Department of Electrical Engineering
Engineering Quantum Mechanics. Fall 2010.
TTh 11.00 a.m. – 12.20 a.m., KAP 166.

Web site: http://www.usc.edu/alevi
Web site: http://web-app.usc.edu/soc/20103/ee.html
Web site: http://www.usc.edu/students/enrollment/classes/term_20103/

EE539: Abstract and Prerequisites

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Office Hours:
TTh 8:00 a.m. - 9:30 a.m.
or by appointment

Grading:

Midterm	**35%**
Homework	**10%**
Final Exam	**55%**

Final Exam:
8:00 a.m. - 10:00 a.m.,
Tuesday, December 14, 2010,
KAP 166

Required Text:
Applied Quantum Mechanics
A.F.J. Levi
Cambridge University Press (2006)
ISBN 9780521860963

Last day of class – Thursday, December 2, 2010

Abstract
Quantum mechanics is the basis for understanding physical phenomena on the atomic and nano-meter scale. There are numerous applications of quantum mechanics in biology, chemistry and engineering. Those with significant economic impact include semiconductor transistors, lasers, quantum optics and photonics. As technology advances, an increasing number of new electronic and opto-electronic devices will operate in ways that can only be understood using quantum mechanics. Over the next twenty years fundamentally quantum devices such as single-electron memory cells and photonic signal processing systems will become common-place. The purpose of this course is to cover a few selected applications and to provide a solid foundation in the tools and methods of quantum mechanics. The intent is that this understanding will enable insight and contributions to future, as yet unknown, applications.

Prerequisites
Mathematics:
A basic working knowledge of differential calculus, linear algebra, statistics and geometry.
Computer skills:
An ability to program numerical algorithms in C, MATLAB, FORTRAN or similar language and display results in graphical form.
Physics background:
Should include a basic understanding of Newtonian mechanics, waves and Maxwell's equations.

Introduction: *Lectures 1 - 3*

Lecture 1

TOWARDS QUANTUM MECHANICS – PARTICLES AND WAVES

Diffraction, interference, and correlation functions for light
Black-body radiation and evidence for quantization of light
Photoelectric effect and the photon particle

Lecture 2

Secure quantum communication
The link between quantization of photons and quantization of other particles
Diffraction and interference of electrons
When is a particle a wave?

Lecture 3

THE SCHRÖDINGER WAVE EQUATION

The wave function description of an electron of mass m_0 in free-space
The electron wave packet and dispersion
The Bohr model of the hydrogen atom
Calculation of the average radius of an electron orbit in hydrogen
Calculation of energy difference between electron orbits in hydrogen
Periodic table of elements
Crystal structure
Three types of solid classified according to atomic arrangement
Two-dimensional square lattice, cubic lattices in three-dimensions
Electronic properties of semiconductor crystals
The semiconductor heterostructure

Using the Schrödinger wave equation: *Lectures 4 - 6*

Lecture 4

INTRODUCTION

The effect of discontinuities in the wave function and its derivative

WAVE FUNCTION NORMALIZATION AND COMPLETENESS

INVERSION SYMMETRY IN THE POTENTIAL

Particle in a one-dimensional square potential well with infinite barrier energy

NUMERICAL SOLUTION OF THE SCHRÖDINGER EQUATION

Matrix solution to the descretized Schrödinger equation
Nontransmitting boundary conditions. Periodic boundary conditions

CURRENT FLOW

Current flow in a one-dimensional infinite square potential well
Current flow due to a traveling wave

DEGENERACY IS A CONSEQUENCE OF SYMMETRY

Bound states in three-dimensions and degeneracy of eigenvalues

Lecture 5

BOUND STATES OF A SYMMETRIC SQUARE POTENTIAL WELL

Symmetric square potential well with finite barrier energy

TRANSMISSION AND REFLECTION OF UNBOUND STATES
Scattering from a potential step when effective electron mass changes
Probability current density for scattering at a step
Impedance matching for unity transmission

Lecture 6
PARTICLE TUNNELING
Electron tunneling limit to reduction in size of CMOS transistors
THE NONEQUILIBRIUM ELECTRON TRANSISTOR

Scattering in one-dimension: The propagation method: *Lectures 7 - 10*
Lecture 7
THE PROPAGATION MATRIX METHOD
Writing a computer program for the propagation method
TIME REVERSAL SYMMETRY
CURRENT CONSERVATION AND THE PROPAGATION MATRIX

Lecture 8
THE RECTANGULAR POTENTIAL BARRIER
Tunneling
RESONANT TUNNELING
Localization threshold
Multiple potential barriers
THE POTENIAL BARRIER IN THE δ-FUNCTION LIMIT

Lecture 9
ENERGY BANDS IN PERIODIC POTENTIALS: THE KRONIG-PENNY POTENTIAL
Bloch's theorem
Propagation matrix in a periodic potential

Lecture 10
THE TIGHT BINDING MODEL FOR ELECTRONIC BAND STRUCTURE
Nearest neighbor and long-range interactions
Crystal momentum and effective electron mass
USE OF THE PROPAGATION MATRIX TO SOLVE OTHER PROBLEMS IN ENGINEERING
THE WKB APPROXIMATION
Tunneling

Related mathematics: *Lecture 11 - 12*
Lecture 11
ONE PARTICLE WAVE FUNCTION SPACE
PROPERTIES OF LINEAR OPERATORS
Hermitian operators
Commutator algebra

DIRAC NOTATION
MEASUREMENT OF REAL NUMBERS
Time dependence of expectation values. Uncertainty in expectation value
The generalized uncertainty relation
THE NO CLONING THEOREM

Lecture 12
DENSITY OF STATES
Density of states of particle mass *m* in 3D, 2D, 1D and 0D
Quantum conductance
Numerically evaluating density of states from a dispersion relation
Density of photon states

The harmonic oscillator: *Lectures 13 - 14*
Lecture 13
THE HARMONIC OSCILLATOR POTENTIAL
CREATION AND ANNIHILATION OPERATORS
The ground state. Excited states
HARMONIC OSCILLATOR WAVE FUNCTIONS
Classical turning point
TIME DEPENDENCE
The superposition operator. Measurement of a superposition state

Lecture 14
Time dependence in the Heisenberg representation
Charged particle in harmonic potential subject to constant electric field
ELECTROMAGNETIC FIELDS
Laser light
Quantization of an electrical resonator
Quantization of lattice vibrations
Quantization of mechanical vibrations

Fermions and Bosons: *Lecture 15 - 16*
Lecture 15
INTRODUCTION
The symmetry of indistinguishable particles. Slater determinant
Pauli exclusion principle. Fermion creation and annihilation operators – application to tight-binding Hamiltonian

Lecture 16
FERMI-DIRAC DISTRIBUTION FUNCTION
Equilibrium statistics
Writing a computer program to calculate the Fermi-Dirac distribution
BOSE-EINSTIEN DISTRIBUTION FUNCTION

Time dependent perturbation theory and the laser diode: *Lectures 17 - 21*

Lecture 17

FIRST-ORDER TIME-DEPENDENT PERTURBATION THEORY

Abrupt change in potential

Time dependent change in potential

CHARGED PARTICLE IN A HARMONIC POTENTIAL

FIRST-ORDER TIME-DEPENDENT PERTURBATION

Lecture 18

FERMI'S GOLDEN RULE

IONIZED IMPURITY ELASTIC SCATTERING RATE IN GaAs

The coulomb potential. Linear screening of the coulomb potential

Correlation effects in position of dopant atoms

Calculating the electron mean free path

Lecture 19

EMISSION OF PHOTONS DUE TO TRANSITIONS BETWEEN ELECTRONIC STATES

Density of optical modes in three dimensions

Light intensity

Background photon energy density at thermal equilibrium

Fermi's golden rule for stimulated optical transitions

The Einstein A and B coefficients

Occupation factor for photons in thermal equilibrium in a two-level system

Derivation of the relationship between spontaneous emission rate and gain

Lecture 20

THE SEMICONDUCTOR LASER DIODE

Spontaneous and stimulated emission

Optical gain in a semiconductor. Optical gain in the presence of electron scattering

DESIGNING A LASER CAVITY

Resonant optical cavity. Mirror loss and photon lifetime

The Fabry-Perot laser diode. Rate equation models

Lecture 21

NUMERICAL METHOD OF SOLVING RATE EQUATIONS

The Runge-Kutta method. Large-signal transient response. Cavity formation

NOISE IN LASER DIODE LIGHT EMISSION

Effect of photon and electron number quantization

Time independent perturbation theory: *Lectures 22 - 23*

Lecture 22

NON-DEGENERATE CASE

Hamiltonian subject to perturbation W

First-order correction. Second order correction

Harmonic oscillator subject to perturbing potential in x, x^2 and x^3

Lecture 23

DEGENERATE CASE

Secular equation
Two states
Perturbation of two-dimensional harmonic oscillator
Perturbation of two-dimensional potential with infinite barrier

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Angular momentum and the hydrogenic atom: *Lectures 24 - 26*

Lecture 24

ANGULAR MOMENTUM

Classical angular momentum
The angular momentum operator
Eigenvalues of the angular momentum operators L_z and L^2
Geometric representation

Lecture 25

SPHERICAL COORDINATES, SPHERICAL HARMONICS AND THE HYDROGEN ATOM

Spherical coordinates and spherical harmonics
The rigid rotator
Quantization of the hydrogenic atom
Radial and angular probability density

Lecture 26

ELECTROMAGNETIC RADIATION

No eigenstate radiation
Superposition of eigenstates
Hydrogenic selection rules for dipole radiation
Fine structure
Hybridization
