Quantum Mechanics
A Paradigms Approach

This popular undergraduate quantum mechanics textbook is now available in a more affordable printing from Cambridge University Press. Unlike many other books on quantum mechanics, this text begins by examining experimental quantum phenomena such as the Stern-Gerlach experiment and spin measurements, using them as the basis for developing the theoretical principles of quantum mechanics. Dirac notation is developed from the outset, offering an intuitive and powerful mathematical toolset for calculation, and familiarizing students with this important notational system. This non-traditional approach is designed to deepen students’ conceptual understanding of the subject, and has been extensively class tested. Suitable for undergraduate physics students, worked examples are included throughout and end of chapter problems act to reinforce and extend important concepts. Additional activities for students are provided online, including interactive simulations of Stern-Gerlach experiments, and a fully worked solutions manual is available for instructors.

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Quantum Mechanics

A Paradigms Approach

David H. McIntyre

Oregon State University
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Preface

This text is designed to introduce undergraduates at the junior and senior levels to quantum mechanics. The text is an outgrowth of the new physics major curriculum developed by the Paradigms in Physics program at Oregon State University. This new curriculum distributes material from the subdisciplines throughout the two upper-division years and provides students with a more gradual transition between introductory and advanced levels. We have also incorporated and developed modern pedagogical strategies to help improve student learning. This text covers the quantum mechanical aspects of our curriculum in a way that can also be used in traditional curricula, but that still preserves the advantages of the Paradigms approach to the ordering of materials and the use of student engagement activities.

PARADIGMS PROGRAM

The Paradigms project began in 1997, when the Department of Physics at Oregon State University began an extensive revision of the upper-division physics major. In an effort to encourage students to draw connections between the subdisciplines of physics, the structure of the Paradigms has been crafted to mimic the organization of expert physics knowledge. Students are presented with a model of how physicists organize their understanding of physical phenomena and problem solving. Each of the nine short junior-year Paradigms courses focuses on a specific paradigm or class of physics problems that serves as the centerpiece of the course and on which different tools and skills are built. In the senior year, students resume a more traditional curriculum, taking six capstone courses in the traditional disciplines. This curriculum incorporates a diverse set of student activities that allow students to stay actively engaged in the classroom and to work together in constructing their understanding of physics. Computer resources are used frequently to help students visualize the systems they are studying.

CONTENT AND APPROACH

Quantum mechanics is integrated into four of the junior-year Paradigms courses and one senior-year capstone course at Oregon State University. This text includes all the quantum mechanics topics covered in those five courses. We adopt a "spins-first" approach by introducing quantum mechanics through the analysis of sequential Stern-Gerlach spin measurements. This approach is based upon previous presentations of spin systems by Feynman, Leighton, and Sands; Cohen-Tannoudji, Diu, and Laloe; Sakurai; and Townsend. The aim of the spins-first approach is twofold: (1) To immediately immerse students in the inherently quantum mechanical aspects of physics by focusing on simple measurements that have no classical explanation, and (2) To give students early and extensive experience with the mechanics of quantum mechanics in the forms of Dirac and matrix notation.
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The simplicity of the spin-1/2 and spin-1 systems allows the students to focus on these new features, which run counter to classical mechanics.

The first three chapters of this text deal exclusively with spin systems and extensions to general two- and three-state quantum mechanical systems. The basic postulates of quantum mechanics are illustrated through their manifestation in the Stern-Gerlach experiments. After these three chapters, students have the tools to tackle any quantum mechanical problem presented in Dirac or matrix notation. After a brief interlude into quantum spookiness (the EPR Paradox and Schrödinger’s cat) in Chapter 4, we tackle the traditional wave function aspects of quantum mechanics. We present several quantum systems—a particle in a box, on a ring, on a sphere, the hydrogen atom, and the harmonic oscillator—and emphasize their common features and their connections to the basic postulates. The differential equations of angular momentum and the hydrogen atom radial problem are solved in detail to expose students to the rigor of series solutions, though we stress that these are again eigenvalue equations, no different in principle from the spin eigenvalue equations. Whenever possible, we continue the use of Dirac notation and matrix notation learned in the spin chapters, emphasizing the importance of fluency in multiple representations. We build upon the spins-first approach by using the spin-1/2 example to introduce perturbation theory, the addition of angular momentum, and identical particles.

USAGE

At Oregon State University, the content of this text is taught in five courses as shown below.

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For a traditional curriculum, the content of this text would cover a full-year course, either two semesters or three quarters. A proposed weekly outline for two 15-week semesters or three 10-week quarters is shown below.
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AUDIENCE AND EXPECTED BACKGROUND

The intended audience is junior and senior physics majors, who are expected to have taken intermediate-level courses in modern physics and linear algebra. No other upper-level physics or mathematics courses are required. For our own students, we review matrix algebra in a seven contact hour “preface” course that precedes the Paradigms courses that teach quantum mechanics. The material for that preface course is in Appendix C. The material in Appendix B summarizes an earlier Paradigms course on oscillations, and the material in Appendix D summarizes the classical wave part of the Paradigms course on waves.

STUDENT ACTIVITIES AND WEBSITE

Student engagement activities are an integral part of the Paradigms curriculum. All of the activities that we have developed are freely available on our wiki website:

http://physics.oregonstate.edu/portfolioswiki

The wiki contains a wealth of information about the Paradigms project, the courses we teach, and the materials we have developed. Details about individual activities include descriptions, student handouts, instructor’s guides, advice about how to use active engagement strategies, videos of classroom practice, narratives of classroom activities, and comments from users—both internal and external to Oregon State University. This is a dynamic website that is continually updated as we develop new activities and improve existing ones. We encourage you to visit the website and join the community. E-mail us with corrections, additions, and suggestions.

Each of the quantum mechanics activities that we use in our five courses is referenced in the resource section at the end of the appropriate chapter in the text. The quantum mechanics activities are collected within the wiki website with a direct link:

www.physics.oregonstate.edu/qmactivities

These activities include different types of activities such as computer-based activities, group activities, and class response activities. The most extensive activity is a computer simulation of Stern-Gerlach experiments. This SPINS software is a full-featured, menu-driven application that allows students to simulate successive Stern-Gerlach measurements and explore incompatible observables, eigenstate expansions, interference, and quantum dynamics. The use of the SPINS software facilitates our spins-first approach. The beauty of the simulation is that students steeped in classical physics perform a foundational quantum experiment and learn the most fascinating and counterintuitive aspects of quantum mechanics at an early stage.

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David H. McIntyre
Corvallis, Oregon
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Prologue

It was a dark and stormy night. Erwin huddled under his covers as he had done numerous times that summer. As the wind and rain lashed at the window, he feared having to retreat to the storm cellar once again. The residents of Erwin’s apartment building sought shelter whenever there were threats of tornadoes in the area. While it was safe down there, Erwin feared the ridicule he would face once again from the other school boys. In the rush to the cellar, Erwin seemed to always end up with a random pair of socks, and the other boys teased him about it mercilessly.

Not that Erwin hadn’t tried hard to solve this problem. He had a very simple collection of socks—black or white, for either school or play; short or long, for either trousers or lederhosen. After the first few teasing episodes from the other boys, Erwin had sorted his socks into two separate drawers. He placed all the black socks in one drawer and all the white socks in another drawer. Erwin figured he could determine an individual sock’s length in the dark of night simply by feeling it, but he had to have them presorted into white and black because the apartment generally lost power before the call to the shelter.

Unfortunately, Erwin found that this presorting of the socks by color was ineffective. Whenever he reached into the white sock drawer and chose two long socks, or two short socks, there was a 50% probability of any one sock being black or white. The results from the black sock drawer were the same. The socks seemed to have “forgotten” the color that Erwin had determined previously.

Erwin also tried sorting the socks into two drawers based upon their length, without regard to color. When he chose black or white socks from these long and short drawers, the socks had also “forgotten” whether they were long or short.

After these fruitless attempts to solve his problem through experiments, Erwin decided to save himself the fashion embarrassment, and he replaced his sock collection with a set of medium length brown socks. However, he continued to ponder the mysteries of the socks throughout his childhood.

After many years of daydreaming about the mystery socks, Erwin Schrödinger proposed his theory of “Quantum Socks” and became famous. And that is the beginning of the story of the quantum socks.

The End.

Farfetched?? You bet. But Erwin’s adventure with his socks is the way quantum mechanics works. Read on.