

PH 411/511 INTRODUCTION TO QUANTUM MECHANICS

Fall-2009
Room CH -325
Tue & Th: 16:40 -18:30
<http://www.physics.pdx.edu/~larosaa/>

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Office hours: Tue & Th: 18:30 -19:30

Textbook:

The course is being developed towards a self sustained lecture notes (see below), but I am not there yet. The contents from my current lectures notes have mainly followed **Richard Feynman**, "**The Feynman Lectures on Physics**," **Volume III**, Addison Wesley, 1989. Physics majors typically have this book. I have placed one copy in the Library Reserve Room.) Another good complementary reference is **R. Eisberg and R. Resnick**, "**Quantum Physics**," 2nd Edition, Wiley, 1985, although I have not used it as much as the Feynman book.). This book fits well the interest of both engineering and physics majors. A copy is also available in the Library Reserve Room

Students should be able to follow this course with any standard Quantum Mechanics textbook (plus the lecture notes). But if you decided to purchase a textbook for your own I would suggest: "**Introduction to Quantum Mechanics**" by **David Griffiths**; 2nd Edition, Pearson Prentice Hall.

Grading: **Homework 30%** To be assigned regularly
1st Exam 30% Tuesday, November 3rd Time 16:40 - 18:30
Final exam 40% Tuesday, December 8th, Time 17:30 - 19:20

90-100 A	85-89 A-	80-84 B+	75-79 B
70-74 B-	65-69 C+	60-64 C	55-59 C- 50-54 D

Lecture Notes Lectures notes that cover those sections of the course prepared following the Feynman textbook will be available at <http://www.physics.pdx.edu/~larosaa>

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SYLLABUS

Part- I: The TRANSITION from CLASSICAL to QUANTUM PHYSICS

CHAPTER-1 ABOUT THIS COURSE

Introduction, philosophy of the course, course organization

CHAPTER 2 CLASSICAL PHYSICS (REVIEW)

2.1 Electromagnetism

(The Maxwell's equations, light as electromagnetic radiation, Michelson-Morley experiment, Lorentz' length-contraction hypothesis, the Lorentz' transformation.)

2.2 Special theory of relativity

(Electromagnetism and the principle of relativity, Einstein's principles of relativity, relationship of space-time coordinates in different inertial reference frames, required modification of the classical mechanics laws for compatibility with the relativity principles, relativistic mass, four-components vectors and symmetry)

CHAPTER 3 THE ORIGINS OF QUANTUM PHYSICS

3.1 Black body radiation

(Thermal equilibrium of radiation, classical approach to calculate average energy, Planck's hypothesis to calculate average energy.)

3.2 Particle-like properties of radiation

3.3 Wave-like properties of particles

3.4 Wave-particle duality

Part II: MAKING PREDICTIONS in QUANTUM MECHANICS and the HEISENBERG's PRINCIPLE

CHAPTER-4 WAVEPACKETS: DESCRIPTION of the FREE PARTICLE MOTION

4.1 **Spectral Decomposition of the wavefunction (relative to base states)** (The scalar product, spectral decomposition using complex variable: the Fourier transform, brackets notation.)

4.2 Phase Velocity and Group Velocity

Planes, traveling plane waves, phase velocity, Group Velocity

4.3 Description of a free-particle motion

(Wavefunction with a definite momentum, a wavepacket as a wavefunction.)

CHAPTER-5 QUANTUM BEHAVIOR of PARTICLES and the HEISENBERG'S UNCERTAINTY PRINCIPLE

- 5.1 Quantum behavior of particles passing through two slits**
(The concept of probability, contrast between experiments with bullets, experiment with light, attempts to track electrons' trajectories)
- 5.2 The Heisenberg's Uncertainty Principle**
 - 5.2.A Uncertainty in the position Δx and linear momentum Δp .**
 - 5.2.B Use of the grating resolving power to show the uncertainty the measurement of the energy content ΔE of a pulse and the time Δt required for the measurement.** Gratings, phasors (addition of multiple waves), gratings and spectral resolution, condition for the minimum length time Δt required for the measurement of the energy E with a resolution ΔE .
 - 5.2.C. Uncertainty principle and the resolving power of a microscope.** Image formation and the resolving power of a lens. Watching electrons through the microscope
- 5.3 Interpretation of the Wavefunction**
The need of a wavepacket (rather than a single harmonic function) to describe a free particle motion, Einstein's interpretation of the granularity of the electromagnetic field, Max Born's probabilistic Interpretation of the wavefunction, the concept of ensemble. The philosophy of Quantum Theory

CHAPTER-6 THE CONCEPT of AMPLITUDE PROBABILITY

- 6.1 Quantum mechanics description in terms of base-states**
- 6.2 Probability amplitude**
- 6.3 General guiding principles to assign amplitude probabilities**
- 6.4 Interference between Amplitude Probabilities**
 - 6.4.1 Two-slit experiment: Watching electrons' trajectories**
Adding amplitude-probabilities for events producing the same final state. Adding probabilities for vents producing different final states.
 - 6.4.2 Scattering from a crystal**
 - 6.4.3 Identical Particles**

SECTION- III The HAMILTONIAN OPERATOR and the SCHRODINGER EQUATION

CHAPTER-7 THE HAMILTONIAN MATRIX. How Do States Change with Time?

- 7.1 What are the base states?**
- 7.2 How do states change with time?**
 - 7.2.A The Evolution Operator**
 - 7.2.B The Hamiltonian Matrix**
- 7.3 General characteristic of the Hamiltonian Matrix**

- 7.3.A Symmetric components
- 7.3.B Stationary states
- 7.3.C Physical Interpretation of the Hamiltonian matrix
- 7.4 Two-State Systems
 - 7.4.A The ammonia Molecule
 - 7.4.A.a Case $H_{12} = H_{21} = 0$ Absence of crosstalk
 - 7.4.A.b Case: $H_{12} = H_{21} \neq 0$ Quantum Tunneling
 - Figuring out the Hamiltonian Matrix
 - Time evolution of the quantum states
 - Conservation of the total probability
 - Stationary states
 - 7.4.B Molecule in a static electric field
 - 7.4.C Molecule in a time dependent electric field
 - Operation of the ammonia maser
 - Transitions at resonance
 - 7.4.D Spin $\frac{1}{2}$ particle in a magnetic field

CHAPTER-8 From the HAMILTONIAN EQUATIONS to the SCHRODINGER EQUATION.

The case of an electron propagating in a crystal lattice

- 8.1 Hamiltonian for an electron propagating in a crystal lattice
 - 8.1.A Defining the Base States and the Hamiltonian Matrix
 - 8.1.B Stationary States
 - Energy bands
 - 8.1.C Time-dependent States
 - Electron wave-packet and group velocity
 - Effective mass (case of low energy electrons)
- 8.2 Hamiltonian equations in the limit when the lattice space tends to zero
 - 8.2.A From a discrete to a continuum basis
 - 8.2.B The dependence of amplitude probability on position.
 - Transition *from* describing a quantum state $|\Psi\rangle$ in very general terms, *to* a detailed account of the amplitude-probability dependence on position $\Psi(x)$
 - 8.2.C Equation describing an electron in an external potential $V = V(x, t)$
- 8.3 The Postulated Schrodinger Equation

CHAPTER-9 WAVEFUNCTIONS and OPERATORS

- 9.1 The Wavefunction
 - 9.1.A Representation of the wavefunction in the spatial coordinates basis $\{|x\rangle\}$
 - 9.1.A1 The Delta Dirac

- 9.1.A2 Compatibility between the physical concept of amplitude probability and the notation used for the inner product.
- 9.1.B Representation of the wavefunction in the momentum coordinates basis $\{|p\rangle\}$
 - 9.1.B1 Representation of the $|p\rangle$ state in space-coordinates basis
 - 9.1.B2 Identifying the amplitude probability $\langle p|\Psi\rangle$ as the Fourier transform of the function $\Psi(x)$
- 9.1.C The Hamiltonian equations expressed in the continuum space coordinates. The Schrodinger Equation.
 - 9.1.C1 Born's Interpretation of the Wavefunction
 - Einstein's view on the granularity nature of the electromagnetic radiation.
 - Max Born's probabilistic interpretation of the wavefunction.
 - Deterministic evolution of the wavefunction
 - Ensemble
 - 9.1.C2 Normalization condition for the wavefunction
 - Hilbert space
 - Conservation of probability
 - 9.1.C3 The Philosophy of Quantum Theory
- 9.2 Expectation values
 - 9.2.A Expectation value of a particle's position
 - 9.2.B Expectation (average) values are calculated in an ensemble of identically prepared systems
 - 9.2.C Expectation value of the particle's momentum
- 9.3 Observables and Operators
 - 9.3.1 Observables and operator's eigenvalues
 - 9.3.2 Defining an operator \tilde{F} associated to an observable f
 - 9.3.3 Definition of the linear momentum operator
 - 9.3.3A The linear momentum operator in the momentum space
 - 9.3.3B The linear momentum operator in the spatial coordinates space
 - 9.3.4 Definition of the Position Operator

SECTION- IV SOLVING the SCHRODINGER EQUATION

CHAPTER-10 THE SCHRODINGER EQUATION (in one spatial dimension)

10.1 FINDING A DIFFERENTIAL EQUATION for the WAVEFUNCTION $\Psi(x,t)$

10.1.A Arguments leading to the Schrodinger equation

10.1.B Looking for a differential equation that is compatible with the de Broglie hypothesis and the conservation of energy

10.1.B.a Case: Free particle (constant potential)

10.1.B.b Particle in a potential $V=V(x,t)$

10.1.C Normalization condition for the wavefunction

10.1.D Expectation values

10.2 TIME INDEPENDENT SCHRODINGER EQUATION

10.2.A The zero potential

10.2.B The step potential

10.2.C The barrier potential

10.2.D The square well potential

10.2.E The simple harmonic oscillator potential

CHAPTER-11 ONE ELECTRON ATOMS

11.1 SEPARATION of the TIME INDEPENDENT EQUATION

11.2 SOLUTION TO THE RADIAL COMPONENT

11.3 SOLUTION to the ANGULAR COMPONENT

SECTION- V IDENTICAL PARTICLES

CHAPTER-12 BOSON PARTICLES

12.1 States with two particles

11.1.A Case: Two distinguishable particles

11.1.B Two indistinguishable Bose particles

12.2 Density of probability

11.2.A Case: Two distinguishable particles

11.2.B Case: Two indistinguishable particles

12.3 States with n particles

11.3.A The case of distinguishable particles

11.3.B Bose particles