**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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**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](http://theory.caltech.edu/~preskill/ph219/index.html#lecture)

**Course Website:** [https://wp.optics.arizona.edu/opti646/](https://wp.optics.arizona.edu/opti646/)

**Grading:** Homework (30%), student presentation (40%) and class participation (30%). Each student is required to give a lecture presentation 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
  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
  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
  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
  Quantum Information Theory - Holevo Information, Accessible Information

Student Lecture Topics 2010
  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 Algorithm for Data Base Search
  Quantum Trajectories and Quantum Monte Carlo Simulation
**Student Lecture Topics 2012**
- 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**
- Quantum non-demolition measurements
- Superoperators and decoherence
- Dynamical decoupling and composite pulses
- Measurement based one-way quantum computation

**Student Lecture Topics 2018**
- Quantum Repeaters
- Surface Code Quantum Computing
- Grovers Algorithm
- Quantum Tomography
- Squeezed States