Course Requisites (if applicable)

Pre-requisites	For graduate students: No pre-requisites For undergraduates: PH3404 Physics of Classical & Quantum Information or MH2500 Probability & Introduction to Statistics), and PHY (PPHY) or PHY (APHY) programme and CGPA 4.0 or higher
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course aims to equip you with the central theoretical framework and tools which are paramount to understanding the advantage brought by quantum information processing and some experimental basics of realizing these technologies. You will learn a comprehensive overview of central topics of interest in active research areas. These skills are critical for you who are aiming at a career in quantum information technologies.

Course's Intended Learning Outcomes (ILOs)

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

ILO 1	Demonstrate an understanding of the structure and properties of objects in quantum information (classical random variables and channels, density matrices, quantum processes) and interpret the physical meaning behind these objects.
ILO 2	Translate a preparation procedure into typical multipartite density matrices such as classical-quantum states.
ILO 3	Compute probabilities corresponding to the output of a quantum measurement after a series of entangling quantum gates.
ILO 4	Identify the techniques that allow for a proof of quantum advantage in quantum cryptography
ILO 5	Distinguish between problems in different computational complexity classes
ILO 6	Derive the speedup in basic quantum algorithms

Course Content

1) Theory Classical random variables, entropic quantities, and properties, basic overview of channel coding theorems Quantum information formalism: states, unitaries and quantum circuit model Entropic measures and uncertainty relations, no-go theorem Computational and query complexity classes in quantum computing Quantum cryptography: QKD Unit quantum protocols: superdense coding & teleportation Quantum states (density matrices) and channels (CPTPMs, CJ isomorphism, Kraus theorem, main studied examples) Distance measures (distance norms, fidelity variants) elementary quantum algorithms: Quantum Fourier Transform, Grover's algorithm, phase estimation, overview of modern algorithms Classical and quantum typicality, quantum versions of coding theorems 2) Experiment Ultracold atoms: Atomic Qubits / Qubit realization / Rydberg Interaction / Optical lattices / Atom arrays / Ion Traps / trapping Superconducting Quantum Electronics: Circuit realization of qubits (various flavours) Characterization (T1 / T2) Various physical realization single and two qubit gates / benchmarking Readout strategies / State Tomography Implementation of algorithms Noise and other challenges 3) Research seminars Quantum linear optics / continuous variable quantum information Quantum metrology and sensing Quantum simulators Quantum resource theories

Reading and References (if applicable)

1. Quantum Computation and quantum information, M. Nielsen and I. Chuang, Cambridge University Press (2010). ISBN: 978-1107002173 2. Quantum Information Theory, Mark Wilde, Cambridge University Press (2017) ISBN: 978-1107176164 3. Learning quantum computation using Qiskit, online textbook, Qiskit (No ISBN Number, online resource)

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Classical information theory	1a	Textbook, lecture notes, videos		
2	Pure quantum states and properties	1b	Textbook, lecture notes, videos		
3	Limits of quantum information	1c, 1d, 1e	Textbook, lecture notes, videos		
4	Density matrices, Quantum channels	1g	Textbook, lecture notes, videos		
5	Quantum communication protocols, Quantum channels, Experimental quantum information: cold atoms Quiz 1	1f, 2a, 2c	Textbook, lecture notes, videos		
6	Quantum Fourier Transform, Experimental quantum information: superconducting qubits	2b, 2c	Guest lecture, textbook, lecture notes		
7	Phase estimation, Application in Shor's algorithm	1i	Textbook, lecture notes, videos		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
8	Grover's algorithm, Closeness measures	1i, 1h	Textbook, lecture notes, videos		
9	Classical and quantum typicality, Quantum versions of data compression, Channel capacity theorems	1j			
10	Continuous variable quantum information, Quantum metrology and sensing	3a, 3b	Guest lecture/ research seminar given by instructor		
11	Quantum simulation, Resource theories	3c, 3d	Guest lecture/ research seminar given by instructor		
12	Student presentations Quiz 2	N.A.	Student presentations, lecture notes		
13	Student presentations Concluding remarks	N.A.	Student presentations, lecture notes		

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Lectures provide the necessary content and practice of problem solving and discussion of conceptual understanding.
Tutorial	The students review and discuss main concepts learned in lectures by working through problems.
Homework	The homework comprises practice questions that are covered during tutorials, allowing for formative assessment and feedback.
Project	Students read a milestone paper in the field of quantum information and present it to their peers.

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): Test/Quiz(test 1)	All		20	Individual	Analytic	Not Applicable
2	Continuous Assessment (CA): Test/Quiz(test 2)	All		20	Individual	Analytic	Not Applicable
3	Continuous Assessment (CA): Assignment(assignments (e.g. term paper, essay) CA - Homework)	All		25	Individual	Analytic	Not Applicable
4	Continuous Assessment (CA): Presentation(presentations)	All		35	Individual	Holistic	Not Applicable

Description of Assessment Components (if applicable)

Formative Feedback

Formative feedback is given weekly through assignments marking and tutorial classes. During the tutorial hours, the instructor discusses the progress, pace, and difficulty level of lectures.

NTU Graduate Attributes/Competency Mapping

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

Attributes/Competency	Level
Learning Agility	Intermediate
Problem Solving	Intermediate
Transdisciplinarity	Intermediate
Critical Thinking	Intermediate
Embrace Challenge	Intermediate

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)

Policy (Absenteeism)

If you are sick and unable to attend class, you must:

1. Inform the course instructor via email prior to the start of the class,

2. Submit the original Medical Certificate* or official letter of excuse to NTU portal,

3. Attend the assigned replacement class (subject to availability).

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

Policy (Others, if applicable)

Last Updated Date: 23-01-2025 07:55:16