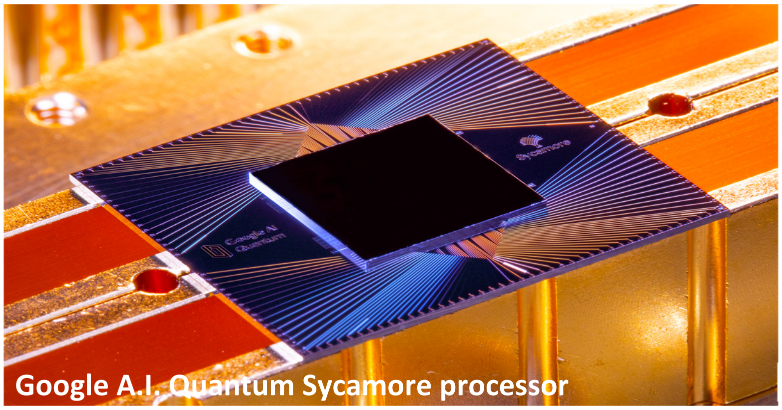
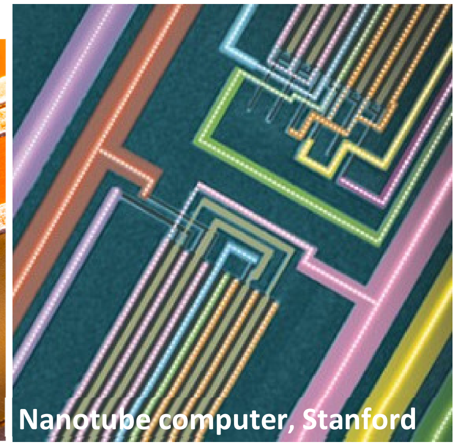
Quantum Mechanics for Engineers

EE 521
Winter Quarter

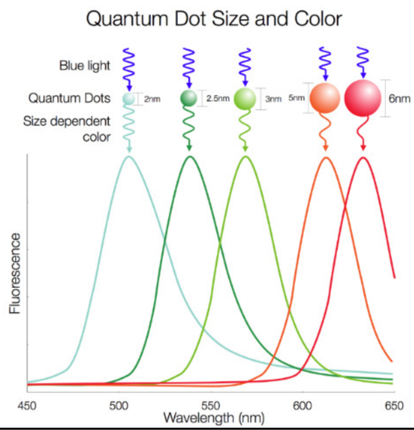


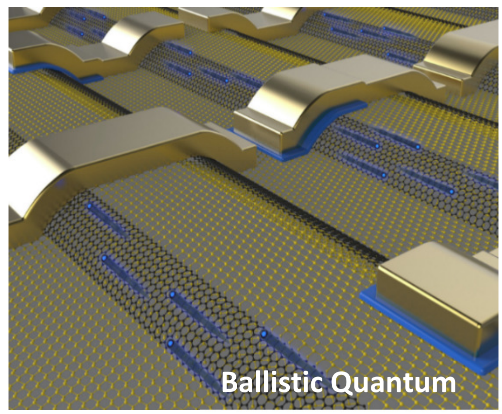
Google A.I. Quantum Sycamore processor



Nanotube computer, Stanford

IBM Quantum Computer





Ballistic Quantum

- **Qubit versus bit || Quantum Entanglement**
- **Problems that a quantum computer can solve?**
- **Bell's Theorem**
- **What is Quantum Supremacy?**

- **Grover's Algorithm for sorting**
- **Nanotubes, graphene**
- **Bloch's theorem**
- **Quantum of Conductance**

This course is designed for students who are interested in applied quantum mechanics. Students will be introduced to the basic physical and mathematical aspects of quantum mechanics. The focus will be on applying principles of quantization, uncertainty principle and superposition principle to understand how to engineer better emitters of light, conductors and computers. Learn about quantum dots, ballistic transport, Bloch's theorem, graphene, nanotubes, qubits, quantum information, Bell's theorem and Grover's Algorithm. (Prereq: MATH 307)

Instructor: M. P. Anantram
E-mail: anant@uw.edu

EE 521: Quantum Mechanics for Engineers (Winter Quarter)

"Think quantum"

Description

The focus of this course is to introduce students to quantum mechanics using 1D, 2D and 3D nanomaterials and quantum computing. The students will develop a working knowledge of qubits, quantization in quantum dots/wells/wires, band structure, Applications will focus on qubits, nanodevices, nanomaterials, basics of quantum information.

You will get to use *IBM's software on quantum computing/information Qiskit* in this course.

Instructor

M. P. Anantram (Anant)
anant@uw.edu
Phone: 206-221-5162
Office : EE Building, Room # M218

What are the primary learning objectives for the course?

The learning objectives for EE 521:

1) Learn to *think quantum* so as to aid reading literature
2) Interpret and use the solutions of Schrodinger's wave equation
3) Interpret De Broglie's Uncertainty Principle and Energy-Time Uncertainty Principle correctly
4) Develop the ability to perform simple quantum calculations and numerically solve Schrodinger's equation in 1D
5) Calculate basic expressions for tunneling through barriers and resonant tunneling phenomena
6) Learn to calculate the role of quantization in technological relevant examples: quantum dots, nanowires, quantum wells
7) Learn to use method of separation of variables
8) Learn the basic principles behind the tight binding method
9) Learn to apply Bloch's theorem in bulk and nanomaterials to calculate the bandstructure
10) Learn how current is carried from quantum principles
11) Learn the basics of spin
12) Learn the basics of quantum information and computing
13) Perturbation theory (timed dependent and time indpendent versions)

Detailed Topics

1. Basic Quantum Mechanics

- a. Historical Motivation for Quantum Mechanics
- b. Schrodinger's Equation
- c. Solving 1D Schrodinger's eqn on the computer: Discretization of Schrodinger's equation
- d. Properties of the Wavefunction (Orthonormality, Superposition & Expectation value)
  - i. Probability

ii. Orthonormality of wave functions
iii. Superposition Principle and Quantum Measurement
iv. Average value / Expectation value
e. Uncertainty Relationship
f. Continuity equation for Probability Density and expression for Probability Current Density
g. Hilbert Spaces
h. A brief recollection of the 3D real space vector (review)
i. A brief recollection of Fourier expansion (review)
j. An introduction to Hilbert's vector space
i. Braket notation
ii. Operators in Matrix form

2. Quantum Information

a. Prelude to Chapter: Quantum Measurement
b. Introduction
c. Product state
d. Entangled state
e. Qubits in matrix form
f. Bloch sphere
g. Basic gates
h. Pauli & Hadamard operators
i. Clifford gate
j. More logic gates
k. Controlled Pauli, Controlled Hadamard and Controlled Toffoli gates
l. Bell's inequality
m. Grover's algorithm
n. Basic Public key distribution
o. Basic Quantum teleportation

3. Tunneling

a. Introduction
b. Tunneling through single barriers
i. Derivation
ii. Wide-Tall barriers
c. Tunneling time through a single rectangular barrier
d. Tunneling though a Double Barrier Resonant Tunneling Structure
i. Resonant tunneling diode – qualitative discussion
e. Breit-Wigner Formula
f. Tunneling through multiple barriers

4. Quantum dots, wells and nanowires: Separation of variable

a. Introduction to separation of variables using the effective mass equation
b. Quantum Dots
c. Quantum wells

d. Nanowires

5. Spins

a. Summary of important equations from Force, energy and electromagnetic fields
b. Hamiltonian of charge particle
c. Stern-Gerlach experiment
d. Some facts and Jargon in describing spin
e. Spin-orbit interaction
f. Relationship between spin angular momentum and torque

6. Crystalline solids

a. Unit cell and Basis vectors
b. Real space and Reciprocal space
c. Bloch's theorem (Energy levels, wave function)
   - Carbon nanotubes
   - Graphene
   - Diamond

7. Density of states, electron density and current density

a. Density of states (DOS) definition
b. DOS of 1D free particle
c. DOS of 2D and 3D free particles
d. DOS of nanowire with finite cross sectional area
e. DOS of quantum well
f. Electron density
g. Derivation of classic formula for electron & hole density in semiconductors
h. Current density
i. Landauer-Buttiker formula
j. Conductance quantum

8. Perturbation theory

a. First order perturbation theory
b. Time-dependent perturbation theory
c. Two-level system
d. Scattering rates / Transition probability
   i. Optical absorption / dipole matrix elements

Reading Material

Main Text :

Quantum Mechanics for Engineers

M. P. Anantram and Daryoush Shiri

An e-copy of the draft will be provided to students.

Supplementary Books :

1) Quantum Mechanics: For Engineering, Materials Science, and Applied Physics: 1st Edition(3/7/1994) by Herbert Kroemer, Publisher: Prentice Hall (Book for general quantum mechanics)
2) Quantum Mechanics For Scientists and Engineers, by David A. B. Miller, Cambridge University Press
3) Atoms to Transistors, by Supriyo Datta, Cambridge University Press.

Grading

EE521: HW: 34%, Late Midterm: 33%, Project : 33% (No final exam)