City University of Hong Kong
Course Syllabus

offered by Department of Physics
with effect from Semester A 2024/25

Part I Course Overview

Course Title:	**Introduction to Quantum Information**
Course Code:	**PHY6603**
Course Duration:	**One semester**
Credit Units:	**3 credits**
Level:	**P6**
Medium of Instruction:	**English**
Medium of Assessment:	**English**
Prerequisites: *(Course Code and Title)*	**(1) PHY3205 Electrodynamics or equivalent AND (2) PHY3251 Quantum Mechanics or equivalent**
Precursors: *(Course Code and Title)*	**NIL**
Equivalent Courses: *(Course Code and Title)*	**NIL**
Exclusive Courses: *(Course Code and Title)*	**PHY8603 Introduction to Quantum Information**

Part II Course Details

1. Abstract

Quantum information science extends classical information science such as computation and communication to the physical regime of quantum superposition. This course aims to bring the students up to the level of being able to access the research literature in the field. Firstly, the key theoretical formalism is described, including how to model states, measurements and dynamics. A tour of some key insights concerning the use of quantum superposition and entanglement as resources for information science tasks follows. The course then focusses on physical realisations via quantum optics, including how to create and manipulate quantum superposition and entanglement using lasers and optical elements. The course then describes information theory and quantum computation theoretically followed by how to implement quantum information protocols physically with quantum-optical processes.

2. Course Intended Learning Outcomes (CILOs)

(CILOs state what the student is expected to be able to do at the end of the course according to a given standard of performance.)

No.	CILOs	Weighting (if applicable)	Discovery-enriched curriculum related learning outcomes (please tick where appropriate)		
			A1	*A2*	*A3*
1.	Understand how to model states and measurements (Dirac notation, Born rule, mixed states, quantum interference, generalised measurements).		√	√	
2.	Understand how to model dynamics (unitary dynamics, measurement update rules, some open systems).		√	√	
3.	Understand key theoretical protocols in quantum information science (teleportation, communication over quantum channels, quantum key distribution).		√	√	
4.	Understand how to model quantum EM fields as in quantum optics, including number states and phase-space representations.		√	√	
5.	Understand multi-photon interference and photon counting techniques.		√	√	
6.	Understand quantum interference as observed in quantum optical experiments, in particular the Hong-Ou-Mandel effect.		√	√	
7.	Understand homodyne detection techniques for continuous variables and how it relates to quantum noise.				
8.	Understand entropy as a method to quantify information (classical entropy, quantum entropy, information compression, mutual information and channel capacity).		√	√	
9.	Understand essential idea of quantum computation (Quantum search and hidden subgroup algorithms).		√	√	
10.	Quantum optical implementation of quantum computing.		√	√	
		100%			

A1: *Attitude*
Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: *Ability*
Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines

or applying academic knowledge to real-life problems.

A3: *Accomplishments*
Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

3. Learning and Teaching Activities (LTAs)

(LTAs designed to facilitate students' achievement of the CILOs.)

LTA	Brief Description	CILO No.										Hours/week (if applicable)
		1	2	3	4	5	6	7	8	9	10	
Lectures	Presentation of course material	√	√	√	√	√	√	√	√	√	√	3hrs

4. Assessment Tasks/Activities (ATs)

(ATs are designed to assess how well the students achieve the CILOs.)

Assessment Tasks/Activities	CILO No.										Weighting	Remarks
	1	2	3	4	5	6	7	8	9	10		
Continuous Assessment: 70%												
Tests	√	√	√	√	√	√	√	√	√	√	30%	
Assignments	√	√	√	√	√	√	√	√	√	√	40%	
Final Examination: 30% (duration: 2 hours)												
											100%	

5. Assessment Rubrics

(Grading of student achievements is based on student performance in assessment tasks/activities with the following rubrics.)

Applicable to students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter

Assessment Task	Criterion	Excellent (A+, A, A-)	Good (B+, B, B-)	Fair (C+, C, C-)	Marginal (D)	Failure (F)
1. Tests	Capacity for using physics knowledge and theory to solve problems	Will exhibit a high level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit a good level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding, explaining, and integrating the knowledge in written format	Will exhibit lack of competence in understanding, explaining, and integrating the knowledge in written format
2. Assignments	Capacity for using physics knowledge and theory to solve problems	Will exhibit a high level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit a good level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding about experimental methods and the interpretation of results	Will exhibit some deficiencies in understanding about experimental methods and the interpretation of results	Will exhibit lack of competence in understanding, explaining, and integrating the knowledge in written format
3. Examination	Capacity for using physics knowledge and theory to solve problems	Will exhibit a high level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit a good level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding, explaining, and integrating the knowledge in written format	Will exhibit lack of competence in understanding, explaining, and integrating the knowledge in written format

<u>Applicable to students admitted from Semester A 2022/23 to Summer Term 2024</u>

Assessment Task	Criterion	Excellent (A+, A, A-)	Good (B+, B)	Marginal (B-, C+, C)	Failure (F)
1. Tests	Capacity for using physics knowledge and theory to solve problems	Will exhibit a high level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit a good level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding, explaining, and integrating the knowledge in written format	Will exhibit lack of competence in understanding, explaining, and integrating the knowledge in written format
2. Assignments	Capacity for using physics knowledge and theory to solve problems	Will exhibit a high level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit a good level of competence in understanding, explaining, and integrating the knowledge in written format	Will exhibit some deficiencies in understanding about experimental methods and the interpretation of results	Will exhibit lack of competence in understanding, explaining, and integrating the knowledge in written format
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Part III Other Information

1. Keyword Syllabus

1. States and measurements (Dirac notation, Born rule, mixed states, quantum interference, generalised measurements).
2. Dynamics (unitary dynamics, measurement update rules, some open systems).
3. Key theoretical protocols in quantum information science (teleportation, communication over quantum channels, quantum key distribution).
4. Quantum optics theory for light, including mode description of EM fields and their quantization, quantum states for optical fields – photon number states, squeezed states, entangled states, and more general Glauber-Sudarshan P-representation of quantum states.
5. Photon counting technique for discrete variables – multi-photon interference
6. Homodyne detection technique for continuous variables – quantum noise
7. Linear and nonlinear interactions for the generation and manipulation of quantum states 8. Entropy as a method to quantify information (classical entropy, quantum entropy, information compression, mutual information and channel capacity).
9. Quantum computation (Quantum search and hidden subgroup algorithms).
10. Quantum optical implementation of quantum information protocols.

2. Reading List

2.1 Compulsory Readings

(Compulsory readings can include books, book chapters, or journal/magazine articles. There are also collections of e-books, e-journals available from the CityU Library.)

1.	Michael A. Nielsen, Isaac L. Chuang Quantum Computation and Quantum Information CUP 2010. https://doi.org/10.1017/CBO9780511976667
2.	Zheyu Jeff Ou, Quantum Optics for Experimentalists, 1st Edition (WSPC, 2017)

2.2 Additional Readings

(Additional references for students to learn to expand their knowledge about the subject.)

1.	Caltech, Course Information for Physics 219/Computer Science 219 Quantum Computation: theory.caltech.edu/~preskill/ph229/
2.	R. Loudon, *Quantum Theory of Light,* 3rd Edition (Oxford University Press, 2000)