Ministry of Higher Education and Scientific research

Department of Physics

College of Education

University of Salahaddin- Hawler

Subject: Quantum Mechanics

Course Book for (B.Sc.) Student

Lecturer's name: DR. SATTAR OTHMAN HASAN

Academic Year: 2023/2024

Course Book

1. Course name	**Quantum Mechanics**
2. Lecturer in charge	Dr. **Sattar Othman Hasan**
3. Department/ College	**Physics / Education**
4. Contact	e-mail: sattar.hasan@su.edu.krd e-mail: star_os2004@yahoo.com Tel: **(0750 4514637)**
5. Time (hours) per week	**3 HOURS**
6. Office hours	**Monday:** From 09:00 AM To 02:00 PM **Tuesday:** From 12:30 AM To 02:00 PM **Wednesday:** From 12:30 AM To 02:30 PM **Thursday:** From 09:30 AM To 01:00 PM

7. Teacher's Academic Profile:

- I am a Staff member in **physical** Department of Education College at **Salahaddin** University-Erbil.
- I earned a **BSc** degree in Physics at **1990-1991** with first class honor from Physical department of Education college, university of Salahaddin.
- **MSc** degree in theoretical nuclear physics at **1998-1999** under the title of “The Background Function Effects on the Analysis of Gamma-Ray Spectrum” with honor degree.
- **PhD** in communication “Electromagnetic Theory” at **2005-2007** with the title of “Analysis and Design of Compact Microstrip Antenna Using Cavity Model” from Physical department of Science college, university of Salahaddin.
- From **2000-2002**, I was a head of register unit within the college of education.
- During **2002-2003** I was a deputy of deans of Education College, University of Salahaddin. I was a representative of teaching staff at College of Education for about eight years.
- I was a dean of Hawler **Tourism** Technical **Institute** during the years of **2008-2010.**
- I was a dean of Hawler **Technology** Institute during the years of **2010-2014**.
- I am an assistant professor of theoretical Electromagnetic Theory “Field of Communication”, and I have **several** research publications in different field of physics.
- My research interests span a number of topical themes in electromagnetic wave propagation, theoretical physics and mobile communication.
- Finally, I supervised **four M.Sc.** and **two Ph.D.** students in the field of Communication.

8. Course Objective:

This **course** book presents a **comprehensive** course of quantum mechanics for **undergraduate** and **graduate** students which covers the experimental basis of quantum physics including the following topics:

- The course starts with an overview of the **historical** evidence that led to the development of a **quantum** theory of matter and light such as: **Black** body radiation, **Photoelectric** effect, **Compton** scattering, **Franck**-Hertz experiment, the **Bohr** atom, **electron** diffraction, de-**Broglie** waves, and the wave-particle **duality** of matter and light.
- After a brief outline of the innovative ideas that lead up to the quantum theory, through the course a reviews property of the **Schrödinger** equation, the **quantization** phenomena and the physical meaning of **wave functions** are clarified.
- This is followed by an introduction to the key elements of **quantum** mechanics, including the **statistical interpretation** of wave functions, the role of **operators** and their connection with observables.
- The **postulates** of quantum mechanics, **expectation** values, **Ehrenfest's** theorem, wave **packets**, **probability** amplitudes, **stationary** states, the **Heisenberg** uncertainty **principle**, and **zero**-point energies are also explained in detail.
- Solutions to **Schrödinger's** equation in **one** dimension: **transmission** and **reflection** at a barrier, **barrier** penetration, **potential** wells, the simple **harmonic** oscillator are described.
- Schrödinger's equation in **three** dimensions: central potentials and introduction to **hydrogenic** atom systems with interpretation of the tunnelling phenomena of **alpha** particle are discussed.
- The fundamental **principles** with the **mathematical** formalism introduced, and illustrated through a **number** of solved examples.
- At the end of each **chapter**, exercises and **review** questions, generally designed as per the **examination** pattern, serve to **reinforce** the material learnt.

9. Forms of Teaching:

- Different forms of **teaching** will be used to come across with **objectives** of the course.
- Power point presentations for the **head** titles, definitions, **graphs** and many useful illustrations with **summary** at the end of each **chapter** will be presented and discussed.
- All the lecture outlines are prepared and will be a subject of open discussion inside the **lectures**.
- In the **beginning** of each lecture a brief **summary** of the previous lecture will be remembered and the **headlines** of the forward lecture is identified and determined.
- Throughout the **lectures** as well as at the end of each chapter there will be home work problems given to the students as a review and assessments.
- In the last **half** hour of each **lecture** there will be a seminar **prepared** by a student whom selects a quantum subject to be prepared as a presentation and will be open to discussion.
- In addition, the **lecture** will cover enough information about the **description** of the subjects, solution of many examples, analysis and derivation for all necessary equations and proving theorems and many problems are presented as a home work for improving student abilities.

10. Assessment Scheme:

Attaining the requirements set to **succeed** in this study subject requires developing a **mathematical** sense, related to this topic, based on emergent analytical and problem-solving skills and memorizing topics cannot **secure** success.

- In this system the **maximum** mark is **(100%)**.
- The grading system is based on the summation of **two** categories of **evaluations**:
- **First**, **(40%)** of the **mark** is based on the **academic** semester effort of the student which includes:
  - **30%** for **the** semester examination.
  - **5%** for preparing a **seminar** about the a subject related to quantum mechanical subjects and its application to a given physical problem.
  - **5%** for solving **home** works.
- **Second**, **(60%)** of the **mark** is based on **final** examination that is comprehensive for the whole of the study material **reviewed** during the academic **season** and it usually occurs after completing the course semester.

11. Student Learning Outcome:

On satisfying the **quantum** **mechanics** requirements of this course, students will have the knowledge and skills to:

1. Have gained **knowledge** of mathematical structure of **quantum** mechanics and to be able to apply this **knowledge** in order to solve certain problems related to **quantum** mechanics.
2. Identify and **understand** the kinds of experimental results which are **incompatible** with **classical** physics and which **required** the development of a **quantum** theory of matter and light.
3. **Interpret** the wave function and apply **operators** to it to obtain **information** about a particle's **physical** properties such as position, **momentum** and energy
4. Understand the role of **uncertainty** in quantum physics, and use the **commutation** relations of **operators** to determine whether or **not** two **physical** properties can be simultaneously measured
5. Solve the **Schrödinger** equation for systems such as the particle in a **box**, different potential **barrier** harmonic oscillator, rigid rotor, the **Hydrogen** atom and estimate the shape of the **wavefunction** based on the **shape** of the potential.
6. Applying the technique of **separation** of variables to solve problems in more than **one** dimension and to understand the role of **degeneracy** in the occurrence of **electron** shell structure in atoms.
7. Have learned how to use the **Dirac** formalism, and how to apply **operator** algebra to quantize **angular** momentum and the **harmonic** oscillator,

12. Course Reading and List of References:

1. Nouredine Zettili, "**Quantum Mechanics Concepts and Applications**", Wiley, Second edition, **2009**.
2. A. K. Saxena, "**Textbook of Quantum Mechanics** " , First Edition, New Delhi, **2007**.
3. Amnon Yariv, "**An Introduction to Theory and Applications of Quantum Mechanics**", John Wiley and Sons, Inc. New York, **1989**.
4. Mahesh C. Jain, "**Quantum Mechanics A textbook for Undergraduates**", PHI Learning Private Limited, New Delhi, Second Edition, **2011**.
5. Ajit Kumar, "**Fundamental of Quantum Mechanics**", University Printing House, Cambridge CB2 8BS, United Kingdom First published **2018**,
6. G. Aruldhas, "**Quantum Mechanics 500 Problems with Solutions**", PHI Learning Private Limited, New Delhi, Second Edition, **2011**.
7. R. B. Singh, "**Introduction to Modern Physics**", Second Edition, New Age International (P) Limited, New Delhi, **2009.**
8. Charles E. Burkhardt · Jacob J. Leventhal, "**Foundation of Quantum Physics**", New York, Springer Science +Business Media, LLC, **2008.**

13. The Topics:	Syllabus
FIRST SEMESTER	
Chapter One **Origen of Quantum Mechanic Concepts** **5 Weeks**	I-1: Historical Introduction I-2: Failure of Classical Mechanics I-3: Thermal Radiation I-4: Black Body Radiation I-5: Photoelectric Effect I-6: Short Wavelength Limit in X-Rays I-7: The Compton Effect I-8: History of Atomic Models I-9: Bohr's Theory of the Atom & Hydrogen Spectrum. I-10: Somerfield's Theory I-11: The Franck-Hertz Experiment I-12: Pauli's Exclusion Principle I-13: De-Broglie's Hypothesis I-14: Experimental Verification of De-Broglie's Hypothesis I-15: The Need for a Wave Function I-16: Born Interpretation of the Wave Function I-17: Representation of Particle by a Wave Packet I-18: Heisenberg's Uncertainty Principle I-19: Applications / Consequences of the Uncertainty Principle

Chapter Two **Schrodinger Equation and its Applications** **2 Weeks**	2-1: Introduction 2-2: The Necessity for a Wave Equation 2-3: Physical Significance of Wave Function [$\psi(r,t)$] 2-4: The Time-Dependent Schrodinger Equation 2-5: Particle in a Force-Field 2-6: The Time-Independent Schrodinger or Stationary States 2-7: Wave Function Interpretation and Probability Conservation 2-8: Probability Conservation and Hermiticity of the Hamiltonian 2-9: Expectation Values of Dynamical Variables 2-10: Motion of Wave Packets: Ehrenfest's Theorem 2-11: Exact Statement of the Position Momentum Uncertainty Relation.
Chapter Three **Formal Structure of Quantum Mechanics** **2 Weeks**	3-1: The Formal Structure of Quantum Mechanics 3-2: The Dirac Notation 3-3: Operators 3-4: Hermitian Operators 3-5: Commutator 3-6: Orthogonal Functions 3-7: Eigenvalues and Eigenfunctions 3-8: Degeneracy 3-9: Reality of Eigenvalues 3-10: Stationary States 3-11: Orthogonality of Eigenfunctions 3-12: Parity Operators 3-13: Postulate of Quantum Mechanics 3-14: A Note on the Superposition Principle
Chapter Four **Particle in a Potential Well** **3 Weeks**	4-1: Free Particle 4-2: Particle in a Potential Well 4-3: One-Dimensional Infinite Square Well 4-4: Three-Dimensional Infinite Square Well 4-5: One-Dimensional Finite Square Well (First Type) 4-6: One-Dimensional Finite Square Well (Second Type)
SECOND SEMESTER	
Chapter Five **Potential Barrier** **3 Weeks**	5-1: Scattering of Particles by Barriers and Wells 5-2: The Potential Step 5-3: The Square Potential Barrier 5-4: Variable Potential Barrier 5-5: Explanation of Alpha Decay 5-6: The Square Potential Well
Chapter Six **Simple Harmonic Oscillator** **3 Weeks**	6-1: The Linear Harmonic Oscillator 6-2: The Hermite Polynomial 6-3: Recurrence Relations 6-3: The Harmonic Oscillator Wave Functions 6-5: Operator Method of Linear Harmonic Oscillator

Chapter Seven **Angular Momentum** **4 Weeks**	7-1: Orbital Angular Momentum in Quantum Mechanics 7-2: The Orbital Angular Momentum Operator and its Cartesian Components 7-3: The Orbital Angular Momentum Commutation Relations 7-4: Angular Momentum Operators in Spherical Polar Coordinates 7-5: Eigenvalues and Eigenfunctions of $[\mathbf{L}^2 \ and \ \mathbf{L}_z]$ 7-6: Spherical Harmonics 7-7: Effect of the Operators $(\mathbf{L}_x \ and \ \mathbf{L}_y)$ 7-8: Vector Model of Angular Momentum; Space Quantization 7-9: The Rigid Rotator 7-10: Commutation Relations for Ladder Operators 7-11: Matrix Representation of Angular Momentum
Chapter Eight **Hydrogen's Atom** **4 Weeks**	8-1: Spherically Symmetric Potential and Hydrogen Atom 8-2: Separation of the Wave Equation into Radial and Angular Parts 8-3: The angular part equation 8-4: The Radial part equation 8-5: Reduction of a Two-Body Problem to One-Body Problem 8-6: Hydrogenic Atoms 8-7: Most probable Distance of Electron from Nucleus 8-8: Properties of Hydrogen Atom Wave Functions 8-9: The Zeeman Effect

14. Examinations: Different types of questions will be provided to the student as an exercise and also in examinations such as mathematical **derivation** and **explanation** questions for different subjects.

15. Extra Notes:

Due to a number of **unforeseen** reasons that may lead to the **shifting** of the academic season **program**, it may be subjected to **modifications**. Also extra **curriculum** hours may be **needed** to cover all the **topics** mentioned above. The students shall be **notified** of the **changes** if and when they may **occur**.