OPTI 646
Introduction to Quantum Information and Computation

The course covers the foundations of quantum information and selected topics in quantum communication and quantum computation, including physical implementations.

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http://theory.caltech.edu/~preskill/ph219/index.html#lecture

Course Website: https://wp.optics.arizona.edu/opti646/

Lectures: Meinel 432, Tuesdays and Thursdays 12noon-1:30pm.

Zoom Link: https://arizona.zoom.us/j/89787418732 / PW QuISE646

Office Hours: Tuesdays and Thursdays 2-3:30pm.
If you give me a heads-up beforehand, I can often 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 on the course website, but these recordings are not meant to substitute for in-person attendance.

Grading: Homework (30%), student presentation or paper (40%), and class participation (30%). Each student is required to give a lecture presentation or submit a paper on a topic related to Quantum Information Science

Prerequisites: A solid knowledge and understanding of graduate level quantum mechanics is essential, as developed for example in OPTI/PHY 570A “Quantum Mechanics” or equivalent.
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
Quantum Information Theory
Shannon entropy, classical data compression
Shannon's noiseless coding theorem, Noisy channel coding theorem
Von Neumann entropy
Quantum data compression, Schumacher compression,
Schumacher's noiseless coding theorem
Mixed-state coding

Quantum Computation
Classical circuits, universal gate sets
Classical circuit complexity, complexity classes (P, NP, NPC, NPI)
Quantum circuits, Quantum complexity (BQP)
Universal quantum gates, Deutsch’s gate, other universal sets
Quantum database search, Grovers algorithm

Student Lecture 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 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 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
Shors algorithm for factoring
Topological quantum computing
Student Lecture 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 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 Topics 2015 (4)
- Quantum non-demolition measurements
- Superoperators and decoherence
- Dynamical decoupling and composite pulses
- Measurement based one-way quantum computation

Student Lecture Topics 2018 (5)
- Quantum Repeaters
- Surface Code Quantum Computing
- Grover’s Algorithm
- Quantum Tomography
- Squeezed States

Student Lecture 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