PHYS 612: Quantum Information Physics
MW 2:00 – 3:15 PM, Physics 107

Instructor: Dr. Jason Kestner
Pre-reqs: PHYS 601
Office: Physics 316
Office Hour: Friday 2-3pm, or email for an appointment.
Email: jkestner@umbc.edu
Textbook: *Quantum Computation and Quantum Information*, Nielsen & Chuang
Resources: Preskill's lectures (www.theory.caltech.edu/people/preskill/ph229)
Quantum Computer Science: An Introduction, Mermin
Explorations in Quantum Computing, Williams
IBM Qiskit (https://qiskit.org/learn/)

Course Description

This course gives an introduction to the fundamental concepts of quantum information processing with an emphasis on the physics of its implementation. The focus is on the nascent field of quantum computing, with some results in quantum communication discussed as well.

This is a rapidly evolving field, so the structure of this course also has some fluidity and your input is welcome throughout the semester. The class sessions will not be lecture-based, but will require your active participation, with me as your expert (or in any case, fearless) guide. In order for you to benefit, it is **imperative** for you to **read** the assigned sections of the textbook before each class. I am counting on you to do so. We will generally follow the classic textbook of Nielsen & Chuang, though for some sessions we may toggle over to Preskill or another reference.

Academic Objectives

By the semester's end you should be able to demonstrate understanding of:

- How a quantum computer is expected to provide exponential improvement over a classical computer.

- Basic quantum algorithms, such as Deutsch-Josza, Grover, and Shor.

- The basic idea of quantum error correction.

- The physics of the various types of qubits currently being researched.
- Basic ideas of quantum cryptography.
- Outstanding physics challenges that must be overcome to realize the quantum technology revolution.

Assignments

Extensive readings will be assigned before each class. It is essential that you actually do read them and work to understand them. This will take a serious time commitment – at least 2 hours for each class meeting – and must be done *prior* to the class meeting. To help motivate this, there will be accompanying short questions due for credit at the beginning of each class.

In addition, homeworks will be assigned semi-regularly. The work you turn in must be self-contained, logical, and neat.

Individual study is absolutely key to internalizing concepts, but consulting others (classmates, me, the internet) is also an essential part of scholarly practice and is a good way to overcome roadblocks. However, all submitted work must be your own. Copied or paraphrased work is unacceptable. It is fine to use somebody else's idea in your solution, but you must cite them.

You may use Mathematica or other software freely. When you do so, attach a printout to your homework.

Final Project

You will choose a final project topic in consultation with the instructor. You will start by posing a genuine question about anything related to quantum information that makes you curious. Throughout the semester, you will document your search for an answer. By spring break you should identify an aspect of the answer that requires a deep dive into the literature (or even original research!). A written paper reviewing what you have learned will be due at the end of the semester, as well as a 30-minute oral presentation to the class, in lieu of a final exam.

Overall Grades

Your course grade will be determined by the following components:

Homework	35%
Reading questions	35%
Final project oral	10%
Final project written	20%

This course will not be graded on a curve. Total scores translate to grades in the following way:

Score	Grade
90–100	A
88–90	A-
85–88	B+
81–85	B
78–81	B-
75–78	C+
71–75	C
68–71	C-
65–68	D
0–65	F

Course schedule (subject to change)

Idea and algorithms

Meetings 1-2	Overview, Bell's inequality, Deutsch-Josza algorithm, complexity classes (Chap. 1)
Meetings 3-5	Quantum gates and universality (Chap. 4)
Meetings 6-8	Quantum Fourier Transform and its applications (Chap. 5)
Meetings 9-10	Grover's algorithm and its applications (Chap. 6)

Fault tolerance

Meetings 11-12	Schmidt decomposition, purification (Chap. 2)
Meetings 13-14	Quantum noise and superoperators (Chap. 8)
Meetings 15-20	Fault-tolerant error-correcting codes (Chap. 10)

Physical implementations

Meetings 21-22	Photonic qubits (Chap. 7 + supplemental material)
Meetings 22-24	Superconducting qubits (Chap. 7 + supplemental material)
Meeting 25	Trapped ion qubits (Chap. 7 + supplemental material)

Meeting 26	Spin qubits (supplemental material)
Meeting 27	Majorana qubits (supplemental material)

Other topics

Meeting 28	Quantum cryptography (Chap. 12)
Meeting 29	TBD