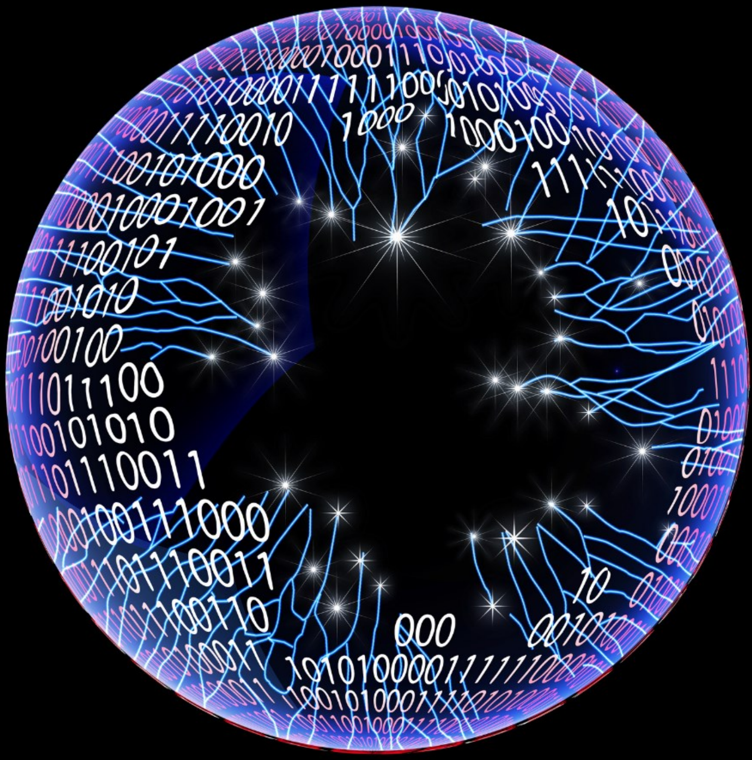
University of Glasgow | School of Physics & Astronomy



PHYS5039 Quantum Information

Course Information Guide

1 Course Details

PHYS5039 Quantum Information is a level 5 Physics Masters course. It is composed of 10 lectures and accompanying full-class tutorials, all given in Semester 2.

Lecturer: Dr Adetunmise Dada

Time and place: Normally Mondays 12:00 – 13:00 and Wednesdays 12:00 - 13:00.

Recommended Text: There is no required course text, but there are several good introductory texts on the subject. The recommended textbook is Barnett *Quantum Information*, published by Oxford University Press.

Course notes and problem sets will be made available on Moodle.

2 Assessment

The course will be assessed via continuous assessment in the form of set exercises as take-home assignments and/or class tests (20%), and an examination in the April/May diet (80%). This 20% will be comprised solely of two summative assignments. Additionally, there will be two formative assignments to further aid learning. This arrangement provides 10 M-level credits.

3 Required Knowledge

Students should have taken PHYS4026 Quantum Theory (required) and be familiar with the *bra* and *ket* notation for quantum states and the use of these operators to extract probabilities and expectation values. These elements will be reviewed at the beginning of the course, but students will need to be ready to apply these techniques to solving problems.

4 Intended Learning Outcomes

By the end of the course students will be able to: (i) Explain the difference between a bit, the classical carrier of information, and a qubit, the quantum carrier of information. (ii) Give examples of generalized quantum measurements and evaluate the probabilities of measurement outcomes. (iii) Determine the evolution of a pure or a mixed quantum state under a given quantum operation. (iv) Determine whether a composite state is entangled and understand some of the applications of entanglement. (v) Analyze simple quantum circuits. (vi) Critically assess the fidelity and functionality of key quantum resource states, such as entangled states in quantum computing and communication. (vii) Understand and explain important examples of quantum protocols including dense coding, teleportation, quantum key distribution, Grover's algorithm and Shor's algorithm.

5 Course Outline

5.1 Fundamentals

The first part of the course reviews or introduces background material and techniques needed to explore quantum information.

Elements of quantum theory: We start with a review of the basic elements of quantum mechanics including the bra and ket notation, operators and states. We will learn about mixed quantum states, composite quantum systems, unitary operators for state-evolution and introduce the idea of a qubit.

Probabilities and information: We will develop the Bayesian approach to probabilities and information, based on conditional probabilities. We introduce entropy as a measure of information.

Elements of computing science and quantum circuits: We review elements of classical information processing based on digital electronics and introduce the notion of computational complexity. The extension into the quantum domain leads us to introduce quantum gates. We will also potentially introduce IBM Qiskit (or similar) to code elementary quantum circuits.

5.2 Basic quantum protocols

In the second part of the course, we will introduce some of the earliest examples of quantum information protocols, which form building blocks for more complicated quantum algorithms.

Quantum state discrimination: We introduce a more general description of measurement, a positive operator-valued measure, or POVM, which gives a mathematical description of any possible measurement that can be performed in the lab. We explore the use of this formalism in constructing optimal measurements.

Applications of entanglement: We study entanglement and introduce quantum teleportation and dense coding.

Quantum key distribution: We explore the importance of information security and review the classical methods that are currently employed. We describe the method of quantum key distribution upon which quantum-secure communications are based.

5.3 Quantum computing

Quantum information processing and algorithms: We explore further the quantum circuit model, theoretically (and potentially using IBM Qiskit or similar). We introduce the earliest examples of quantum algorithms, the Deutsch algorithm and Simon's problem, the first indicators that computers operating under the laws of quantum mechanics may be able to out-perform classical computers.

We discuss the two most important known quantum algorithms: Grover's search algorithm, and Shor's factoring algorithm.