MSE 142: Quantum Mechanics of Nanoscale Materials

Course Information

Basic info

Prof. Aaron Lindenberg
Office Hours: Wednesday, 5:30-6:30 pm (join via canvas)
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TA: Chenyi Xia
Office hours: Thursday, 2:30-4:30 pm

The course home page can be found on canvas. I will regularly post assignments, announcements, and other materials there. As you know, all of spring quarter is virtual. I will make every effort to try to make this class a rewarding and educational experience but I can guarantee it will not be completely smooth!

Textbook

We will not be closely following a textbook throughout the course. The closest and best formal book I think for outside references is Introduction to Quantum Mechanics by David Griffiths but we will make many diversions from this. We have a dedicated set of course lecture notes (developed by a former Stanford student who took this course) which I will post on canvas and assign reading ahead of the topics we discuss in class.

Other recommended books for outside reading:

Applied Quantum Mechanics by David Levi
Applied Quantum Mechanics by Walter A. Harrison
An Introduction to Quantum Physics by A.P. French and Edwin F. Taylor

There are many others, in fact, hundreds of them!

Problem Sets

There will be problem sets due on most fridays. You are encouraged to work together and collaborate on the problems but everyone needs to write up his or her own solutions. There will be some difficult problems and some easier ones, mainly designed to make sure you are following along - Learning quantum mechanics is tough and requires lots of practice. It has been said that if you think you understand quantum mechanics then you don’t understand quantum mechanics. Keep this in mind. Working hard on these problem sets and asking lots of questions is the most important way to ensure you do well in this course. I am very happy during office hours to go over the problems and discuss them in detail.

Grading

Grading will be based on problem sets. There will be no final or midterm exam but the problem sets will be cumulative. Generally the course material builds on itself very strongly so it’s important not to fall behind.

Turning in problem sets: Please scan your work. If you do not have access to a physical scanner, several free scanning apps are available for most smartphone types (e.g. scannable for iPhone, or CamScanner for Android). Please let me know as soon as possible if you do not have access to either a physical scanner or a free document scanning app. Save your work as a PDF, with both your first and last name in the title. Upload your work to canvas. For example, homework 3 should be submitted to “HW3” in the assignments tab. Please do not submit multiple PDFs but rather a single one which includes all problems assigned.
Course Summary and Goals

This is a course about Quantum Mechanics. No prior background in the subject is assumed - in terms of preparation you will be fine assuming you have basic understanding of high school physics and calculus. We will make use of many more advanced mathematical concepts such as partial differential equations, linear algebra, topology etc. but this will be developed as we go along and prior knowledge of these subjects is not required.

While Quantum Mechanics was created to describe and explain a world of atoms and electrons far removed from everyday human experience (and is usually thought of as not having much relevance), it has impacted and continues to make a giant impact on all of our daily lives. Everything from computers and iphones to fiber-optic communication networks and lasers, to solar cells and batteries, to solid-state lighting, to broad aspects of nanotechnology, to the mechanical properties of materials, to geology and the inner workings of the earth, to the water you drink, to the large scale structure of our universe (this list can go on and on) depends crucially on quantum mechanical effects to make them work and to understand how they work. The properties of materials from a very general perspective emerge from the ways in which atoms combine to form solids, and quantum mechanics lies at the heart of this. Nanoscale materials lie somewhere at the boundary where classical mechanics meets quantum mechanics, and many novel and useful properties emerge on these length-scales. It is possible in essence to engineer the functional properties of materials through nanomaterials design and these concepts have at their basis an understanding of the quantum mechanical properties of matter. Additionally, a broad range of characterization tools in materials science depend upon quantum mechanical effects to make them work and we will be discussing many of these applications.

In this course, we’ll start at a very basic level and, by the end of the quarter, work up to some very cool, interesting, and advanced topics. The mathematical foundations of quantum mechanics are quite advanced, but we’ll develop things as we go along. I think you will find that the hard part of this course isn’t the math - instead it’s learning to think in a completely different way and apply this thinking in an abstract and quantitative way to things that are very far from one’s common sense intuition. You will see, for example, that despite the fact that the basic ideas of quantum mechanics were developed about one hundred years ago, there is still controversy about what it means and how to interpret it. My goal is to provide a basic intro to the subject, in particular focusing on topics fundamental to most of modern materials science and nanotechnology.

Rough course outline

Introduction - course overview
Historical background; breakdown of classical physics; Key experiments: The photoelectric effect; The Stern-Gerlach Experiment.
Particles and waves; Analogies with light; The double-slit experiment and quantum interference; The Aharonov-Bohm effect
The Schrodinger wave equation
First applications of the Schrodinger equation: Particle in a box and application to quantum dots, nanocrystals, semiconductor heterostructures.
The uncertainty principle and applications
Quantum tunneling and applications to nanoscale devices, the scanning tunneling microscope, resonant tunneling diodes, quantum cascade lasers.
Electron motion in materials and basic concepts of the band structure of materials; application to transport properties, semiconductors, metals, insulators; solar cells.
The simple harmonic oscillator and application to vibrational motion and phonons in materials; the Casimir effect and related applications.
General aspects of topology in quantum mechanics.
Introduction to quantum computing / Shor’s algorithm.