QUANTUM MECHANICS I - III

PHYS 516 - 518

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Course Schedule: MWF 11:00 - 11:50, Disque 919

Objective: To provide the foundations for modern physics.

Course Topics

- Schrödinger's Papers
  1. Quantization as an Eigenvalue Problem: Part I
  2. Quantization as an Eigenvalue Problem: Part II
  3. Quantization as an Eigenvalue Problem: Part III
  4. Quantization as an Eigenvalue Problem: Part IV
- Forms of Quantum Theory: Matrix Mechanics, Wave Mechanics, Path Integrals
- Separation of Variables:
  1. Klein-Gordan Equation
  2. Schrödinger Equation
- Frobenius's Method
- Eigenvalues and Eigenvectors
- Brief Remarks: Spherical Harmonics

- Time-Independent Perturbation Theory
- Applictions:
  1. Finite nuclear size
  2. Zeeman Effect
  3. Stark Effect
  4. Crossed Fields
- Harmonic Oscillator
  1. Analytic solution: Frobenius' Method
  2. Operator solution
  3. Discretization and Matrix Diagonalization
  4. Ginzburg-Landau Quartic Potential
- Coupled Oscillators
  1. Linear Molecules and Normal Modes
  2. One-Dimensional Solids
     (a) One atom/unit cell
     (b) Two atoms/unit cell
     (c) Three atoms/unit cell
  3. Two-dimensional solids
  4. Three-dimensional solids
- Electromagnetic Field
  1. Maxwell's Equations
  2. Vector and Scalar Potentials
  3. Normal Modes
  4. Independent Oscillators
  5. Quantization
- Time Dependence
- Time-dependent perturbation theory
- Representations:
  1. Schrödinger
  2. Interaction
  3. Heisenberg

- Applictions:
  1. Perturbed harmonic oscillator
  2. Fermi golden Rule
  3. Lorentzians
- Angular Momentum
  1. Analytic representation, angular variables: L
  2. Algebraic representation, $|l, m_l\rangle$
  3. $J \simeq a^\dagger a$
  4. Spin angular momentum: S
  5. Total angular momentum: J
  6. Spherical harmonics
  7. Clebsch-Gordan coefficients
- Angular Momentum Applications
  1. Shielded Coulomb Potential $\rightarrow$ Mendelyeev
  2. Harmonic + Square Well + Spin Orbit = Nuclear Shell Model
  3. Hydrogen $\rightarrow$ Positronium $\rightarrow$ Charmonium $\rightarrow$ Bottomonium

Quantization as an Eigenvalue Problem. I
1. Variational formulation.
2. Standard formulation.
3. Hydrogen atom: Bound states.
4. Hydrogen atom: Scattering states.

Quantization as an Eigenvalue Problem. II
1. Harmonic oscillator.
2. Rotator with fixed axis (2D).
3. Rigid rotator with free axis (3D).
4. Diatomic molecule.
5. Two-dimensional oscillators.
6. Three-dimensional oscillators.
7. Coupled oscillations.
8. Coherent states. (After the first of his 2 intermediate papers.)

Quantization as an Eigenvalue Problem. III
1. Perturbation theory.
2. Stark effect.
3. Line strengths.

Quantization as an Eigenvalue Problem. IV

1. Time-dependent wave equation.
2. Perturbation theory (time-dependent).
3. Resonance phenomena.
4. Minimal electromagnetic coupling.

Ehrenfest Theorems:
1. Expectation values and density matrices/operators.
2. Newton's Equations.
3. Harmonic motion.
4. Orbital angular momentum and torque.
5. Angular momentum and precession.
6. Lorentz force.
7. Hamilton's Equations.
8. The Virial.
9. Quadrupoles.
10. Euler's Equations.
11. Runge Lenz vector and precession (S.R. & G.R.)

Matrix Mechanics
1. Born, Heisenberg, and Jordan.
2. Schrödinger's demonstration of equivalence.
3. Then and Now: the Swing of the Pendulum.
4. Matrix computations.
5. FEM

Feynman's Path Integrals
1. A particle goes along all possible paths.
2. The Action Integral.
3. Equivalence with Schrödinger's Equation (time-dependent).
4. 2-Slit interference pattern (Young diffration pattern).
5. Single-Slit interference pattern (Fraunhofer diffration pattern).
6. Diffraction gratings.
7. Interferometers: Matrix methods.
8. Resonators: Matrix methods.
9. Networks: S-matrices.
10. Networks: eigenstates.

Broad Historical Sweep
1. The light dialogue: From Newton to Einstein (?) and Beyond?
2. The gravity dialogue: From Newton to Einstein (?) and Beyond?
3. Problems with ∞: Planck $\hbar$; Bohr atom; Renormalization; Casimir.
4. The Phases of Quantum Theory: 1913, 1926, 1964.
5. 1913: Correspondence Principle.
6. 1926: Ehrenfest Theorems.

7. 1935: EPR and Schrödinger's Cat.
8. 1964: Bell's Theorem unlocks the flood.
9. 2000 $\rightarrow$ "At last, we're free from our classical manacles." ("The Quantum world is weirder that we could possibly have imagined.")

Uncertainties
1. Position and momentum: $\Delta x \Delta p \geq \hbar/2$.
2. Time and energy: $\Delta t \Delta E \geq \hbar/2$.
3. Angle and angular momentum: $\Delta\theta \Delta L_\theta \geq \hbar/2$.
4. Number and phase: $\Delta N \Delta\phi \geq 1$.
5. Amplitude and phase: $\Delta A \Delta\phi \geq \pi$.
6. Light Blitz Box: 2 ships passing in the night.
7. Squeezed states: trading uncertainties.
8. COBE and an absolute rest frame.
9. Nyquist Theorem.
10. Cramer-Rao Uncertainty Relations.
11. Uncertainty Relations of Statistical Mechanics: $\Delta U \Delta \frac{1}{T} \geq k$.

Symmetry
1. Solving equations.
2. Symmetry $\Rightarrow$ degeneracy.
3. Dynamical symmetry.
4. Classification of states.
5. Point Groups, Space Groups.
6. $SU(2)$ and rotations.
7. $SU(3)$ and particles.
8. $SU(5)$
9. Symmetry-breaking.

Gauge Theories
1. Measuring the gravitational field.
2. Measuring the phase of an electric field.
3. Global gauge transformations: $U(1)$.
4. Local gauge transformations: $U(1)$.
5. Yang-Mills, Nuclear Forces and Mesons: $SU(2)$.
6. Utiyama.
7. Groups and gauge theories: gauge bosons.
8. Renormalizable gauge theories.

Troublesome Infinities
1. The Ultraviolet Catastrophe: Planck and $\hbar$.
2. The Hydrogen Catastrophe: Bohr and the Old Quantum Theory.
3. Electron Self-Energy Catastrophe: Renormalization Group Theory.
4. Zero-Point Fluctuation Catastrophes: Casimir Effect.

Quantum Theory: Phase III

1. Phase I: The Old Quantum Theory.
2. Phase II: Quantum theory: 1925 $\rightarrow$ present.
3. Phase III: The Great Smokey Dragon.
4. EPR & Schrödinger: Entanglement and Decoherence.
5. von Neumann's "proof"
6. Bohm's Hidden Variables: A Counterexample.
7. Bell's theorem (1964).
8. The first three measurements.
9. Later Measurements (Aspect).
10. The Floodgates are Opened: GHZ and others.
11. Entanglement at a Distance: The Danube.
12. Measuring Decoherence.
13. Looking at Pilot Waves (Yves Couder).
14. Delayed choice Experiment.
15. Quantum Eraser.
16. Bounding the speed of Quantum Information: V_{QI}/c.

C^3: Quantum Cryptography, Computing, Communication

(to be supplied)