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.

Professor: Poul Jessen, Meinel 604. Email: jessen@optics.arizona.edu

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

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/PHYS 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
- Shannons noiseless coding theorem, Noisy channel coding theorem
- Von Neumann entropy
- Quantum data compression, Schumacher compression,
- Schumachers 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
Grovers Agorithm 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
Grovers 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
Grovers 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