# PHYS 370 Syllabus Fall 2023, UIUC

Title: Introduction to Quantum Information and Computing

#### Credit Hours: 3 cr.

**Description:** Introduction to quantum information and computing for sophomores, juniors and seniors from any major. Self-contained description of quantum states and qubits, operators, measurements, tensor products, density matrices, quantum gates and circuits, and quantum computing/simulation algorithms. One of the key points of departure from classical physics, quantum entanglement, is threaded throughout all these topics including a dedicated discussion of Bell's theorem. Students will apply these basic aspects of quantum mechanics to program online quantum computers (e.g., IBM cloud) to gain insight into canonical algorithms such as Deutsch-Jozsa, Shor, and/or Grover as well as standard protocols such as teleportation and entanglement swapping. Course Information: Prerequisite: PHYS 214.

The course schedule can be found below.

When: Mon/Wed 10:00-11:20am

Where: 1047 Sidney Lu Mech Engr Bldg

#### Who:

<u>Prof. Jake Covey</u> 327 Loomis jcovey@illinois.edu 320-223-0373 Office Hours: Friday, 2-4pm

## Tahereh Mozafarishamsi (HW) 271 Loomis tahereh2@illinois.edu Office Hours:

#### **Course website:**

https://sites.google.com/view/coveylab/teaching (the teaching tab on my group website: coveylab.com)

#### **Course Material:**

Lecture notes, homeworks, homework solutions, and exam solutions and be available from the course website.

We will also use the *gradebook* to keep track of scores.

## Lecture participation:

We will not use iClicker.

Lecture attendance will be 5% of your grade. Attendance will be recorded with a sign-in sheet. Participation is not strictly required, but it is highly encouraged and is the intent of the attendance points. You will have four drops throughout the semester.

## **Class forum:**

We will use Campuswire to ask and answer questions outside of class time: I encourage you to do both! You will receive an invitation email close to the start of the semester.

### Homework:

Homework will be due every Wednesday by 10am. I prefer to take an "old school" approach where you will turn in a paper copy of your homework at the beginning of the Wednesday lecture. We will hand out a paper copy of the next homework during the Wednesday lecture. Homeworks and their solutions can also be found on the course website.

Homeworks can be turned in up to one week late for 80% credit, or before the final course deadline (whichever is sooner). Accordingly, the homework solutions will not be available until one week after their (100% credit) due date.

### Exams:

Exams for this course will be in-class/in-person. Dates are on the schedule below. The two midterm exams will be 80 min; the final exam will be 180 min.

### Grading:

The course will comprise weekly homework (40%), class attendance (5%), two midterm exams (15% each), and one final exam (25%). Exams may be curved; final course grades will not be curved. The (lower) grade boundaries will be A+ (97), A (94), A- (91), B+ (88), B (85), B- (82), C+ (78), C (74), C- (70), D+ (66), D (62), D- (58), F (54)

### Text:

D. McMahon, Quantum Computing Explained, 1st Edition, 2008 (required).
M. Nielsen and I. Chuang, Quantum Computation and Quantum Information, 10th Anniversary Edition available electronically (reference)

## **Class responsibilities:**

See here: https://courses.physics.illinois.edu/phys370/sp2023/Class%20responsibilities.html

## Diversity, equity, and inclusion responsibilities:

The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors directly through the Office of the Vice Chancellor for Diversity Equity and Inclusion (https://diversity.illinois.edu/diversity-campus-culture/belonging-resources). Based on your report, members of the OVCDEI will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

## Academic Integrity:

All activities in this course, including documentation submitted for petition for an excused absence, are subject to the Academic Integrity rules as described in Article 1, Part 4, Academic Integrity, of the Student Code: <a href="https://studentcode.illinois.edu/article1/part4/1-401/">https://studentcode.illinois.edu/article1/part4/1-401/</a>

## In case of emergency:

Here is a list of emergency resources: <u>https://publish.illinois.edu/illinistudentresources/?page\_id=46</u>

References on reserve at the Grainger Library:

- Wilde, Mark; Quantum Information Theory (2017) available online
- Holik, Federico, et al; What is Quantum Information (2017) available online
- Marinescu, Dan & Marinescu, Gabriela; Classical and Quantum Information (2012) available online
- Hayashi, Masahito; Introduction to quantum information science (2014) available online
- Benatti, Fabio; Quantum Information, Computation and Cryptography: An Introductory Survey of Theory, Technology and Experiments (2010) available online
- Hidary, Jack; Quantum Computing: An Applied Approach (2019) available online
- Bernhardt, Chris; Quantum Computing for Everyone (2019) available online
- Fujii, Keisuke, Quantum Computation with Topological Codes: From Qubits to Fault-Tolerance (2015) available online
- Pathak, Anirban; Elements of Quantum Computation and Quantum Communication (2013) available online
- Bera, Rajendra; The Amazing World of Quantum Computing (2020) available online
- Motodi, Tzvetan, et al.; Quantum Computing for Computer Architects (2011) available online
- Mermin, David; Quantum Computer Science: An Introduction (2007) available online

Unit 1: Single qubits     Model       1     Mr, 08/21     Introduction to quantum systems: Infinite Square Well and electron spin     PHYS 214 recap, Accompanying notes       2     Wr, 08/23     Qubits and the Bloch sphere Well and operators     MM: Ch. 2, pp. 11-19 Ref: NGC; sec. 1.2       3     Mr, 08/28     Matrices and operators     MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49       4     Wr, 08/30     Manipulating and preserving qubits     Accompanying notes       5     Wr, 08/10     Matrices and operators     MM: Ch. 3, pp. 57-62, 66-69, 70-71       6     Mr, 09/11     The density operator, mixed states, Fidelity     MM: Ch. 3, pp. 57-62, 66-69, 70-71       7     Wr, 09/10     Quantum messurements     MM: Ch. 3, pp. 57-62, 66-69, 70-71       8     Mr, 09/18     Single-qubit gates; towards quantum circuits     MM: Ch. 3, pp. 57-62, 66-69, 70-71       7     Wr, 09/13     Quantum messurements     MM: Ch. 4, pp. 73-84       8     Mr, 09/18     Single-qubit gates; towards quantum circuits     MM: Ch. 4, pp. 73-84       11     Wr, 09/25     Exam 1 - Unit 1     MM: Ch. 7, pp. 157-162       12     Mr, 10/02     Bel's theorem     MM: Ch. 7, pp. 147-155 <th>Lecture</th> <th>Date</th> <th>Title</th> <th>Source material</th>	Lecture	Date	Title	Source material
1   M, 08/21   Introduction to quantum systems: Infinite Square Well and electron spin   PHYS 214 recap, Accompanying notes Infinite Square Well and electron spin     2   W, 08/23   Qubits and the Bloch sphere Well Status and the Bloch sphere Public Status and the Bloch sphere Well Status and the Status and Mell Status and Mell Status and the Status an			Unit 1: Single qubits	
Infinite Square Well and electron spin     MM: Ch. 2, pp. 11-19       2     W, 08/23     Qubits and the Bloch sphere     MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49       3     M, 08/28     Matrices and operators     MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49       3     W, 08/30     Manipulating and preserving qubits     Accompanying notes       5     W, 09/06     Expectation values, unitary     MM: Ch. 3, pp. 57-62, 66-69, 70-71       6     M, 09/11     The density operator, mixed states, Fidelity     MM: Ch. 5, pp. 36-90, 91-108, 115-117       7     W, 09/13     Quantum measurements     MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146       8     M, 09/18     Single-qubit gates; towards quantum circuits     MM: Ch. 4, pp. 73-84       10     M, 09/20     Tensor products of states and operators     MM: Ch. 7, pp. 157-162       11     W, 09/27     Entanglement     MM: Ch. 7, pp. 147-155       13     W, 10/04     Partial trace, density operator, mixed states, and circuits     MM: Ch. 8, pp. 186-195       14     M, 10/09     Quantum gates and circuits     MM: Ch. 13, pp. 279-280, Ch. 10, 225-228       14     M, 10/10     Quantum gate platforms     Accompanying not	1	M, 08/21	Introduction to quantum systems:	PHYS 214 recap, Accompanying notes
2 W, 08/23 Qubits and the Bloch sphere MM: Ch. 2, pp. 11-19 Ref: N&C: sec. 1.2   3 M, 08/28 Matrices and operators MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49   4 W, 08/20 Manipulating and preserving qubits Accompanying notes   5 W, 09/06 Expectation values, unitary transformations, HUP, postulates of QM MM: Ch. 3, pp. 57-62, 66-69, 70-71   6 M, 09/11 The density operator, mixed states, ridelity MM: Ch. 3, pp. 26-69, 91-108, 115-117   7 W, 09/13 Quantum measurements MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146   8 M, 09/18 Single-qubit gates; towards quantum circuits MM: Ch. 7, pp. 157-162   9 W, 09/20 Tensor products of states and operators MM: Ch. 7, pp. 157-162   11 W, 09/27 Examal – Unit 1 MM: Ch. 7, pp. 157-162   12 M, 10/02 Bell's theorem MM: Ch. 7, pp. 147-155   13 W, 10/14 Partial trace, density operator, mixed states, and measurements MM: Ch. 8, pp. 186-195   14 M, 10/09 Quantum agtes and circuits MM: Ch. 13, pp. 279-280, Ch. 10, 225-228   14 M, 10/04 Partial trace, density operator, mixed states, and measurements Accompanying notes   15 W, 10/11 No cloning theorem, teleportation, quantum repeater MM: Ch. 13, pp. 27			Infinite Square Well and electron spin	
Ref. N&C: sec. 1.23M, 08/28Matrices and operatorsMM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-494W, 08/30Manipulating and preserving qubitsAccompanying notes5W, 09/06Expectation values, unitary transformations, HUP, postulates of QMMM: Ch. 3, pp. 57-62, 66-69, 70-716M, 09/11The density operator, mixed states, FidelityMM: Ch. 3, pp. 57-62, 66-69, 70-717W, 09/13Quantum measurementsMM: Ch. 5, pp. 86-90, 91-108, 115-1178M, 09/18Single-qubit gates; towards quantum circuitsMM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-1468M, 09/20Tensor products of states and operatorsMM: Ch. 4, pp. 73-849W, 09/20Tensor products of states and operatorsMM: Ch. 7, pp. 157-16211W, 09/27EntanglementMM: Ch. 7, pp. 157-16212M, 10/02Bell's theoremMM: Ch. 7, pp. 147-15513W, 10/04Partial trace, density operator, mixed states, and measurementsMM: Ch. 8, pp. 111-115; Ch. 6, pp. 132-13914M, 10/09Quantum gates and circuitsMM: Ch. 8, pp. 136-19515W, 10/11No cloning theorem, teleportation, quantum repeaterAccompanying notes16M, 10/12Trapped ionsAccompanying notes18M, 10/23Trapped ionsAccompanying notes19W, 10/24Spins in solidsAccompanying notes21W, 11/18Deutral atomsAccompanying notes22M, 11/06Exam 2 - Unit 2 and 3Accompanyi	2	W, 08/23	Qubits and the Bloch sphere	MM: Ch. 2, pp. 11-19
3 M, 08/28 Matrices and operators MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49   4 W, 08/30 Manipulating and preserving qubits Accompanying notes   5 W, 09/06 Expectation values, unitary transformations, HUP, postulates of QM MM: Ch. 3, pp. 57-62, 66-69, 70-71   6 M, 09/11 The density operator, mixed states, Fidelity MM: Ch. 3, pp. 36-90, 91-108, 115-117   7 W, 09/13 Quantum measurements MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146   8 M, 09/18 Single-qubit gates; towards quantum circuits MM: Ch. 4, pp. 73-84   9 W, 09/20 Tensor products of states and operators MM: Ch. 7, pp. 157-162   10 M, 09/25 Exam 1 - Unit 1 MM: Ch. 7, pp. 157-162   11 W, 00/27 Entanglement MM: Ch. 7, pp. 147-155   13 W, 10/04 Partial trace, density operator, mixed states, and measurements MM: Ch. 7, pp. 147-155   14 M, 10/09 Quantum gates and circuits MM: Ch. 13, pp. 279-280, Ch. 10, 225-228   15 W, 10/11 No cloning theorem, teleportation, quantum repeater MA: Ch. 8, pp. 136-195   16 M, 10/28 Ivantum hardware platforms Accompanying notes   17 W, 10/18 Neutral atoms Accompanying notes   17 W, 10/25 Spin				Ref: N&C: sec. 1.2
4 W. 08/30 Manipulating and preserving qubits Accompanying notes   5 W. 09/06 Expectation values, unitary MM: Ch. 3, pp. 57-62, 66-69, 70-71   6 M, 09/11 The density operator, mixed states, Fidelity MM: Ch. 3, pp. 57-62, 66-69, 70-71   7 W, 09/13 Quantum measurements MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146   8 M, 09/18 Single-qubit gates; towards quantum circuits MM: Ch. 4, pp. 73-84   10 M, 09/20 Tensor products of states and operators MM: Ch. 4, pp. 73-84   10 M, 09/21 Entanglement MM: Ch. 7, pp. 157-162   11 W, 09/20 Tensor products of states and operators MM: Ch. 7, pp. 147-155   13 W, 10/02 Bell's theorem MM: Ch. 5, pp. 186-195   14 M, 10/04 Partial trace, density operator, mixed states, and measurements MM: Ch. 13, pp. 279-280, Ch. 10, 225-228   16 M, 10/11 No cloning theorem, teleportation, quantum repeater Accompanying notes   17 W, 10/28 Harmonic oscillators: phonons and photons Accompanying notes   18 M, 10/23 Trapped ions Accompanying notes   19 W, 10/25 Sips in solids Accompanying notes   12 M, 11/06 Exam 2 – Units 2 and 3 MM: Ch. 9, pp. 203-210<	3	M, 08/28	Matrices and operators	MM: Ch. 2, pp. 19-26, 28-31; Ch. 3, pp. 39-49
5 W, 09/06 Expectation values, unitary transformations, HUP, postulates of QM MM: Ch. 3, pp. 57-62, 66-69, 70-71   6 M, 09/11 The density operator, mixed states, Fidelity MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146   7 W, 09/13 Quantum measurements MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146   8 M, 09/18 Single-qubit gates; towards quantum circuits MM: Ch. 3, 62-66; Ch. 6, pp. 127-132, 139-146   9 W, 09/20 Tensor products of states and operators MM: Ch. 4, pp. 73-84   10 M, 09/25 Exam 1 – Unit 1 MM: Ch. 7, pp. 157-162   11 W, 09/20 Bell's theorem MM: Ch. 7, pp. 137-162   12 M, 10/02 Bell's theorem, teleportation, quantum gates and circuits MM: Ch. 7, pp. 137-162   14 M, 10/09 Quantum gates and circuits MM: Ch. 7, pp. 136-195   15 W, 10/10 No cloning theorem, teleportation, quantum repeater MM: Ch. 13, pp. 279-208, Ch. 10, 225-228   16 M, 10/16 Harmonic oscillators: phonons and photons Accompanying notes   17 W, 10/21 Superconducting circuits Accompanying notes   18 M, 10/23 Trapped ions Accompanying notes   19 W, 10/30 Superconducting circuits Accompanying notes   20 M, 11/08	4	W, 08/30	Manipulating and preserving qubits	Accompanying notes
Interformations, HUP, postulates of QM6M, 09/11The density operator, mixed states, FidelityMM: Ch. 5, pp. 86-90, 91-108, 115-1177W, 09/13Quantum measurementsMM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-1468M, 09/18Single-qubit gates; towards quantum circuitsMM: Ch. 8, pp. 176-186, Ch. 9, pp. 197-2049W, 09/20Tensor products of states and operatorsMM: Ch. 4, pp. 73-8410M, 09/25Exam 1 - Unit 111W, 09/27Entanglement11W, 09/27Entanglement12M, 10/02Bell's theorem13W, 10/04Partial trace, density operator, mixed states, and measurementsMM: Ch. 7, pp. 137-16214M, 10/09Quantum gates and circuitsMM: Ch. 5, pp. 111-115; Ch. 6, pp. 132-13915W, 10/11No cloning theorem, teleportation, quantum repeaterMM: Ch. 3, pp. 279-280, Ch. 10, 225-22816M, 10/16Harmonic oscillators: phonons and photonsAccompanying notes17W, 10/18Neutral atomsAccompanying notes18M, 10/23Trapped ionsAccompanying notes20M, 11/04Deta dal dal diporithmsAccompanying notes21W, 11/13Fourier transform on a quantum computerMM: Ch. 9, pp. 211-213 Ref: N&C: sec. 5.14, 3, 1.4.424M, 11/13Fourier transform on a quantum computerMM: Ch. 9, pp. 211-213 Ref: N&C: sec. 5.14, 3, 1.4.424M, 11/14Pourier transform on a quantum computerMM: Ch. 9, pp. 218-221 Phase	5	W, 09/06	Expectation values, unitary	MM: Ch. 3, pp. 57-62, 66-69, 70-71
6   M, 09/11   The density operator, mixed states, Fidelity   MM: Ch. 5, pp. 86-90, 91-108, 115-117     7   W, 09/13   Quantum measurements   MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146     8   M, 09/18   Single-qubit gates; towards quantum circuits   MM: Ch. 8, pp. 176-186, Ch. 9, pp. 197-204     9   W, 09/20   Tensor products of states and operators   MM: Ch. 7, pp. 157-162     10   M, 09/25   Exam 1 – Unit 1   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 157-162     12   M, 10/02   Bell's theorem   MM: Ch. 7, pp. 147-155     13   W, 10/04   Partial trace, density operator, mixed Accompanying notes   MM: Ch. 8, pp. 186-195     14   M, 10/09   Quantum gates and circuits   MM: Ch. 18, pp. 279-280, Ch. 10, 225-228     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   MM: Ch. 8, pp. 186-195     16   M, 10/26   Sipis in solids   Accompanying notes     17   W, 10/18   Neutral atoms   Accompanying notes     19   W, 10/25   Spins in solids   Accompanying notes     20   M, 10/30   Superconducting circuits   Accompanying			transformations, HUP, postulates of QM	
7   W, 09/13   Quantum measurements   MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146     8   M, 09/18   Single-qubit gates; towards quantum circuits   MM: Ch. 8, pp. 176-186, Ch. 9, pp. 197-204     9   W, 09/20   Tensor products of states and operators   MM: Ch. 4, pp. 73-84     10   M, 09/25   Exam 1 – Unit 1   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 147-155     13   W, 10/02   Bell's theorem   MM: Ch. 5, pp. 111-115; Ch. 6, pp. 132-139     14   M, 10/09   Quantum gates and circuits   MM: Ch. 8, pp. 186-195     14   M, 10/09   Quantum gates and circuits   MM: Ch. 13, pp. 279-280, Ch. 10, 225-228     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   Ref: N&C secs. 1.3.5. 1.3.7, Box 12.1     16   M, 10/26   Harmonic oscillators: phonons and photons   Accompanying notes     17   W, 10/18   Neutral atoms   Accompanying notes     18   M, 10/23   Sips in solids   Accompanying notes     20   M, 10/30   Superconducting circuits   Accompanying notes     21   W, 11/16   Exam 2 – Units 2 and 3   MM: Ch. 9, pp. 203-210 <td>6</td> <td>M, 09/11</td> <td>The density operator, mixed states, Fidelity</td> <td>MM: Ch. 5, pp. 86-90, 91-108, 115-117</td>	6	M, 09/11	The density operator, mixed states, Fidelity	MM: Ch. 5, pp. 86-90, 91-108, 115-117
8   M, 09/18   Single-qubit gates; towards quantum circuits   MM: Ch. 8, pp. 176-186, Ch. 9, pp. 197-204     9   W, 09/20   Tensor products of states and operators   MM: Ch. 4, pp. 73-84     10   M, 09/25   Exam 1 – Unit 1   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 157-162     12   M, 10/02   Bell's theorem   MM: Ch. 7, pp. 147-155     13   W, 10/04   Partial trace, density operator, mixed states, and measurements   Accompanying notes     14   M, 10/09   Quantum gates and circuits   MM: Ch. 8, pp. 186-195     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   MM: Ch. 8, pp. 186-195     16   M, 10/18   Neutral atoms   Accompanying notes     17   W, 10/18   Neutral atoms   Accompanying notes     18   M, 10/23   Trapped ions   Accompanying notes     20   M, 10/30   Superconducting circuits   Accompanying notes     21   W, 11/01   QED and QAD (not covered on exams)   Accompanying notes     22   M, 11/06   Exam 2 – Units 2 and 3   MM: Ch. 9, pp. 203-210     23   W, 11/08	7	W, 09/13	Quantum measurements	MM: Ch. 3, 62-66; Ch. 6, pp. 121-132, 139-146
Circuits     Circuits       9     W, 09/20     Tensor products of states and operators     MM: Ch. 4, pp. 73-84       10     M, 09/25     Exam 1 – Unit 1     MM: Ch. 7, pp. 157-162       11     W, 09/27     Entanglement     MM: Ch. 7, pp. 147-155       13     W, 10/04     Partial trace, density operator, mixed states, and measurements     Accompanying notes       14     M, 10/09     Quantum gates and circuits     MM: Ch. 8, pp. 186-195       15     W, 10/11     No cloning theorem, teleportation, quantum repeater     MM: Ch. 8, pp. 186-195       16     M, 10/16     Harmonic oscillators: phonons and photons     Accompanying notes       17     W, 10/18     Neutral atoms     Accompanying notes       18     M, 10/23     Trapped ions     Accompanying notes       20     M, 10/30     Superconducting circuits     Accompanying notes       21     W, 11/01     QED and QAD (not covered on exams)     Accompanying notes       22     M, 11/04     Exam 2 – Units 2 and 3     MM: Ch. 9, pp. 203-210       23     W, 11/08     Deutsch (-Jozsa) algorithm     MM: Ch. 9, pp. 203-210       24	8	M, 09/18	Single-qubit gates; towards quantum	MM: Ch. 8, pp. 176-186, Ch. 9, pp. 197-204
9   W, 09/20   Tensor products of states and operators   MM: Ch. 4, pp. 73-84     10   M, 09/25   Exam 1 – Unit 1   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 147-155     12   M, 10/02   Bell's theorem   MM: Ch. 5, pp. 111-115; Ch. 6, pp. 132-139     13   W, 10/04   Partial trace, density operator, mixed   MM: Ch. 5, pp. 111-115; Ch. 6, pp. 132-139     14   M, 10/09   Quantum gates and circuits   MM: Ch. 3, pp. 186-195     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   Ref: N&C: secs. 1.3.5. 1.3.7, Box 12.1     16   M, 10/16   Harmonic oscillators: phonons and photons   Accompanying notes     17   W, 10/18   Neutral atoms   Accompanying notes     18   M, 10/25   Spins in solids   Accompanying notes     20   M, 10/26   Exam 2 - Units 2 and 3   Accompanying notes     21   W, 11/01   QED and QAD (not covered on exams)   Accompanying notes     22   M, 11/08   Deutsch (-Jozsa) algorithm   MM: Ch. 9, pp. 203-210     23   W, 11/08   Deutsch (-Jozsa) algorithm   MM: Ch. 9, pp. 211-213			Circuits	
3   W, 09/20   Tension products of states and operators   MM: Ch. 4, pp. 73-84     10   M, 09/25   Exam 1 – Unit 1   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 147-155     13   W, 10/02   Bell's theorem   MM: Ch. 7, pp. 147-155     13   W, 10/04   Partial trace, density operator, mixed states, and measurements   Accompanying notes     14   M, 10/09   Quantum gates and circuits   MM: Ch. 13, pp. 279-280, Ch. 10, 225-228     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   MM: Ch. 13, pp. 279-280, Ch. 10, 225-228     16   M, 10/16   Harmonic oscillators: phonons and photons   Accompanying notes     17   W, 10/18   Neutral atoms   Acccompanying notes     18   M, 10/25   Spins in solids   Accompanying notes     20   M, 10/30   Superconducting circuits   Accompanying notes     21   W, 11/10   QED and QAD (not covered on exams)   Accompanying notes     23   W, 11/08   Deutsch (-Jozsa) algorithm   MM: Ch. 9, pp. 203-210     24   M, 11/13   Fourier transform on a quantum computer   Ref: N&C: sec. 5.1  <	0	W/ 00/20	Tensor products of states and operators	MM: Ch 4 nn 72 84
10   M, 99/23   Entanglement   MM: Ch. 7, pp. 157-162     11   W, 09/27   Entanglement   MM: Ch. 7, pp. 147-155     13   W, 10/04   Partial trace, density operator, mixed states, and measurements   MM: Ch. 7, pp. 111-115; Ch. 6, pp. 132-139     14   M, 10/09   Quantum gates and circuits   MM: Ch. 8, pp. 186-195     15   W, 10/11   No cloning theorem, teleportation, quantum repeater   MM: Ch. 13, pp. 279-280, Ch. 10, 225-228     16   M, 10/16   Harmonic oscillators: phonons and photons   Accompanying notes     17   W, 10/18   Neutral atoms   Accompanying notes     18   M, 10/23   Trapped ions   Accompanying notes     19   W, 10/25   Spins in solids   Accompanying notes     20   M, 11/06   Exam 2 – Units 2 and 3   Accompanying notes     21   W, 11/10   QED and QAD (not covered on exams)   Accompanying notes     22   M, 11/13   Fourier transform on a quantum computer   MM: Ch. 9, pp. 203-210 Ref: N&C: secs. 5.1     23   W, 11/15   Phase estimation and Shor's algorithm   MM: Ch. 9, pp. 211-213 Ref: N&C: sec. 5.2, pp. 221-223 Shor's algorithm: MM: Ch. 9, pp. 216-218; Ref: N&C: sec. 5.3     26 <t< td=""><td>9</td><td>VV, 09/20</td><td>Exam 1 – Unit 1</td><td>WW. Cli. 4, pp. 75-84</td></t<>	9	VV, 09/20	Exam 1 – Unit 1	WW. Cli. 4, pp. 75-84
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