

**Department of Electrical Engineering  
Engineering Quantum Mechanics. Fall 2007.  
TTh 11.00 a.m. – 12.20 a.m., VHE 210.**

**Web site:** <http://www.usc.edu/alevi>

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**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 18, 2007,**

**VHE 210**

**Required Text:**

**Applied Quantum Mechanics**

**A.F.J. Levi**

**Cambridge University Press (2006)**

**ISBN 9780521860963**

Last day of classes – Friday, December 7, 2007

**Abstract**

Today, 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*

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

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**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 discretized 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*

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**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 POTENTIAL BARRIER IN THE  $\delta$ -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 BANDSTRUCTURE*

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

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**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

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**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

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**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-EINSTEIN DISTRIBUTION FUNCTION*

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**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*

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**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  $L^2$   
Geometrical 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

