OPTI 646

Introduction to Quantum Information and Computation

This course covers the foundations of Quantum Information Science and selected topics in Quantum Communication and Quantum Computation, including physical implementations.

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Text: "Quantum Information and Computation", lecture notes by John Preskill, Caltech 1998. Can be downloaded for free at

http://theory.caltech.edu/~preskill/ph229/notes/book.ps

(There are several versions of the notes; make sure you get the version that contains Chapters 1-6 in a single file)

- Course Website: <u>https://wp.optics.arizona.edu/opti646/</u>
- Lectures: Meinel 305, Tuesdays and Thursdays 12noon-1:30pm.
- Office Hours: Tuesdays and Thursdays 2-3:30pm. If you give me a heads-up beforehand, I can usually find time for a chat outside regular office hours.
- **NOTE:** OPTI 646 is taught in a live, in-person format. I plan to zoom-record lectures and post video and slides on the course website, but these recordings are not meant to substitute for in-person attendance.
- **Grading:** Homework (30%), Student Presentation or Term Paper (40%), and class participation (30%). In place of final exams, each student is required to give a Lecture or submit a Term Paper on a topic related to Quantum Information Science.

Prerequisites:

A solid knowledge and understanding of graduate level quantum mechanics is essential, as developed in, for example, OPTI/PHYS 570A "Quantum Mechanics", or equivalent.

This course uses the notation and conceptual language of the "Cohen-Tannoudji school of quantum mechanics", adapted in the OPTI 570/544/646 series of graduate level courses.

Topics

Introduction and overview

Physics of information, Quantum computation Quantum parallelism, Deutsch's problem Quantum error correction Physical implementation: Ion trap, Cavity QED, NMR

Review of quantum mechanics I - basics

State vectors, Linear operators, Observables Postulates of quantum mechanics

Review of quantum mechanics II – bipartite systems

Tensor product of state spaces Measurements on one part of a system Density operator, Separate description of part of a system, Partial trace

Qubits, spin-1/2 & other 2-level systems

Spin observables, Pauli matrices Pure states, density operator, Bloch picture Rotations, Schrödinger evolution, single-qubit gates.

Entanglement

2-spin state space Alice & Bob joint experiments, Local measurements and correlations Sending non-orthogonal states, Significance of ensemble decomposition Local hidden variable theories, Bell inequalities

Quantum Communication

Information in entangled pairs, Dense coding Quantum key distribution, Security against eavesdroppers, No cloning theorem Quantum teleportation

General Theory of Measurement

Von Neumanns theory of orthogonal measurement, System-meter model Non-orthogonal measurements – POVM's Implementation as orthogonal measurement in extended state space

Superoperators and Decoherence

Operator-sum representation, Kraus operators, Super-operators Decohering quantum channels – depolarizing, phase & amplitude damping

Student Lectures and Term Papers 2002 - 2020

Student Lecture/Term Paper Topics 2002 (7)

EPR and GHZ, loopholes Quantum teleportation Quantum communication and quantum cryptography Neutral atom quantum computation – optical lattices Slow light and quantum data storage Quantum games Quantum measurement – QND and POVM

Student Lecture/Term Paper Topics 2005 (6)

Quantum Computing with Ion Traps Quantum Data Storage in Ensembles Quantum Algorithms Quantum Key Distribution Solid State Implementations of Quantum Computation Classical Wave Simulations of QM

Student Lecture/Term Paper Topics 2008 (14)

EPR experiments Quantum Non-Demolition Measurements Quantum State Reconstruction Public Key Cryptography and the RSA cryptosystem Slow light and quantum data storage Quantum teleportation Ion trap quantum computation Linear optics quantum computation Solid state implementations of quantum computation Robust quantum control of qubits Quantum simulation of model Hamiltonians Shor's algorithm for factoring Topological quantum computing Quantum Information Theory - Holevo Information, Accessibe Information

Student Lecture/Term Paper Topics 2010 (9)

EPR experiments Quantum Non-Demolition measurements Quantum State Reconstruction Quantum Metrology Public Key Cryptography and the RSA cryptosystem Slow Light and Quantum Data Storage Ion Trap Quantum Computation Grovers Agorithm for Data Base Search Quantum Trajectories and Quantum Monte Carlo Simulation

Student Lecture/Term Paper Topics 2012 (7)

Quantum Non-Demolition measurements Spin Squeezing Weak Values in Quantum Measurement Quantum Cryptography Grovers Algorithm Adiabatic Quantum Computing Quantum Simulation in Chemistry

Student Lecture/Term Paper Topics 2015 (4)

Quantum non-demolition measurements Superoperators and decoherence Dynamical decoupling and composite pulses Measurement based one-way quantum computation

Student Lecture/Term Paper Topics 2018 (5)

Quantum Repeaters Surface Code Quantum Computing Grovers Algorithm Quantum Tomography Squeezed States

Student Lecture/Term Paper Topics 2020 (13)

Frequency Combs and Quantum Computation Overview of Quantum Gates for Ion Trap Quantum Computers Quantum Non-Demolition Measurements in Quantum Optomechanics GHZ States and Tests of LVH Theories Quantum Neural Networks Continuous Measurement and Quantum Control Analog vs Digital Simulation and the Effects of Trotterization Variational Quantum Eigensolver (VQE) Quantum Metrology: Quantum Fisher Information and Estimation Strategies Quantum Memory: A Review Shor's Algorithm A Review of Quantum Error Correction of a Qubit Encoded in Grid States Quantum Error Correction Codes

Student Lecture/Term Paper Topics 2022 (15)

Quantum Annealing Blind Quantum Computation Measurement Based and Delegated QC Topological QC Optical Computing with CV Cluster States Semiconductor Spin Qubits Qubits in Harmonic Oscillators Quantum Fisher Information and Cramer Rao Bounds Quantum Neural Networks Optical Coherent State Discrimination Quantum Causality Gaussian Boson Sampling Survey of Optical Quantum Computing Quantum Acoustics and Quantum Control Quantum Key Distribution