First Day Handout, Physics 530A

(Dated: today)

Phys 530A, Graduate Quantum Mechanics

Meeting times: MW 4:00-5:15 PM

Text: The primary text will be "Principles of Quantum Mechanics," by R. Shankar, Second Edition
There are many good texts on quantum mechanics. Find one (or more) that you prefer and use it as a secondary reference. Recommended references include (in no particular order):

A. "Quantum Mechanics," Schiff.

B. "Quantum Mechanics: Foundations and Applications," A. Bohm

C. "Quantum Mechanics," Messiah

D. "Quantum Mechanics," Merzbacher

E. "Modern Quantum Mechanics," Sakurai

F. "Quantum Mechanics," Cohen-Tanoudji (Especially Detailed)

G. "Introduction to Quantum Mechanics," Griffiths.

H. "Quantum States of Atoms, Molecules and Solids," by Morrison, Estle and Lane.

Instructor: Professor Byrd

Office: Neckers 491, **email:** mbyrd@physics.siu.edu

Office Hours: TBA

Grades:

- **Homework:** 30 %
- **Midterm:** 35 %
- **Final:** 35 %

"Homework" includes projects, in-class assignments, and problems assigned from the text.

Tentative Course Outline

I.) Mathematical Background

A.) Vector Spaces, Inner Product Spaces, and Dirac Notation
1. Definitions
2. Types of inner products
3. Dirac Notation

B.) Operators: Linear Operators, Matrix Elements and Transformations
1. Linear independence,
2. Gram-Schmidt
3. Subspaces
4. Vectors, Matrices and Tensors
5. Similarity Transformations

C.) Eigenvalues and Eigenvectors
1. Hermitian Operators
2. Anti-Hermitian Operators
3. Unitary Operators
4. Eigenvalues
5. Eigenvectors
6. Diagonalization
7. Mutual Diagonalization/Compatibility
8. Infinite Dimensions

II.) Introduction to Quantum Phenomena

A.) Origin of Quanta and Waves vs. Particles (Discussion only):
1. light: particle or wave? Definitely wave
2. Black-body radiation
3. Extensions of Black-body
4. Bohr atom: atoms don't radiate constantly
5. photo electric effect
6. electron and neutron double slit experiments

B.) Postulates of Quantum Mechanics
1. States' descriptions
2. Measurements
3. The Schrödinger Equation/Unitary evolution
4. Expectation values
5. Uncertainty and compatible observables
6. Density Operator/Matrix
7. Continuity Equation
8. Tensor products

III.) Basic Quantum Problems

A.) Two-state systems
1. Stern-Gerlach Experiment
2. Spin-1/2 states

3. Angular Momentum Commutation relations
4. Density Operator for a Two-state system

B.) Uncertainty relation

1. Derivation of the uncertainty relation
2. No-cloning theorem
3. Best classical encryption
4. Quantum Cryptography/Quantum Key Distribution

C.) Free Particles, 1-D Box, Simple Potentials and Tunneling (Discussion Only)

D.) Simple Harmonic Oscillator

1. Differential Equation (finish for HW)
2. Raising and lowering operators
3. Spectrum
4. Eigenfunctions using R-n-L operators

IV.) Symmetries in Quantum Mechanics I

A.) Translations

1. Generator of Translations
2. Aside: Ehrenfest's Theorem
3. Conservation of Momentum
4. Finite Translations

B.) Rotations and Conservation of Angular Momentum

1. Generator of Rotations
2. Raising and Lowering operators
3. Total angular momentum (squared)
4. Simultaneous Eigenfunctions and their forms: Spherical Harmonics
5. Conservation of Angular Momentum

V.) The Hydrogen Atom

A.) The Schrödinger equation for a central potential

1. Energy Eigenstates
2. Spherical symmetry: $V = V(r)$
3. Conservation of Angular Momentum

B.) Differential Equation

1. Center of mass and relative coordinates
2. Separation of variables
3. Solving for the "r" part

C.) Quantum numbers of the Hydrogenic Atoms

1. Wave functions for the Hydrogenic atoms: ψ_{nlm}
2. Forms and interpretation of ψs
3. Spectroscopic notation

D.) The periodic Table of the elements

1. Pauli exclusion
2. Rows of Periodic Table
3. Columns, closed shells, screening, and reactivity

VI.) Angular Momentum and Spin

A.) Spin

1. What is spin?

2. Total Angular Momentum
3. Pauli Matrices: properties and interpretation
4. Identical Particles
5. Bosons, Fermions and exclusion

B.) Addition of Angular Momenta

1. Example: Two spin-1/2 particles
2. An introduction to group theory
3. Conservation Laws and Group theory: Representation Theory
4. Wigner-Clebsch-Gordan Coefficients
5. Using the tables

VII.) Special Topcis

A.) Open Quantum Systems and noise in quantum qhysics

1. An Example with Implications
2. Local vs. Non-local Operators
3. Operator-sum decomposition (sometimes called Kraus decomposition) with examples
4. Measurements

B.) Entanglement and Bell's Inequality

1. Derivation of Bell's Inequality
2. Peres Condition
3. Examples
4. Peres-Horodecki Condition for Separability

C.) Methods of Solving the Time-dependent Schrödinger Equation

1. Schrödinger Picture
2. Heisenberg Picture
3. Interaction Picture
4. Time-dependent perturbative expansion

D.) Two-State Systems in Nuclear Magnetic Resonance Experiments

1. Resonance
2. Classical treatment of spin in a static field
3. Effect of an alternating magnetic field
4. Quantum Mechanical treatment of a rotating magnetic field
5. Time-dependent expectation values of the spin

VIII.) More Symmetries in Quantum Mechanics

A.) Discrete Symmetries: X-tals and tight-binding (introduction)

B.) Character Tables (classes, characters and symmetries)

C.) Bucky Balls and Carbon Tubes

D.) 6-12 Potentials

E.) Scattering

This outline is quite ambitious and we will need to start immediately and work steadily. Homework will be assigned weekly or daily.

A Note on Your Background

You will be expected to know the material in Chapters 2, 3 and 5 of Shankar.