Introduction to Quantum Computation

PHY 320.001 Topics in Physics --- Spring 2017 Syllabus
Physics Department --- Mercer University

Main Texts: Six Quantum Pieces. A First Course in Quantum Physics, by Valerio Scarani; and Quantum Computing. A Gentle Introduction, by Elearor Rieffel and Wolfgang Polak
Class Meetings: TR 1:40-2:55pm, SEB 140
Instructor: Dr. Jose L. Balduz Jr
email: balduz_jl@mercer.edu, **phone:** 478-301-2229, **office:** SEB 205,
office hours (tentative): T 10am-2pm, R 4-6pm, or by appointment (try email)...
Course web page: http://physics.mercer.edu/balduz/QComp/defaultS17.htm
Please also see Physics Department home page at http://physics.mercer.edu.

This course is an introduction to the exciting emerging field of quantum information and quantum computation, including basic concepts in quantum physics and requisite mathematical tools. It is intended primarily for physics majors, but should be of interest also to many other students, especially those majoring in computer science, computer or electrical engineering and mathematics. Topics include (a) the basic mathematics that describes quantum information, exemplified by the Dirac notation; (b) non-classical features of quantum physics, such as quantum cryptography and teleportation; (c) and quantum computing such as Shor's and Grover's algorithms. Prerequisites are (a) a year of calculus **MAT 191/192 Calculus I/II**, and (b) a year of calculus-based physics **PHY 161/162 General Physics I/II**.

The field of quantum information science includes quantum computation, quantum information and quantum control: It is a dynamic new area of inter-disciplinary research involving physicists, computer scientists, mathematicians and engineers. Any computation is essentially a (quantum) physical process. As computers get smaller and faster, we approach the molecular/atomic domain where strange quantum behavior is the norm. In particular, quantum physics offers an entirely new form of computational parallelism that will make quantum computers more powerful than conventional computers by many orders of magnitude. Recent and future lines of investigation include the control of system coherence and decoherence; quantum computer algorithms; quantum cryptography and secure quantum communications; fundamental and practical understanding of entanglement, and how this can be used in novel processes like quantum teleportation; and the continuing work on physical systems for quantum computation, including the development of the necessary logic gates and error-correction techniques to bring this theory to practice.

The primary goal of this course is for students to develop conceptual understanding of these topics rather than detailed knowledge, which they can gain in more advanced courses. The secondary goal is for students to learn the basic conceptual and mathematical tools of quantum physics as applied to quantum computation and quantum information. When necessary, we will include supplementary material in basic quantum theory, differential equations, matrix algebra and linear algebra. These will be presented as they are required by students to fully appreciate the text material and to efficiently carry out calculations in homework sets and exams.

(Required) BASIC TEXTBOOK

<u>Six Quantum Pieces. A First Course in Quantum Physics</u>, by Valerio Scarani, with Chua Lynn and Liu Shi Yang, 140 pages, World Scientific (2010), ISBN-10: 981-4327-54-9 (pbk), ISBN-13: 978-981-4327-54-1 (pbk).

<u>Notions and Formalism</u>
1 Introducing Quantum Physics with Polarization
<u>Six Pieces</u>
2 Quantum Cryptography
3 Quantum Cloning
4 Quantum Teleportation
5 Quantum Correlations and Bell's Inequality
6 The GHZ Argument for Quantum Correlations
7 Measurement and Decoherence
<u>Beyond the Six Pieces</u>
8 Other Two-Level Systems
9 Link with More Traditional Presentations of Quantum Physics

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(Recommended) INTERMEDIATE TEXTBOOK

<u>Quantum Computing from the Ground Up</u>, by Riley Tipton Terry, 240 pages, World Scientific (2012), ISBN: 978-981-4412-11-7 (pbk).

1 Introduction
2 Computer Science
3 Mathematics for Quantum Computing
4 Quantum Mechanics
5 Quantum Computing
6 Information Theory
7 Quantum Algorithms
8 Using Quantum Mechanical Devices and Recent Developments

(Required) ADVANCED TEXTBOOK

<u>Quantum Computing. A Gentle Introduction</u>, by Eleanor Rieffel and Wolfgang Polak, 372 pages, MIT Press (2011), ISBN: 978-00-262-52667-8 (pbk).

1 Introduction
<u>I Quantum Building Blocks</u>

2 Single-Qubit Quantum Systems
3 Multiple-Qubit Systems
4 Measurement of Multiple-Qubit States
5 Quantum State Transformations
6 Quantum Versions of Classical Computations

II Quantum Algorithms

7 Introduction to Quantum Algorithms
8 Shor's Algorithm
9 Grover's Algorithm and Generalizations

III Entangled Subsystems and Robust Quantum Computation

10 Quantum Subsystems and Properties of Entangled States
11 Quantum Error Correction
12 Fault Tolerance and Robust Quantum Computing
13 Further Topics in Quantum Information Processing

Appendices

A Some Relations Between Quantum Mechanics and Probability Theory
B Solving the Abelian Hidden Subgroup Problem

Lectures: Much of the class meeting time will be devoted to conventional lectures. We will go over the text in detail, including derivations and examples. We will also discuss the material in general and go over homework and test problems.

Office hours: Please come see me! If you're doing well in the course, we can talk about physics concepts and the big picture; or about your life after Mercer; or other things... If you're not doing so well in this class, I can try to help you one-on-one, before you get too far behind. Typically that means talking about the material with you, but also having you work problems with me right in my office. There's no substitute for working through a problem yourself, with someone by your side that knows the way...

Homework: The instructor will assign sets of homework problems related to the material in the required texts, to be worked by the students and handed in for grading. Students are encouraged to collaborate on these; however, each must hand in their own separate paper. After the papers are collected, a solution sheet will be provided. Altogether, the homework will count for 50% of the total grade.

In-class tests: There will be several of these during regular class periods, containing primarily numerical problems and derivations, but also some conceptual questions. They will be open-book tests (including class notes). Altogether, the tests will count for 25% of the total grade.

Final Exam: This will take place on **Thursday, May 4** at 7-10pm. It will be similar to the in-class tests. It will be comprehensive and will count for 25% of the total grade.

Grading: The percentage for each activity is shown in the left table below. To convert the total percent to a letter grade, use the scale shown in the right table below.

	#	total %
Homework sets	10	50
Tests	var	25
Final Exam	1	25
		Total: 100

	GP	%
A	4.0	90-100
B+	3.5	85-89
B	3.0	80-84
C+	2.5	75-79
C	2.0	70-74
D	1.0	60-69
F	0.0	0-59

Miscellaneous policies:

If changes to this syllabus are necessary, they will be implemented after discussion and negotiation with the students. Note that the accompanying course schedule is not a part of the syllabus: it is tentative and subject to revision, including all due dates.

Assignment due dates: Homework assignments are always due in class on the due date: However, they will not be considered late as long as they are turned in before the next sunrise (or first thing in the morning). Beyond that, any late assignments will suffer a 5% penalty per day (excluding weekends and holidays) until they are handed in: i.e., 5% on the first day, 10% on the second day...; up to a maximum penalty of 50% after 10 days.

There will be no dropped grades or extra-credit work. All work done in the course will be counted.

Honor Code: The College of Liberal Arts' academic misconduct policy will be followed. All students are bound by the Mercer University Honor Code...

Disability support: Students requiring accommodations for a disability should inform the instructor at the close of the first class meeting or as soon as possible. The instructor will refer you to the Disability Support Services Coordinator to document your disability, determine eligibility for accommodations under the ADAAA/Section 504 and to request a Faculty Accommodation Form. Disability accommodations or status will not be indicated on academic transcripts. In order to receive accommodations in a class, students with sensory, learning, psychological, physical or medical disabilities must provide their instructor with a Faculty Accommodation Form to sign. Students must return the signed form to the Disability Services Coordinator. A new form must be requested each semester. Students with a history of a disability, perceived as having a disability, or with a current disability, who do not wish to use academic accommodations are also strongly encouraged to register with the Disability Services Coordinator and request a Faculty Accommodation Form each semester.

For further information, please contact Carole Burrowbridge, Disability Services Coordinator, at 301-2778 or visit the Disability Support Services website at http://www.mercer.edu/studentaffairs/disabilityservices

All requests for reasonable accommodation are welcome also in regard to absence from class for school representation (i.e., athletic or other events) or personal/family problems.