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. It is advisable to take this course only after having completed a senior-level undergraduate quantum mechanics course. For a deeper understanding of the meaning of quantum mechanics toward the end of the term, it is also desirable to have a good grasp of classical Lagrangian and Hamiltonian 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. I will also give a plausibility argument leading to the time-independent Schrödinger equation. This provides a first rough sketch of the quantum mechanical fundamentals.

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).

Instead of Fourier theory, 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.

Historically 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 illustration 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. The extent to which we can treat this and related topics at the interface between classical and quantum physics will also depend on your progress in graduate classical mechanics which most of you are taking in parallel. In particular, the Lagrangian and Hamiltonian formulations of mechanics will have to be recalled.

**Approximate weekly breakdown of topics:**

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>Quantum experiments: Electron diffraction etc.</td>
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<tr>
<td>2</td>
<td>Wave functions, Fourier transforms, width of a function</td>
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<td>3</td>
<td>Uncertainty relations</td>
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<tr>
<td>11</td>
<td>Wave functions in position and momentum space</td>
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<td>12</td>
<td>Quantum Dynamics: Time evolution and Schrödinger equation for kets</td>
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<tr>
<td>13</td>
<td>Schrödinger vs. Heisenberg picture</td>
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<tr>
<td>14</td>
<td>Ehrenfests's theorem, transition amplitudes</td>
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<tr>
<td>15</td>
<td>Simple harmonic oscillator: creation and annihilation operators</td>
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<tr>
<td>16</td>
<td>Wave equation in position representation: time-dependent and time-independent</td>
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<td>17</td>
<td>The classical limit</td>
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<tr>
<td>18</td>
<td>Feynman path integrals</td>
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<tr>
<td>19</td>
<td>Review</td>
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</table>
4: Time-independent Schrödinger equation
5: Stern-Gerlach experiment, polarization
6: Kets, bras and operators
7: Matrix representations
8: Observables, uncertainty relations from operator algebra
9: Change of basis, linear algebra
10: Position, momentum and translation
11: Wave functions in position and momentum space
12: Quantum Dynamics: Time evolution and Schrödinger equation for kets
13: Schrödinger vs. Heisenberg picture
14: Ehrenfests's theorem, transition amplitudes
15: Simple harmonic oscillator: creation and annihilation operators
16: Wave equation in position representation: time-dependent and time-independent
17: The classical limit
18: Propagators
19: Feynman path integrals
20: Review

Lecture notes

The hand-written notes from each class will be posted on Blackboard, under "Course Documents."

Homework and grading

The grader for the course is Imran Mirza.

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 set which will be posted on Blackboard. 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 with details so we can make appropriate arrangements.

Office hour

Thursdays 3-4pm.

Learning Objectives

The material of the course is self-contained in the sense that it doesn't rely explicitly on any prior knowledge of specific quantum physics, e.g. elementary particles or atomic structure. However, this is a theoretical course, 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.

Conceptual understanding and methodological training are equally important in this class. 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 and electromagnetism: Although the "force" concept of classical mechanics is practically absent in quantum physics, there is still a Hamiltonian, and equations of motions can be derived from it. You
will learn what questions one can and cannot ask in quantum mechanics; for those that can be asked, you will get some practice finding the answers.

Required Materials

We will be using the online text

Quantum Mechanics

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:

J.J.Sakurai, Modern Quantum Mechanics

Unlike other books, 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 two weeks of the course will be quite different from the introductory chapters of this book.

A second textbook that I would recommend as additional reading is:

R. Shankar, Principles of Quantum Mechanics

Both this 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.