Physics 370

1. Title: Introduction to Quantum Information and Computing
2. Abbreviated title:
3. Short description:

Introduction to quantum information and computing for sophomores and juniors from any major. Self-contained description of quantum states and qubits, operators, measurements, tensor products, density matrices, entanglement, gates and circuits and algorithms. Students will apply the basic components of quantum mechanics to program online quantum computers to gain insight into the Deutsch-Jozsa, Grover and Shor algorithms, as well as teleportation, super-dense coding and entanglement swapping.

1. Justification: Quantum information and computing is a topic of great current interest as evidenced by the large efforts in both industry (e.g. Google, IBM, Microsoft, Amazon, etc.), academia (IQUIST, etc.) and government (National Quantum Initiative, 5 National Quantum Information Science Research Centers). There are no other introductory quantum information and computing courses on campus. Related higher-level courses include ECE498EC (more concentration on theory, quantum communication, about 15% overlap with proposed PHY370), PHYS5?? Atomic physics graduate-level courses that focus on applications in laser physics with < 10% overlap (Kwiat), atomic physics, about 10% overlap, (DeMarco) and superconducting systems, < 10% overlap (van Harlingen). The Physics grad courses are all at a significantly higher level and focus on applications of what would be taught in Phys. 370. There is also a graduate level course in Math 490QC: mathematical techniques relevant for quantum information theory, again an overlap of about 10%. In this case the Math course, taught at a higher level would provide rigorous mathematical background relevant for the simplified presentation in Phys. 370.
2. Credit hours: 3
3. Who else can teach: DeMarco, Kwiat, Covey, Lorenz, Pfaff, Kou, Clark, …
4. Prerequisites: Phys. 214
5. Concurrent enrollment courses: none
6. Text: David McMahon, Quantum Computing Explained, 1st edition
7. Learning objectives:
   1. Understand the basic differences between quantum information/computing and classical information/computing
   2. Become familiar with and be able to use quantum states/qubits, operators, measurements, tensor products, density matrices and entanglement
   3. Become familiar with and be able to develop quantum algorithms and programs using quantum gates and circuits
   4. Become familiar with and program “classic” quantum algorithms including teleportation, Deutsch-Jozsa, Shor, Grover, superdense coding and entanglement swapping
8. Weekly schedule

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| Week | Class |  | McMahon reading | HW Sp2023 |
| 1 | 1 | Intro and qubits | Ch. 2 pp 11-18 | HW1  |
|  | 2 | Bra-ket, matrices and operators | Ch 2. 28-31, Ch. 3 pp 39-45 |  |
| 2 | 3 | Quantum gates and circuits | Ch 8 pp. 176-180, 185-192 | HW2  |
|  | 4 | No cloning, teleportation | Ch 13 pp. 279-280, 225-228 |  |
| 3 | 5 | Basis sets, inner product, orthonormality | Ch. 2 pp 19-28 | HW3  |
| 4 | 6 | Hermitian operators, etc., eigenstuff, trace | Ch 3 pp. 46-57 |  |
|  | 7 | Hadamard through quantum interference | Ch 9. pp 197-203 | HW4  |
| 5 | 8 | Deutsch(-Jozsa) | Ch 9. pp 203-210 | HW5  |
|  | 9 | **Review** |  |  |
| 6 | 10 | Midterm I |  |  |
|  | 11 | Expectation values, unitary transformations, projection operators | Ch. 3 pp. 57-66 | HW6  |
| 7 | 12 | Fundamentals of QM: commutators, HUP, SE | Ch 3 pp. 66-71 |  |
|  | 13 | Tensor products of states and operators | Ch 4 pp. 73-84 | HW7  |
| 8 | 14 | QFT | Ch 9 pp. 211-216 |  |
|  | 15 | Shor/QPE | Ch 9 pp. 216-218 | HW8  |
| 9 | 16 | Density operator | Ch 5 pp. 85-92 |  |
|  | 17 | Key properties of the density operator | Ch 5 pp. 92-99 | HW9  |
| 10 | 18 | Characterizing mixed states | Ch 5 pp. 99-111 | HW10  |
|  | 19 | **Review** |  |  |
| 11 | 20 | Midterm II |  |  |
|  | 21 | Partial trace, Bloch vector | Ch 5 pp. 111-117 | HW11  |
| 12 | 22 | Grover | Ch 9 pp. 218-221 | HW12  |
|  | 23 | Measurements, projective measurements | Ch 6 pp. 121-132 |  |
| 13 | 24 | Measurements on composite systems | Ch 6 pp. 132-139 | HW13  |
|  | 25 | Entanglement in general | Ch 7 pp. 147-151, 155-162 |  |
| 14 | 26 | Bell's theorem | Ch 7 pp. 151-155 | HW14  |
|  | 27 | Introduction to Error Correction I | Notes provided |  |
| 15 | 28 | Introduction to Error Correction II | Notes provided |  |
|  | 29 | **Review** |  |  |
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1. Grading details: The course will comprise weekly homework (25%), final exam (25%), two midterm exams (15% each), pre-class reading and checkpoint questions (10%), and class participation (10, 9, 7, 4, 0% for 0, 1, 2, 3, 4 absences), recorded in the course gradebook. The late homework policy is 20% reduction if submitted less than 2 weeks late and before the final course deadline, whichever is earlier. There are bonus points (maximum 3%) for checkpoint questions answered correctly in class. 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)
2. Disabilities access statement: please add a standard here—I don’t know where to find this