PHYSICS 481 – QUANTUM MECHANICS II

Spring Semester 2015 TR 12:00-1:15 WAT 114
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Course Description:	Quantum mechanics, along with the theory of relativity, is one of the cornerstones of modern physics. This course comprises the second semester of senior level quantum mechanics at the University of Hawaiʻi. While Physics 480 introduced the fundamental principles and concepts of quantum mechanics, Physics 481 delves more deeply into the applications of these principles in a number of systems. The fundmental system of interest is the hydrogen atom, whose analysis comprises a theoretical tour de force of quantum mechanical concepts and techniques including addition of angular momentum, degenerate and nondegenerate perturbation theory, the fine structure and hyperfine structure, and a number of techniques in higher mathematics. Other applications covered in the course include identical particles, time-dependent perturbations, periodic systems, scattering theory, and an introduction to advanced topics.
Primary textbook:	David H. McIntyre, *Quantum Mechanics, A Paradigms Approach,* Pearson Higher Ed., 2012
Supplemental text:	James Binney & David Skinner, *The Physics of Quantum Mechanics,* Cappella Archive, 2013, available online at http://www-thphys.physics.ox.ac.uk/people/JamesBinney/QBhome.htm
Course website:	https://laulima.hawaii.edu/portal/site/MAN.81882.201530 → Resources

Grade distribution:

Homework (weekly and discussion):	10%, 10%
Midterm examinations 1 and 2:	20%, 20%
Final examination:	40%

Grade ~ assignment:

A+	90 >	B+	75–80	C+	60–65	C–	40–50
A	80–90	B	65–75	C	50–60	D/F	< 40

COURSE OUTLINE

~ Dates	Topics	Chapter
1/13–1/20	*hydrogen atom*: separation of motion; radial eigenvalue equation; energy eigenvalues; radial wavefunctions; properties of hydrogen.	QM 8
1/22–1/29	*time-independent perturbation theory*: non-degenerate theory; degenerate theory; harmonic oscillator; Stark effect.	QM 10
2/3–2/12	*hyperfine structure*: interaction Hamiltonian; review of angular momentum; hyperfine perturbation; addition of angular momentum; Clebsch-Gordan coefficients.	QM 11
February 17	— *Midterm Examination #1* —	
2/19–2/26	*perturbation of hydrogen*: relativistic correction; spin-orbit coupling; Zeeman effect.	QM 12
3/3–3/10	*identical particles*: interacting particles in one dimension; symmetrization; helium and the periodic table; hydrogen molecule and hydrogen molecular ion.	QM 13
3/12–3/19	*time-dependent perturbation theory*: transition probability; harmonic perturbation; dipole interaction; Einstein coefficients; selection rules; adiabatic vs. sudden.	QM 14
March 31	— *Midterm Examination #2* —	
4/2–4/9	*periodic systems*: periodic potentials; energy bands; Bloch's theorem; density of states; Kronig-Penney; metals and semiconductors; effective mass.	QM 15
4/14–4/21	*scattering theory*: fundamentals; Born approximation; partial waves; optical theorem; low-energy scattering; resonances; S-matrix.	Suppl.[t]
4/23–4/30	*modern applications and advanced topics*: Heisenberg and interaction pictures; quantum optics; Bell's inequalities; quantum computing.	QM/BS
5/5	*Summary and Review*	
May 11–15	— *Final Examination* —	

Physics 481 Homework and Problem Sets

Graded homework will consist of two components. The first will comprise regular, weekly problem sets that will be assigned each Thursday and be due at the start of class the following Tuesday. These problem sets will consist of several problems from the textbook or other sources, and will count for 10% of the final score for the course. Students are encouraged to work together on the weekly problem sets. However, students must compile their written solutions in their own words; see the guidelines below. **The use of solution manuals is strictly forbidden under all circumstances.**

The second component will consist of one discussion problem each week, which will be assigned on Tuesday and be due at the start of class each Thursday. The first part of Thursday's class, up to 20–25 minutes or so, will be devoted to a discussion of the solution to this problem. These problems may require you to read ahead in the textbook or to consult other sources, and will count for 10% of the final score for the course. Students should attempt to solve the discussion problems on their own; all of the collaboration is meant to occur during the discussion itself.

The format for the discussion sessions is as follows:

- All students must submit solutions to the discussion problem each Thursday.
- One student will lead the discussion at the board. Everyone else is encouraged to participate in and contribute to the discussion by asking questions, offering advice, etc. (I may take part in the discussions, but I will not lead any of the discussions.) The lowest order discussion may consist simply of the student presenting his or her solution to the problem.
- Leaders of the discussion will automatically receive full marks for the problem, *even if their submitted solutions are incorrect or contain errors.* The discussion leaders will rotate through the class list, with the option to pass in any given week, but each student must lead 2 discussions.
- Leaders should be prepared to lead the discussion in good faith (say, by getting started, identifying any difficulties encountered, guiding the class, offering suggestions or asking questions, etc.)
- If, following the discussion, the other class members are happy with their solutons, that's fine. Otherwise, students may submit a revised solution for a score of up to 8/10.

Guidelines for Weekly Problem Sets

1. All problem set solutions should be composed entirely in complete English sentences.

   The solutions need not be essays. However, each word should appear as part of a complete English sentence (unless it appears as the descriptor in a figure). Similarly, every equation should appear as part of a complete English sentence. Punctuation in this respect is important – colons, semicolons, and periods should be used appropriately and in accordance with the rules of grammar.

2. Each equation (or sequence of derivations) should be written on separate lines. In-line equations that are used to define a parameter or quantity can be written in the main body of text. Previous equations can be referenced by number.

3. Figures should be briefly referenced in the write-up.

4. Results obtained from class or from the text need not be reproduced in the problem solutions, but their origin should be referenced (for example: "… from a result obtained in class …", or "… from *McIntyre*, p. 254, …").

5. *Scratch work will not be accepted!* Solutions with crossed-out results, scribbling, etc., will be returned to the student for revision.

Student Learning Objectives

After completing this course, students are expected to have a good working proficiency with the following general concepts:

1) a good understanding of the lowest order solution of the energy spectrum of the hydrogen atom, including full degeneracy.
2) the separation of center-of-mass and relative motion; the concept of reduced mass; the separation of angular momentum eigenstates in central potentials.
3) the fundamental differences between the quantum mechanical analysis of the hydrogen atom and Bohr's analysis.
4) the general procedures and limitations of perturbation theory; the fundamental difference between degenerate and non-degenerate perturbation theory; the calculation of perturbation solutions up to second order.
5) the analysis of the hyperfine structure of the ground state of hydrogenlike atoms; the fundamental differences between the coupled and uncoupled basis states of angular momentum; the general problem of adding angular momenta, and the meaning of the Clebsch-Gordan coefficients.
6) the calculation of higher orders and perturbations of the hydrogen spectra, including the fine structure and the Zeeman effect; the application of degenerate perturbation theory to these problems.
7) the general procedure of time-dependent perturbation theory, and how it differs from time-independent perturbation theory in both method and objective.
8) the significance of transition probabilities; harmonic perturbation; the electric dipole interaction and the origin of the selection rules.
9) the nature of identical particles; the difference between the exchange symmetry properties of bosons and fermions; the application of the symmetrization postulate and its connection with the Pauli exclusion principle.
10) the basic structure of the periodic table of the elements.
11) the basic quantum mechanical nature of periodic systems; the LCAO model and the origin of the band structure of solids.
12) an understanding of advanced concepts in quantum mechanics, including the Heisenberg and interaction pictures, Bell's inequalities and entangled states, and quantum optics.