# PHYS-UA 124: Quantum Mechanics II
# Course Information - Spring 2018

January 4, 2018

**Instructor** Daniel Stein

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**Office** 726 Broadway, Room 981

**Office Hours** Monday, 3:00-4:00pm, Wednesday, 2:00-3:00pm, 726 Broadway, Room 981

**Lecture**

- - MW 11:00AM - 12:15PM, 726 Broadway, Room 1045

**Recitation** Instructor: Ekapob Kulchoakrungsun. Time and Location: Monday 5:00-6:15pm, 726 Broadway, Room 1045

**Course description** This course is a continuation of Quantum Mechanics I, with a focus on the application of quantum mechanics toward understanding the structure and behavior of atoms in particular, but also molecules, crystalline solids, nuclei, and particles. New techniques will be introduced, in particular time-independent and time-dependent perturbation theory, variational principles, exchange operators, and three-dimensional scattering theory. Topics covered include the fine and hyperfine structure of atoms, many-particle systems, the shell structure of multi-electron atoms, the Pauli exclusion principle and quantum statistics, covalent bonding and simple molecules, conduction in simple metals, and the interaction of matter and radiation. If time permits, more advanced topics in current research will also be covered.

The material we take up in this course has applications in physics, astronomy, chemistry, biology, and electrical engineering. We want you to leave the course not only with computational ability in quantum mechanical problems, but also with the ability to use these notions in their natural scientific contexts, and with an appreciation of their physical and mathematical beauty and power.

**Textbook**

- Gasiorowicz, Stephen. *Quantum Physics*, 3rd Edition.

**Grading** Your final grade will be computed with the following weights:

| | |
|---|---|
| Homework | 30% |
| Two In-Class Exams | 40% |
| Final Exam | 30% |
| Total | 100% |

**A note on grades of W and I** You may drop the course in the first three weeks without it appearing on your transcript. After that, and through the ninth week, you may withdraw and receive a grade of 'W' on your transcript. No withdrawals are granted after the ninth week.

A grade of 'Incomplete' (I) is granted only in the rare circumstances that an emergency prevents a student in good standing from finishing the course in its last few weeks. As per the CAS Bulletin:

> "Students who are ill or have a serious personal problem should see, call, or write to an advisor in the College Advising Center, College of Arts and Science, New York University, Silver Center, 100 Washington Square East, Room 905, New York, NY 10003-6688; 212-998-8130."

**NYU Classes** The chief means of communication for this course will be the NYU Classes site, accessed through home.nyu.edu. Students are expected to check this for up-to-date assignments—including material separate from the text—and announcements.

**Homework** The homework will comprise weekly problem sets consisting both of simple exercises and more in-depth problems requiring greater abstraction, understanding and/or synthesis of various concepts. In many ways, these constitute the heart of the course; rigor in their completion often yields the greatest understanding.

All homework assignments appear on the Assignments page of NYU Classes. *You are responsible* for checking this page and making sure that you hand in the appropriate homework before its due date. Homeworks will be submitted electronically through NYU Classes, and completed assignments must generally be submitted by 11:55pm Thursday night. (Each homework will contain instructions regarding its due date and time.)

**Because the homeworks will all be available for weeks before the due date, no excuses will be accepted for late homeworks. This is out of fairness to your fellow students and to the grader. You are strongly urged not to wait**

**until just before the deadline to submit your homeworks — last-minute problems with internet connectivity will not be accepted as an excuse for late homework.**

We will make every effort to return your graded homework within a week of its due date. Solutions to each homework problem will be posted on the Assignments page the day after its due date.

When calculating the overall homework grade for the semester, the lowest homework grade will be dropped.

**Exams** There will be two in-class exams during the semester. Dates for each and topics covered will be announced at least two weeks in advance.

**Final Exam** The final exam will take place on Monday, May 14, 2018 from 10 – 11:50am.

**Policy On Out-Of-Sequence Exams and Missed Quizzes** We are able to accommodate only a limited number of out-of-sequence exams due to limited availability of rooms and proctors. For this reason, we may approve out-of-sequence exams in the following cases:

- A documented medical excuse.
- A University-sponsored event such as an athletic tournament, a play, or a musical performance. Athletic practices and rehearsals do not fall into this category. Please have your coach, conductor, or other faculty advisor contact your instructor.
- A religious holiday.
- Extreme hardship such as a family emergency.

We will *not* be able to accommodate out-of-sequence exams, quizzes, and finals for purposes of more convenient travel, including already purchased tickets. Please note again the date of the final exam and plan your travel accordingly.

Scheduled out-of-sequence exams and quizzes (those not arising from emergencies) must be taken before the actual scheduled exam.

If you require additional accommodation as determined by the Center for Student Disabilities, please let your instructor know as soon as possible.

**N.B.** If you know in advance that you will not be here on an exam date for any reason, such as observance of a religious holiday or an allowed pre-planned trip out of town as discussed above, you *must* notify your instructor in advance, in writing, at least two weeks before the exam date. All other absences will be considered unexcused and will

result in a grade of zero for that exam. (So please set a backup alarm or have a reliable friend call you that morning if there's a chance you might otherwise miss the exam. We will make absolutely no exceptions to this policy.)

**Extra Credit Policy** The homeworks, two in-class examinations, and final examination provide a more than adequate basis for you to demonstrate how well you've learned the material and for me to determine an accurate course grade. There will be no exceptions in grade assessment made for anyone; in particular, extra credit papers or assignments will *not* be allowed under any circumstances. Please understand that this is to ensure fairness and uniformity of grading standards for everyone.

**Technology** Technology can play an important role in the learning of physics, and as such, graphing and scientific calculators are permitted for class and homework, though they will not be required. Calculators will not be permitted on tests and quizzes, and thus it is emphasized that students learn not to rely on them.

**Academic Honesty** Guidelines regarding cheating and plagiarism are laid out in the College of Arts and Sciences guidelines and will be adhered to strictly. Collaboration is permitted, in fact encouraged, for homework assignments; however, all submitted assignments must be written up independently and represent your own work and understanding.

## COURSE OUTLINE

Below is a syllabus of topics to be covered during the semester. All are subject to change as the semester progresses.

1. Time-Independent Perturbation Theory
    (a) Non-Degenerate Perturbation Theory
        i. Example: The Anharmonic Oscillator
    (b) Degenerate Perturbation Theory
        i. Application: The Stark Effect

2. The *Real* Hydrogen Atom
    (a) Fine Structure of Hydrogen
        i. Spin-Orbit Coupling
        ii. Relativistic Corrections
    (b) Hyperfine Interaction
    (c) Spectroscopic Notation
    (d) Atoms in a Magnetic Field
        i. Normal and Anomalous Zeeman Effect
        ii. Landé g-factor
        iii. LS- and jj-coupling

3. Many-Particle Systems
    (a) Indistinguishability of Identical Particles
        i. Exchange Operator
        ii. Pauli Exclusion Principle
        iii. Fermions and Bosons
        iv. Fermi-Dirac and Bose-Einstein Statistics
        v. Application: Ortho- vs. Para-Hydrogen
    (b) $N$-Particle States
    (c) The Fermi Gas
        i. Application: The Free Electron Theory of Metals
        ii. Application: White Dwarf Stars

4. Multi-Electron Atoms

    (a) Helium Atom

        i. Lowest Excited State

        ii. (If time permits) Heisenberg Hamiltonian and the Origins of Solid-State Magnetism

    (b) Variational (Rayleigh-Ritz) Method

        i. Application: Computation of the Ground State Energy of the Helium Atom

    (c) Many-Electron Atoms

        i. The Periodic Table

        ii. Central-Field Approximation and the Aufbau Principle

        iii. Splitting of Atomic Configurations

        iv. Hund's Rules

        v. (If time permits) Hartree, Hartree-Fock, and Thomas-Fermi Methods

5. Molecules

    (a) Pairing of Electrons and the $H_2$ Molecule

    (b) (If time permits) Hybridization of Molecular Orbitals

6. Time-Dependent Perturbation Theory

    (a) General Theory

    (b) Fermi's Golden Rule

        i. Application: Nuclear Magnetic Resonance (NMR)

    (c) Sudden and Adiabatic Perturbations

7. Interaction of Matter and Radiation

    (a) Einstein's A and B Coefficients; Lasers

    (b) Interaction of Electrons and Electromagnetic Plane Waves

    (c) Atomic Selection Rules

    (d) Rate for Spontaneous Decay of an Excited Atomic State

8. Scattering Theory

   (a) Differential and Total Cross Section

   (b) Partial Wave Analysis

      i. Optical Theorem

      ii. Application: Hard Sphere Scattering

      iii. S-Wave Scattering

      iv. Absorption (if time permits)

   (c) The Born Approximation

      i. Green Functions (if time permits)

      ii. Application: Scattering of Electrons and X-Rays by Atoms

   (d) Effects of Exchange Symmetry

9. Special Topics (if time permits)