta and 3D QM

4. Identify symmetries in a quantum system via calculating certain commutation relations.
5. Perform orbital angular momentum algebra either in position representation (spherical harmonics) or in matrix representation.
6. Perform spin angular momentum algebra in matrix representation.
7. Generalise and perform operator algebra for general angular momentum.
8. Perform addition of angular momentum for orbital, spin and general angular momentum.
9. Solve separable 3D QM problems (such as Hydrogenic atom).

Part 3: Even More Formalism – Perturbation Theory

10. Apply Hellmann-Feynman theorem to simple systems.
11. Apply variational principle to estimate the energy of a ground state of a system.
12. Calculate 1st and 2nd order corrections to energy and states for time-independent Hamiltonians (including non-degenerate and degenerate unperturbed states).
13. Solve problems using the basic ideas of WKB approximation.
14. Calculate transition rates for 1st order time-dependent perturbation.

Course Content

Part 1: Basic Formalism – Kinematics and Dynamics (BF)

1. Recalling some formalism from mathematizing the educational Stern-Gerlach example.
2. Continuing with formalism: From 2 outcomes (eigenvalues) to N eigenvalues.
3. Continuing with formalism: From discrete N eigenvalues to continuous eigenvalues.
4. Quantum-Classical Correspondence.
5. Overall summary of formalism.
6. Simple examples.
7. Closing to Part 1 and some literature.

Not examinable:
A. Things to ponder: Interpretation of QM
B. Accidentally discovering another interpretation of QM
C. Geometrical aspect of Quantum Mechanics

Part 2: More Formalism – Symmetry, Angular Momenta and 3D QM (MF)

1. How to talk about symmetry in Quantum Mechanics?
2. Rotational symmetry: Orbital angular momentum $\vec{L}$.
3. Spin angular momentum $\vec{S}$.
4. Generic angular momentum $\vec{J}$.
5. Addition of angular momentum.
6. 3D QM Example: Hydrogen atom.

A. Separation of Variables: The multi-variable calculus way.
B. Hydrogenic atoms: More details.
C. Collection of special functions.

Part 3: Even More Formalism – Perturbation Theory (EMF)

1. Warm-up ideas.
2. Rayleigh-Ritz Variational Principle.
3. Time-independent perturbation theories.
4. Basic discussion on WKB approximation.
5. Time dependent perturbation theory.

A. Variation of operator exponential function and beta function.
B. More advanced discussion on WKB approximation (not examinable)

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	Competence 1,2,3,4,5 Communication	60%	Individual	Point-based marking

		1			
2. CA1: Online Assessment	All	Competence 1,2,3,4,5 Communication 1	10%	Individual	Point-based marking
3. CA2: Homework	All	Competence 1,2,3,4,5 Communication 1	10%	Individual	Point-based marking
4. CA3: Mid-term Test 1	Range 1-3	Competence 1,2,4,5 Communication 1	10%	Individual	Point-based marking
5. CA4: Mid-term Test 2	Range 4-9	Competence 1,2,3,4,5 Communication 1	10%	Individual	Point-based marking
Total			100%		

Formative feedback

Formative feedback is given through discussion within tutorial lessons as well as interactive, computer based hints and pointers in the Mastering Physics online assignment and resource system.

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 (tutorial and lecture)	You are able to get on-the-spot checking of your understanding of concepts.
Lectures	Reviews of previous materials will be done first. The emphasis is on laying out the logic and the present material will follow on with the logical flow. Some conceptual questions will be interspersed during the lectures.
Tutorial	TAs will review the logical flow and concepts. Then simple questions will be discussed first, leading to longer, tougher questions.
Homework	Comprises of simple questions to check foundations and tougher questions to see if you can synthesize concepts together.

Reading and References

1. Berthold-Georg Englert, Volumes 1,2 and 3 - Lectures on Quantum Mechanics ISBN-13: 978-9812569714
2. B.H. Bransden & C.J. Joachain - Quantum Mechanics (Second Edition) ISBN-13: 978-0582356917
3. Nouredine Zettilli - Quantum Mechanics : Concepts and Applications (Second Edition) ISBN: 978-0-470-02679-3

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
Dr Leek Meng Lee	SPMS-PAP-05-01a	(+65)65927810	MLEEK@NTU.EDU.SG

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Part 1: Basic Formalism – Kinematics and Dynamics	1. Apply kinematical formalism of quantum mechanics to analyse quantum systems with discrete and continuous eigenvalues and eigenstates. The analysis includes casting the states into different representations (such as matrix representation, or position/momentum representations), computing measurement probabilities and expectation values.	Textbook and lecture notes, videos

2	Part 1: Basic Formalism – Kinematics and Dynamics	1. Apply dynamical formalism of quantum mechanics using either Schrodinger, Heisenberg or Interaction picture to determine the time evolution of a quantum operator or state.”	
3	Part 1: Basic Formalism – Kinematics and Dynamics	2. Demonstrate correspondence between classical mechanics and quantum mechanics in simple examples.	
4	Part 2: More Formalism – Symmetry, Angular Momenta & 3D QM	3. identify symmetries in a quantum system via calculating certain commutation relations.	Midterm Test 1
5	Part 2: More Formalism – Symmetry, Angular Momenta & 3D QM	4. perform orbital angular momentum algebra either in position representation (spherical harmonics) or in matrix representation.	
6	Part 2: More Formalism – Symmetry, Angular Momenta & 3D QM	5. perform spin angular momentum algebra in matrix representation.	
7	Part 2: More Formalism – Symmetry, Angular Momenta & 3D QM	6. generalise and perform operator algebra for general angular momentum.	
8	Part 2: More Formalism – Symmetry, Angular Momenta & 3D QM	7. perform addition of angular momentum for orbital, spin and general angular momentum.	
9	Part 3: Even More Formalism – Perturbation Theory	8. solve separable 3D QM problems (such as Hydrogenic atom).	Midterm Test 2
10	Part 3: Even More Formalism – Perturbation Theory	9. apply Hellmann-Feynman theorem to simple systems.	
11	Part 3: Even More Formalism – Perturbation Theory	10. apply variational principle to estimate the energy of a ground state of a system.	
12	Part 3: Even More Formalism – Perturbation Theory	11. calculate 1st and 2nd order corrections to energy and states for time-independent Hamiltonians (including non-degenerate and degenerate unperturbed states).	
13	Part 3: Even More Formalism – Perturbation Theory	12. solve problems using the basic ideas of WKB approximation. 13. calculate transition rates for 1st order time-dependent perturbation.	

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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.