Spring 2014

Graduate Quantum Mechanics II

$$w_{fi} = \frac{2\pi}{\hbar}|V_{fi}|^2\delta(\varepsilon_f - \varepsilon_i - \hbar\omega)$$

Quantum mechanics provides the fundamental framework for modern physics. This course is the second part of the department's two-semester core graduate course in quantum mechanics. In this course you will learn some important concepts of quantum mechanics such as symmetries and conservation laws as well as some techniques useful in real researches.

General Information

- **Instructor**: Dr. Huaiyu "Mike" Duan, <duan@unm.edu>, P&A 1144, 505-277-1508.
- **Instructor's office hour**: Wednesday afternoon after 1:30 PM, P&A 1144.
- **TA**: Ninnat "Tom" Dangniam <ninnat@unm.edu>.
- **TA's office hour**: 3:00 —4:00 PM on Thursday, Department Lobby.
- **Lecture hours**: 9:30 — 10:45 AM on Tuesday and Thursday, P&A 184.
- **Problem session** (PHYC551.058): 7:00 — 8:30 PM on Thursday, P&A 184.
- **Main textbook**: Principles of Quantum Mechanics by R. Shankar (2nd edition, published by Springer, ISBN 978-0-306-44790-7).
- **Course homepage/repository**: UNM Learn <https://learn.unm.edu>.
- **Exam dates**: February 13, March 27, and May ??.
- **Communication**: Notices of the class will be sent to your UNM email address, i.e. <your_unm_net_id@unm.edu>. Please check your UNM mailbox regularly during the week.

Objectives

The primary goals of this course are to deepen students' understandings of quantum mechanics, to help them develop a facility for the mathematical methods of physics, and to acquaint them with some practical techniques that may be useful in their research.

Prerequisites

Students who are going to take this course should have a solid understanding of undergraduate Classical Mechanics, Quantum Mechanics and E&M. (One question you can ask yourself is whether you have passed or are ready to pass the preliminary exams on these topics, especially quantum mechanics.) Unless exempted, students should have passed the (Mathematical) Methods of Theoretical Physics (PHYC466) and graduate Quantum Mechanics I (PHYC521) with grade B-. You may encounter a steep learning curve if the prerequisites are not met.

The topics that have been covered in PHYC521, Fall 2013 include the postulates of quantum mechanics, Hilbert space and Dirac notation, propagator, Gaussian wave packet, 1D square and step potentials, bound and unbound states, Ehrenfest's theorem, Heisenberg uncertainty relations, characteristic energy and length scales, quantum harmonic oscillator, semi-classical (coherent) states, Schrödinger and Heisenberg pictures, tensor product space, entangled state, density matrix, angular momentum, central potentials, and hydrogen atom.

Content

The main subjects to be covered in this course are: identical particles, approximation methods, symmetries and conservation laws (time and space translations, parity, time reversal, gauge, and rotation), addition of angular momenta, perturbation theory, scattering theory, and some selected topics (if we have time).

Pedagogy

The students attending this course come from a very diverse background. Some of them may graduate from small colleges which offer only one semester of quantum mechanics, and some others may graduate from a prestigious institution with good grades. The historic record shows that it can take up to 3 years for some of the students to pass the department preliminary exam on undergraduate quantum mechanics. Some of the pedagogical components of this course are designed to guide the students, especially those with a weak background and/or immature studying habits, to spend their efforts effectively so that they can succeed in this course.

1. **Textbook and supplementary materials.** Study of the textbook and supplementary materials should be the **primary** way for you to develop understanding of the course material. The main textbook is chosen because it is very much self-contained. This book is also very enjoyable to read because it is full of the physical insights that the author has developed over his long research career. It is of great importance that you read the corresponding sections of the textbook before you work on homework problems which may come directly from the textbook. Here are a few reference books that you may also find useful:
    - Quantum Mechanics, vol. I&II, by C. Cohen-Tannoudji, B. Diu, and F. Laloë. (This is a good textbook that requires some time to read. I will use some sections from this book to supplement the main textbook.)
    - Quantum Mechanics, by Eugen Merzbacher. (This is a fairly comprehensive textbook but organized in an unconventional order. I will use some sections from this book to supplement the main textbook).
    - Quantum Mechanics (Non-Relativistic Theory) by L.D. Landau & E.M. Lifshitz. (Read this book if you are bored by my lectures and/or the main textbook.).
    - A Modern Approach to Quantum Mechanics by J. S. Townsend. (This is a undergraduate textbook. This book or any of your favorite undergraduate textbooks on quantum mechanics can be useful when you find it difficult to understand the lectures and/or the main textbook).
2. **Lectures.** The lectures are intended to provide the instructor's perspective, sometimes different from that of the textbook, of the course material. As a result, the lectures do not always follow the order of the textbook. Although skeleton lecture notes are provided through the online repository, they only serve to help you recall the key topics covered during the lectures and to guide your reading of the textbook. You are encouraged to take your own notes during lectures.
3. **Quizzes.** There will be a 10-minute, closed-book quiz approximately every 3 lectures which will focus on the fundamental concepts and frequently used formulas.
4. **Homework assignments and problem sessions.** The best way to learn a subject is by practicing. In this course you practice what you have learned by solving homework problems. *This course has an associated problem session (PHYC551.058) that you should register.* There will be a homework assignment and a problem session approximately every week. In the beginning of the problem session the previous assignments will be collected and the new ones will be distributed. Then the students will work on one

of the homework problems in groups during the problem session. You can also work on assignments with other students outside the class, but the solution that you turn in must be prepared solely by you. It is of great importance that you **thoroughly** work out each homework problem because exam problems will be modeled after homework problems. One of the ways to improve your understanding of the homework is to consult the solution which the instructor has spent many hours to prepare. You may gain a deeper or alternative understanding of the problems even if you have solved them successfully.

5. **Discussions.** Discussion is an invaluable tool of learning. *There is no such thing as a dumb question!* You are greatly encouraged to ask questions and discuss your confusions with me, the TA or other students during *and outside* the lectures, problem sessions and office hours. There may be times that we have to continue the discussions in small group outside the class if the questions are relevant to only a few students.
6. **Exams.** There will be three equally weighted exams focusing on the topics covered before each of them. All the exams of this course are strictly closed-book with no cheat sheet or calculator allowed. The formulas that are not frequently used or too complicated to memorize will be provided during the exams.

Grades and Other Policies

1. **Homework grade** = (sum of all your homework scores) / (maximum total homework score) × 110%. There will be **NO MAKEUP ASSIGNMENT**, and **NO LATE ASSIGNMENT** is accepted. The solution for each assignment is posted in UNM Learn after the assignments have been collected.
2. **Quiz grade** = (sum of all your quiz scores) / (maximum total quiz score) × 120%. There will be **NO MAKEUP QUIZ**.
3. **Final grade** = (homework)×30% + (exam 1)×20% + (exam 2)×20% + (exam 3)×20% + (quiz)×10%. The scores of the exams may be curved.
4. **Final letter grades** can be: A+ (≥100), A (95.0–99.9), A- (90.0–94.9), B+ (85.0–89.9), B (80.0–84.9), B- (75.0–79.9), C+ (70.0–74.9), C (65.0–69.9), C- (60.0–64.9), F (<60).
5. **Problem session:** You will receive Credit for the problem session as long as you register and show up for more than 60% of the time.

Preliminary schedule

Here is a preliminary schedule of this course. The actual schedule may vary which can be found in the Calendar tool in the course home page at UNM Learn. The lectures with numbers in the orange/shaded background are the ones with quizzes.

WEEK	LEC	DATE	TOPIC	BOOK
1	1	1/21	Introduction and review of QM1	
	2	1/23	Identical particles	10.3
2	3	1/28	Variational method	16.1
	4	1/30	WKB method	16.2

WEEK	LEC	DATE	TOPIC	BOOK
3	5	2/4	Time-translational symmetry	11.3
	6	2/6	Space-translational symmetry	11.2
4	7	2/11	Parity symmetry	11.4
		2/13	EXAM I	
5	8	2/18	Time reversal symmetry	11.5
	9	2/20	Gauge symmetry	
6	10	2/25	Electromagnetic interaction	
	11	2/27	Rotational invariance (I)	12.1-4
7	12	3/4	Rotational invariance (II)	12.5
	13	3/6	Rotational invariance (III)	14.1-3
8	14	3/11	Spin Dynamics	14.4
	15	3/13	Hamiltonian with both spin and orbital angular momentum	14.5
9		3/18	SPRING BREAK	
		3/20	SPRING BREAK	
10	16	3/25		
		3/27	EXAM II	
11	17	4/1	Addition of angular momentum (I)	15.1-2
	18	4/3	Addition of angular momentum (II)	15.2-3
12	19	4/8	Tensor operators	15.3
	20	4/10	Time-independent perturbation theory (I)	17.1-2
13	21	4/15	Time-independent perturbation theory (II)	17.3
	22	4/17	Time-dependent perturbation theory (I)	18.1-2
14	23	4/22	Time-dependent perturbation theory (II)	18.3
	24	4/24	Time-dependent perturbation theory (III)	18.5
15	25	4/29	Scattering theory (I)	19.1-3
	26	5/1	Scattering theory (II)	19.4, 19.6

WEEK	LEC	DATE	TOPIC	BOOK
16	27	5/6	Scattering theory (III)	19.5
	28	5/8	Selected topic	
17			EXAM III	