Physics 162b – Quantum Mechanics

Syllabus for Winter/Spring 2009

1 Course description

Physics 162a is typically an introduction to the general formalism of quantum mechanics. In Physics 162b we focus on using quantum mechanics to describe real systems and real phenomena, and learn how to do calculations in more realistic settings, in particular via various approximation methods (esp. perturbation theory).

These approximation methods are at the core of modern physics. While exactly solvable systems teach us a great deal about the basics of quantum mechanics, few physically interesting problems are exactly solvable. In many cases a problem is interesting precisely when it is not exactly solvable. Furthermore, the intuition and computational techniques we will develop are often broadly applicable to other areas of physics.

2 Essentials

1. Instructor: Albion Lawrence.

2. Class place and time: T-F 10:40-noon, Abelson 229. There will be makeup classes W-Th 9:40-11, so please keep these slots open. In particular there will be no classes the week of Jan. 19 and no classes from Feb 2-13; these will be made up the weeks of Jan 12, Jan. 26, and Feb. 23 with classes on the Wednesday and Thursday of that week.

   Further schedule adjustments will be annouced in late February, but all makeup classes will be at the above W-Th times.

3. Office hours/review sessions: by appointment. During weeks I am way I will make every effort to be available by email for questions.

4. My contact info:

   - Office: Abelson 344
   - Phone: 781-736-2865

- email: `albion@brandeis.edu`. As a rule, I don't answer class-related email in the evening, unless it involves a personal emergency or a serious mistake in a problem set.

5. Grader: watch this space.

6. Course website:
   `http://www.brandeis.edu/~albion/162b/course.html`

7. Basis of grades: Problem sets, 60%; Midterm, 10%; Final, 30%. The midterm date is TBA, probably the first week of March. The final will occur at the official time for this block. Both exams are in-class. I will drop the problem set with the lowest percentage and base the grade on your total percentage of the remaining problem sets.

8. Problem set schedule: Problem sets will be handed out every 1-3 weeks (and scaled accordingly), due Friday by the beginning of class unless otherwise announced. Late problem sets will not be accepted, unless: (a) there is an obvious emergency: serious illness, family emergency, etc., or (b) you will be out of town with a good reason (conference, wedding, visiting graduate schools) and you have discussed it with me before the time the problem set is handed out. If a serious mistake is found late in the game – I try hard to avoid it but it does happen – I may extend all or part of the problem set.

   You are advised to start looking at the problem set and taking an initial crack at it early. First, you will know quickly what does and does not totally confuse you, and can either ask questions and do the needed background preparation (reading etc.) Secondly, if you spend some time attacking the problem early on, you may find that you keep working on them subconsciously. None of these will be doable in 1 evening, as a rule. In particular, problem sets which you have more that 1 week to do will generally take more than 1 week to do.

3 Course outline

The schedule is subject to change somewhat, depending on how I feel the class is doing and where your interests, needs, and abilities lie. But the outline below is a pretty good guide to what I expect to cover; the topics are mostly standard and essential. I will be roughly but not precisely following the outline of Sakurai. The material will be a synthesis of the assigned reading and my own understanding of the subject. In part this is because no book is perfect for any given class.

1. Particles in an electromagnetic field (.5 weeks).

2. The Hydrogen atom (1 week). This is a review and warmup, and provides both a bridge to 162a and a classic example for much of the material of this course. (Shankar, chapter 13; Baym, chapter 7)

3. Symmetries and Conservation laws (1.5 weeks). (Sakurai, Chapter 4; Shankar, Chapter 11).

4. Time-independent perturbation theory (1.5 weeks). (Sakurai chapters 5.1-5.3, Shankar chapter 15, Baym chapter 11).

   - First- and second-order degenerate and non-degenerate perturbation theory.
   - Symmetries and selection rules.

5. Variational methods (.5 week) (Sakurai chapter 5.4, Shankar chapter 16, Baym pp 242-244.

6. Time-dependent perturbation theory (2.5 weeks). (Sakurai, chapter 5.5-5.8, Shankar, chapter 18, Baym chaptesr 12-13).

   - The interaction picture. Dyson series.
   - First-order transitions and Fermi's Golden Rule.
   - Periodic perturbations.
   - Interaction of charged particles and electromagnetic radiation.

7. Scattering theory (2 weeks) (Sakurai chapter 7, Shankar chapter 19, Baym chapters 9-10, pp 258-60,pp 289-299. **Recommended**: Landau& Lifschitz chapters 12-13.)

   - Cross sections.
   - Green functions

- The Born approximation.
- Bound states and resonances.

8. Identical particles and second quantization (2.5 weeks). (Sakurai chapter 6, Shankar, chapter 10, Baym, chapters 18-19).

   - Two particles. N particles. Fermi and Bose statistics.
   - The Helium atom.
   - Second quantization.
   - Fermi and Bose gases.

9. Relativistic Quantum mechanics (1.5 weeks).

4 Reading, handouts, etc.

- The required books for the course are J.J. Sakurai's *Modern Quantum Mechanics*, and Baym's *Lectures on Quantum Mechanics.* In particular I'll take many problems from there.
- Supplementary notes, the syllabus, problem sets, important WWW links, and anything I can put online will appear on the course website.
- I or others also recommend the following books, which will be placed on reserve along with a few others. Do let me know if there are others that you like.

  1. Shankar, *Principles of Quantum Mechanics*. This used to be the required text when I taught Physics 162a. In the end it isn't quite what I'm looking for, and the problems weren't meaty enough. But it is a very good and well-written book, and explains some subtle points very well.
  2. Landau and Lifshitz, *Quantum Mechanics* (non-relativistic theory), 3rd edition. This is a beautiful book; it is old-fashioned but still quite useful. Its discussion of group theory in quantum mechanics, and of scattering theory, is superb.

3. P.A.M. Dirac, *Principles of Quantum Mechanics*. A beautiful and important monograph laying out the basic concepts of quantum mechanics. Except for the final section on quantum field theory, it has never gone out of date.
4. E. Merzbacher, *Quantum Mechanics*. A classic. Very solid presentations.
5. A. Messiah, *Quantum Mechanics*. A classic – an older but complete and fairly mathematical treatise.

5 Expectations

- **The lectures** The course is designed around the lectures. No book will be followed strictly, and the material will be presented from the point of view of a practicing physicist. (Though the subjects covered are standard). A certain amount of improvisation can occur depending on questions. So while I won't grade on attendance, it is important that you come to class when you can.

  In the end the responsibility for learning the material is yours. In particular, *please* ask questions during class and office hours, especially if something I say is not clear (I'm not always a good mind reader, so it is your job to tell me if you are lost). My personal experience as a student is that whenever I thought a question was too stupid, somebody else asked it and it was not stupid at all. Secondly, you will need to supplement the lectures with reading on your own. I can't cover everything you need to know, at a comprehensible speed, in the lectures.

- **Problem sets**. The class is meant to be a challenge. First-year graduate courses are supposed to train students to think in new ways, to build their computational muscle, and to develop their intuition for the subject. For all of these, the problem sets are absolutely crucial, and they are mean to be *completed*. Intuition is built on, not a substitute for, experience. Hopefully, they will also be fun. Note that a certain amount of extra thought/reading may be required for some of them. Since the class time is limited, the lectures will be a bit "broad-brush", and the problem sets work to tie the basic ideas to practical calculations.

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. Physics is a highly interactive discipline, and is best learned socially, with and through your peers.

That said, the solutions you present should be your own; you should have understood the solution and written the problem set yourself, in your own words. Identical problem set solutions will be considered as plagiarized, and dealt with as such.