Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

The sections shown on this interface are based on the templates UG OBTL+ or PG OBTL+
If you are revising/duplicating an existing course and do not see the pre-filled contents you expect in the subsequent sections e.g. Course Aims, Intended Learning Outcomes etc. please refer to Data Transformation Status for more information.

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 2
Course Author * Faculty proposing/revising the course	Koh Teck Seng
Course Author Email	kohteckseng@ntu.edu.sg
Course Title	Open Quantum Systems
Course Code	PH3406
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	PH3101 Quantum Mechanics II
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course aims to introduce basic formalism and interpretation of decoherence of open quantum systems, so that you have a more complete understanding of the philosophical, mathematical and experimental foundations of quantum mechanical phenomena. It applies the mathematical formalisms to describe contemporary experiments in quantum computing, and explores the role decoherence plays in interpretations of quantum mechanics.

Course's Intended Learning Outcomes (ILOs)

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

ILO 1	Explain the concepts of entanglement, composite systems, and density matrices, and make use of their mathematical definitions.
ILO 2	Derive and apply the interaction picture formalism to time-dependent quantum systems.
ILO 3	Derive and apply the Lindblad master equation to simple Markovian open systems.
ILO 4	Apply the concepts of decoherence, relaxation and dephasing to simple quantum systems, and calculate their Markovian dynamics.
ILO 5	Apply the formalism of open systems to canonical models of open systems, such as the spin-boson model and the collisional model.
ILO 6	Apply the formalism of linear dynamical maps to describe the evolution of open quantum systems.
ILO 7	Explain and reconcile the approaches from physical arguments and linear maps with the Kraus representation theorem.
ILO 8	Describe standard interpretations of quantum mechanics, implications and paradoxes.
ILO 9	Explain and justify how concepts and implications of decoherence may resolve some paradoxes, and identify their limitations.

Course Content

(I) Standard Quantum Mechanics (closed systems)
I.1 Recap of standard quantum mechanics (PH3101)
I.2 Interaction picture formalism
I.3 Density matrix formalism
I.4 Von-Neumann equation

(II) Formalisms of Open Quantum Systems
II.1 Composite and reduced systems
II.2 System-environment interaction
II.3 Lindblad master equation
II.4 Linear maps and Kraus representation theorem

(III) Models of decoherence and applications
III.1 Collisional model
III.2 Spin-boson model

(IV) Philosophy and quantum foundations
IV.1 Decoherence and quantum-to-classical transition

Reading and References (if applicable)

There is no compulsory reference text. Apart from lecture notes provided, good reference materials are available through NTU Library or as open-source material on the internet. They are:

Open quantum systems

1. Maximilian Schlosshauer, Decoherence and the quantum-to-classical transition, Springer (2007). Available from NTU Library (ebook). Permalink: https://ntu-sp.primo.exlibrisgroup.com/permalink/65NTU_INST/3es15n/alma991016542604305146

2. Maximilian Schlosshauer, *Decoherence, the measurement problem, and interpretations of quantum mechanics,* Rev. Mod. Phys. 76, 1267 (2005). doi:10.1103/RevModPhys.76.1267 https://link.aps.org/doi/10.1103/RevModPhys.76.1267

3. Daniel Lidar, *Lecture notes on the theory of open quantum systems,* arXiv:1902.00967 https://arxiv.org/abs/1902.00967v2

4. H-P Breuer and F Petruccionne, The theory of open quantum systems, Oxford University Press (2002). Available from NTU Library (hardcopy). Permalink: https://ntu-sp.primo.exlibrisgroup.com/permalink/65NTU_INST/12u36pr/alma991012784779705146

Quantum computation and quantum error correction

4. Michael A. Nielsen and Isaac Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2010). Available from NTU Library (ebook). Permalink: https://ntu-sp.primo.exlibrisgroup.com/permalink/65NTU_INST/3es15n/alma991016374261205146

NOTE: The above readings comprise the foundational readings for the course and more up-to-date relevant readings will be provided when they are available.

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Standard quantum mechanics, interaction picture	1—2		In-person	
2	Von-Neumann equation	1—2		In-person	
3	Composite systems	1—2		In-person	
4	Composite systems	1—2		In-person	Homework due
5	Decoherence and quantum foundations	8, 9		In-person	
6	Dynamical maps	4, 6		In-person	
7	Dynamical maps and Kraus representation theorem	4, 6		In-person	Midterm 1
8	Master equation	3—5, 7		In-person	
9	Master equation	3—5, 7		In-person	
10	Models of decoherence	4—5		In-person	Midterm 2
11	Models of decoherence	4—5		In-person	
12	Models of decoherence	4—5		In-person	Homework due
13	Project Presentations	All		In-person	Individual presentations

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Pre-lecture readings will be assigned, in partial flip-classroom approach. Face-to-face lectures in small class sizes for direct interaction and feedback.
Tutorials	Pre-tutorial problems will be assigned, for student preparation before class. Tutorials will have a focus on student-centred learning.
Project	Inquiry approach to project work.

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	Continuous Assessment (CA): Assignment(Homework sets)	1--8		20	Individual	Analytic	Relational
2	Continuous Assessment (CA): Test/Quiz(Midterm Tests)	1--8		20	Individual	Analytic	Extended Abstract
3	Continuous Assessment (CA): Project(Project)	All		20	Individual	Holistic	Extended Abstract
4	Summative Assessment (EXAM): Final exam(Final Examination)	All		40	Individual	Analytic	Extended Abstract

Description of Assessment Components (if applicable)

See Appendix.

Formative Feedback

You will be given feedback in four ways:
1. By working through examples provided during lectures
2. By response to postings on the course discussion board
3. By attending consultation hours
4. By studying the comments provided by the instructors after the grading of homework, midterm, and project

NTU Graduate Attributes/Competency Mapping

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

Attributes/Competency	Level
Communication	Intermediate
Curiosity	Intermediate
Information Literacy	Intermediate
Critical Thinking	Advanced
Systems Thinking	Basic

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 tutorial classes punctually and take all scheduled assignments and tests by due dates. You are expected to participate in all tutorial discussions and activities.

Policy (Absenteeism)

Absence from the midterm test 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. There will be no make-up opportunities for CA components.

All project assignments must be submitted on time. Failure to do so will affect your score.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;
If you feel like your performance in the class is being impacted by your experiences outside of class;
If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;
Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email) about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.

Appendix: Rubrics for Project (20%)

Oral Presentation (Assessed Individually) – 10%

Criteria	Unsatisfactory (1)	Satisfactory (2)	Good (3)	Exemplary (4)
Presentation Skills: (a) Organization (25%)	Inadequate content, with some links across slides. Takeaways are either unclear or contain some ambiguity.	Adequate content with across slides. Key takeaways for some slides clear. Citations are given, but with missing references.	Relevant content, mostly linked coherently across slides. Key takeaways for most slides are clear. Citations are appropriate and in consistent format.	Relevant content are linked coherently across slides. Key takeaways for each slide are clear. Citations are appropriate and in consistent format.
Presentation Skills: (b) Delivery & Timing (25%)	Unclear and unengaging. Grossly under or over-estimate presentation time.	Mostly clear and understandable. Kept to allocated presentation time.	Clear and well prepared. Kept to allocated presentation time. Reasonable emphasis on own contribution	Engaging, clear and well prepared. Kept to allocated presentation time with emphasis on own contribution.
Q&A: (a) Subject Knowledge (25%)	Does not display adequate knowledge of the subject matter.	Displays some knowledge of the subject matter.	Displays good knowledge of the subject matter.	Displays comprehensive and deep knowledge of the subject matter.
Q&A: (b) Ability to Explain Answers (25%)	Unable to understand and answer questions.	Able to understand and answer some questions.	Able to understand and answer most questions.	Able to understand and answer all questions and also provide relevant information.

Written Report (Assessed Individually) – 10%

Criteria	Unsatisfactory (1)	Satisfactory (2)	Good (3)	Exemplary (4)
Organization and Clarity (25%)	Organization has inadequate connection between ideas. Writing is mostly unclear or inaccurate. Word limit not kept.	Organization displays some logical and coherent connection of ideas. Writing is mostly clear and accurate, with many errors. Word limit kept.	Organization displays mostly logical and coherent connection of ideas. Writing is mostly clear and accurate, with some errors. Word limit kept.	Organization displays logical and coherent connection of ideas. Writing is clear and accurate, with no errors. Word limit kept.
Literature Review (25%)	Unclear state of the sub-field. Reviews contain some inappropriate sources. Inadequate background or motivation.	Communicates state of sub-field. Reviews some appropriate sources. Gives some background and/or motivation.	Clearly communicates state of sub-field. Reviews appropriate sources. Gives some background and/or motivation.	Clearly and accurately communicates state of sub-field. Reviews appropriate and up-to-date sources. Gives comprehensive background and motivation.
Application of Physics (50%)	Incorrect or inappropriate use of physical theories in the modeling of problem. Inadequate explanation of methodology, assumptions, approximations or computational techniques.	Correct and appropriate use of physical theories in the modeling of problem. Some aspects of methodology, assumptions, approximations and computational	Correct and appropriate use of physical theories in the modeling of problem. Methodology, assumptions, approximations and computational techniques mostly clearly explained.	Correct and appropriate use of physical theories in the modeling of problem. Methodology, assumptions, approximations and computational techniques clearly and

		techniques missing or lacking in detail.		comprehensively explained.