MSE 142: Quantum Mechanics of Nanoscale Materials

Course Information

Basic info

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Office hours: 5-6 pm, 329 McCullough

The course home page can be found on canvas. I will regularly post assignments, announcements, and other materials there.

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. However this was written about 5 years ago and the course has evolved some during these years so it is also not fully inclusive of all material!

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 roughly every other Friday. 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, with the easier ones mainly designed to make sure you are following along. Learning quantum mechanics is tough and requires a lot 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

There will be one midterm and a final exam. Grades will be based as follows:

Problem sets: 35%
Midterm: 25%
Final: 40%

Generally the course material builds on itself very strongly and by the end of the quarter we will be discussing some quite advanced topics so it's important not to fall behind.

Tours

We will organize several tours of labs throughout the quarter to illustrate important ideas we have been discussing. This usually includes a tour of SLAC which should be quite interesting for you! More details to follow on this.

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 including ordinary and partial differential equations, linear algebra, topology, and more. but this will be developed as we go along and prior knowledge of these subjects is not assumed.

Because quantum Mechanics was created to describe and explain a world of atoms and electrons seemingly far removed from everyday human experience, it is usually thought of as not having much relevance. However it has impacted and continues to make a giant impact on all of our daily lives. Computers (not just quantum computers!), cell phones, lasers, solar cells, solid-state lighting, and photonic devices are all examples where technology has been profoundly influenced by our understanding of quantum mechanics. Biology, including examples like photosynthesis and the mechanisms by which DNA operates cannot be understood directly without including quantum mechanics. The mechanical properties of materials (including why it is that you are not currently falling through your chairs!) to geology and the inner workings of the earth, to the water you drink, to the large scale structure of our universe depends crucially on quantum mechanical effects to make them work and/or 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 specific to materials science, but really extending to pretty much every field of science, depend upon quantum mechanical effects to make them work and we will be discussing many of these applications. By some measures quantum mechanics is the most successful theory in the history of science and the most carefully tested!

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, and to get you excited about many future applications of this amazing topic.

Rough course outline

Introduction - course overview

Brief 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. White dwarfs, neutron stars, and the Chandrasekhar limit.

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.

Quantum computing, entanglement, teleportation, factoring.