Course Syllabus

In this course, quantum mechanics is developed as a fundamental theory by applying a wide array of mathematical methods to non-relativistic physics at the atomic and sub-atomic level. Familiarity with linear algebra, partial differential equations and complex analysis at the advanced undergraduate level is expected, although I will also include review of undergraduate material when needed. For a deeper understanding of the meaning of quantum mechanics toward the end of the term, it is also desirable to have some familiarity with classical Lagrangian mechanics.

We will start by reviewing some experimental facts of quantum physics, in particular the diffraction of matter waves. The probabilistic interpretation of the wave function will be introduced, and the connection between Fourier transforms and uncertainty relations will be recalled. The time-independent Schrödinger equation provides a first framework for doing quantum mechanical calculations.

At that point we will be ready for a second look at the formalism of quantum mechanics, turning in particular to systems with a small number of degrees of freedom (the Stern-Gerlach observation of spatially quantized atomic beam deflection in an inhomogeneous magnetic field is an example, showing similarities to the polarization of classical electromagnetic waves).

We then encounter vector spaces, linear operators and matrices. The ket formalism is used heavily as an abstraction that allows us to treat systems with discrete and continuous observables on the same footing. Momentum and position are continuous observables, whereas angular momentum and spin are examples of discrete observables (a classification that is based on their eigenvalue spectrum).

Important applications of the quantum mechanical formalism include the harmonic oscillator and the hydrogen atom. Reviews of their properties will be interspersed throughout the course because these simple systems are needed for practical application of the abstract concepts.

An alternative conceptual viewpoint from which to attack quantum mechanics is the Feynman path integral. It sheds light on the connection between quantum and classical mechanics.

Approximate weekly breakdown of topics:

1: Quantum experiments: Compton effect, electron diffraction etc.
2: Wave functions of position and momentum
3: Fourier transforms, width of a function, uncertainty
4: Differential operators, scalar products, delta function
5: Time-independent Schrödinger equation
6: Properties of hermitian operators
7: Operators in ket space, Dirac notation
8: Basis changes, completeness relations
9: Operators in more than one dimension, simultaneous eigenfunctions
10: Compatible and inompatible variables
11: Stern-Gerlach experiment, spin
12: Bloch sphere and Pauli matrices
13: Time-dependent Schrödinger equation
14: Current density
15: Time evolution operator, propagators
16: Schrödinger vs. Heisenberg picture
17: Simple harmonic oscillator: creation and annihilation operators
18: WKB approximation
19: Feynman path integrals
20: Review

Lectures and notes

The material will be delivered in a combination of videos and in-class discussion. The hand-written notes from each class will be posted on Canvas, under "Quantum Mechanics Lectures"

Homework and grading

Grader for the course: TBA.

Grades will be based 60% on the weekly homework and 40% on the final exam. Assignments must be turned in by the time and date stated on the problem sheet which will be posted on Canvas. Please turn in assignments in writing, and answer every question on your own. You are allowed to discuss the homework but have to write down the solutions by yourself.

If you have special needs, please contact me (J.U. Nöckel) with details so we can make appropriate arrangements.

Office hour

Mondays 2-3pm.

LEARNING OBJECTIVES

PHYS 631-33 is theoretical physics sequence, and the biggest challenge is not to lose sight of the physical content among the mathematical formalism. This will be a lot easier if you carefully review quantum physics at the undergraduate level before beginning this course. Many of the topics covered in the first term overlap with undergraduate material, but an important goal is to explore the relationships between different formulations and methodologies of quantum mechanics - mainly Schrödinger's differential equation and Heisenberg's matrix equation.

Quantum mechanics is conceptually very different from other fields -- but the more you understand the formalism, the more you will recognize how much the theory owes to ideas from mechanics, electromagnetism and optics. The crucial difference to these classical areas is that a fundamental probabilistic interpretation is assigned to the solutions of otherwise deterministic equations. It's important to keep in mind that all our calculations ultimately involve statistical statements.
REQUIRED MATERIALS:

We will be using the textbook

R. Shankar, Principles of Quantum Mechanics

(available at the UO Duck store)

I also sometimes link to the online text

Quantum Mechanics  (https://farside.ph.utexas.edu/teaching/qm/Quantumhtml/)

by Richard Fitzpatrick (follow the link to get the PDF or HTML version).

This covers essentially the same core topics as the following standard text:

NOT REQUIRED:

J.J. Sakurai, Modern Quantum Mechanics

This text doesn’t start out with Schrödinger’s equation but instead aims to derive it from a more abstract point of view based on operators in a vector space. Because of this approach, prior exposure to quantum physics is highly advisable. It may be useful to buy this book, but it’s not required. In particular, the first couple of weeks of the course will be quite different from the introductory chapters of this book.

The reason I decided to make Shankar required is that it provides a good bridge between undergraduate and graduate material, and at the same time goes deeply into some advanced material so that it will be a good reference for the entire sequence and beyond.

Both Shankar’s book and the online text start with a review of important mathematical facts. We will not explicitly do such a review, but I will address mathematical issues as they arise. Shankar's writing style is less terse than that of Sakurai. In particular, Sakurai's notation is often much too condensed and even sloppy, in particular for the material of the second and third term.

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