

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: <https://wp.optics.arizona.edu/opti646/>

Lectures: Meinel 305, Mondays and Wednesdays 9:30-11am

Office Hours: Room 604, 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 Neumann's 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 - 2022

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, Accessible 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
Grover's Algorithm 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
Grover's 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
Grover's 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 LHV 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