

Physics 162a – Quantum Mechanics

Syllabus for Fall 2009

1 Introduction

This is essentially a standard first-year course in quantum mechanics, the basic language for describing physics at the atomic and subatomic scale. Both the physics and the physical concepts are applicable across all fields of physics in one way or another (often in a surprising way), so this remains a basic required course for graduate students.

I try to teach quantum mechanics as it is seen by *current* practitioners. This means, first, that I don't get too hung up on how "weird" the subject seems, since it matches observations exquisitely well and there are no serious experiments which contradict the theory.

Furthermore, this means spending more time than you may have before developing the language used to describe quantum mechanics. Therefore I open with a couple weeks reviewing linear algebra, the basic language of quantum mechanics. This may seem a bit formal at first, but since this is *exactly* the right language to describe quantum mechanics in any setting, it is important to understand this bit of math to develop a correct physical intuition for the subject, just as it is important to get all the grammar and vocabulary of, say, Spanish before you can start appreciating novels and poetry.

2 Basic data

- Instructor: Prof. Albion Lawrence.
- Classroom: Abelson 229
- Class times: Mondays and Wednesdays, 11:10-12:30.
- Office Hours: To be announced (I usually wait until people have their TA assignments). You should also feel free to make an appointment if the time is bad on any week, or you need more time, or you are more comfortable asking in private (but note for physics questions I

usually find that the question you think is stupid is in fact something everybody is wondering about, so don't be shy!).

- Albion's office: Abelson 344.
- Albion's contact info: office phone 781-736-2865, email albion@brandeis.edu
- Course website: <http://www.brandeis.edu/~albion/162a/course.html>

3 Course outline

Some changes may occur, but this is a pretty good indication of what we will cover.

1. Motivation (1/2 week). Chapters 1 and 2 of Baym, Chapters 1-3, Feynman lectures.
2. Mathematical preliminaries. (2 weeks). Chapter 1 of Shankar, chapter 1 of Sakurai, chapter 4 of Merzbacher.
Vector Spaces.
Hilbert Spaces.
Linear Operators.
Eigenvalues and Eigenvectors.
3. The Principles of Quantum Mechanics (1/2 week). Chapter 4 of Shankar, chapter 1.4 of Sakurai.
4. Illustrating and exploring the basic principles (2 weeks). Feynman lectures v. 6, 9-11. Preskill's notes (see the course website). Nielsen and Chuang.
Two state systems.
Density matrices.
Correlations, EPR.
Quantum statistical mechanics.
Simple examples: quantum information and quantum computation.
5. Quantum Dynamics. (1 week) Chapters 3 and 5 of Baym, chapter 2.1-2.4 of Sakurai, chapter 4.3 of Shankar, Chapter 9 of Shankar.

Time development.
Schrodinger and Heisenberg Pictures.
Schrodinger and Heisenberg Equations of Motion.
Uncertainty Principles.
How do we construct a Hamiltonian?

6. Feynman path integrals (1 weeks) Chapters 8, 21 of Shankar. Chapter 2.5 of Sakurai. Feynman and Hibbs.

7. Simple Examples. (1.5 weeks) – Chapter 5.1, 7 of Shankar, 2.3, 2.5 and 2.6 of Sakurai.

The free particle, again. Propagators and Green functions.
The free particle in a magnetic field. Aharanov-Bohm.
The Simple Harmonic Oscillator. Coherent states.

8. The classical limit (1 week) Chapter 6, 16.2 of Shankar. The classical limit of quantum mechanics.
The WKB approximation.
Measuring a quantum system with a classical measuring device.

9. Symmetries and angular momentum (2 weeks). Chapter 6 of Baym. Chapters 3 of Sakurai. Chapters 11, 12, 14 and 15 of Shankar.
Symmetries in quantum mechanics.
Representations of the rotation group.
Addition of angular momenta.
Wigner-Eckhardt theorem.

10. The Hydrogen Atom (1 week) Chapter 7 of Baym.

4 Reading, handouts, etc.

I have never found a textbook which perfectly suits this course. But there are some very strong ones on the market. I will place the non-required books on reserve in the science library.

- *Modern Quantum Mechanics*, J. J. Sakurai. This is a required textbook, and is the standard textbook for graduate-level quantum mechanics. The first three chapters (roughly the first half of the book) are very clear and well laid-out, and are in essentially the order that this semester will progress. It also contains many good problems. Unfortunately the author died and the remainder of the book is put together from his notes – there is a noticeable drop in clarity as the book goes on.
- *Lectures on Quantum Mechanics*, G. Baym. This is a required textbook, in part because it is superior for the material in 162b, but it has some nice discussions of the material in the first semester as well, although I am not as fond of the organization. I find the book to be very physical, and it contains very good problems.
- *Principles of Quantum Mechanics*, R. Shankar. This is also a very good book with some very physical discussions in it. The organization is not ideal, and in many sections the book is not high-level enough for a full graduate course. Also, as I discovered, the problems in it aren't great for problem sets (though they are good for helping with the reading). Recommended as an alternate source for some of the material, especially the mathematical material at the beginning of this course. Finally, if you have not had a good junior/senior level course in classical mechanics, covering the relationship between Lagrangian and Hamiltonian mechanics, it contains a nice review which you should read.
- *Quantum Mechanics*, E. Merzbacher. This is a classic workhorse, with many good problems and some very nice chapters on more advanced topics – the discussion of scattering and of WKB theory are very good, for example. It is a little old-fashioned and formal for my taste.
- *Quantum Mechanics and Path Integrals*, R. Feynman and A.R. Hibbs. An introduction to the path integral approach to quantum mechanics, famously developed by the first author. The discussion in Sakurai should suffice for us, but if you are interested in exploring this subject further, I recommend this.
- *Quantum Mechanics*, L. Landau and I.M. Lifshitz. Part of the classic Russian series of graduate-level physics textbooks. Although it is

old-fashioned in its presentation, it is very well written and has some superb and superior discussions of many important topics such as the quasiclassical approximation, basic group theory and applications of symmetries, and quantum scattering theory.

- *Principles of Quantum Mechanics*, P.A.M. Dirac. A classic and well worth your time.
- Lecture notes on quantum computation, by J. Preskill. There is a link on the course website. Chapter 1 is a beautiful and highly recommended introduction to the subject.
- *Quantum Computation and Quantum Information*, by I. Chuang and M. Nielsen, a very nicely written introduction to the subject of quantum computation.

Much of the reading I will assign will cover the same topics I cover in lecture, perhaps in a slightly different way. I may also assign some supplementary reading, to illustrate a point I make in the lectures, or to prepare you for an upcoming topic. Any assigned reading is fair game for the exams, whether or not I cover it in class.

5 Problem sets

Problem sets will generally be handed out on Wednesdays. Unless I state otherwise at the time, they will be due at the beginning of class the following Wednesday.

I will *not* accept late assignments unless you will be out of town for physics reasons (eg conference), a serious reason such as a marriage in the immediate family, or of course if there is a health or family emergency. Except for those last two cases, I require two weeks of advance notice.

I expect the students to work through *every* assigned problem. Some of them may seem longer than you are used to. It is still important that you have the experience of working through them. It may happen that I assign a problem on a subject I have not yet covered in class, in which case I have done this on purpose and you should still do it.

6 Exams

There will be a midterm and a final exam. Both will be in-class, open notes, and closed book. This is to encourage you to assemble your notes in a useful form (if you understand the material, you should not need the notes except to look up some formula). The purpose of the midterm exam is mostly diagnostic, for you and for me, so it does not count for much. For graduate students, the final is part of your written qualifier.

7 Grading

The basis of grades in this course will be:

- 1) Homework – 60%.
- 2) Midterm – 10%.
- 3) Final – 30%

8 Feedback from students

Feedback from students is encouraged! If you have questions or concerns about the course as it is progressing, you should feel free to talk to me. There is also of course an end-of-term evaluation.

9 Expectations

The course is designed around the lectures, so while I won't grade on attendance, it is important that you come to class. I will use the lectures to motivate material, and will be taking questions then, so you can get clarifications in real time.

The problem sets are a crucial part of this course, and you will not learn the material unless you have worked through a lot of problems and completed them accurately. You are strongly encouraged to discuss the problem sets with each other. By this I mean discussing what the question means, and what techniques and strategies you might use to solve them. I feel that physics is best learned socially, with your peers.

That said, the solutions you present should be your own; you should have understood the solution and explained it yourself, in your own way, in the

problem set. Simply copying other people's problem set solutions constitutes plagiarism and will be dealt with as such. Furthermore, I find that the lack of independent work shows up in the final exam and in the qualifiers. This is because those who have thought these problems through on their own understand the material; those who have merely copied from their friends or from solutions online do not understand the material.

But I would hate to end on an overly grim note. The course is meant to be challenging, but I hope it is also fun.