PHYSICS 6301: QUANTUM MECHANICS II

Fall 2005

Classes: **MW 12:30-1:45 pm** in **FN 2.104**

INSTRUCTOR: Dr. Yuri Gartstein

Office:	FO 2.610B	Phone:	972-883-2834	E-mail:	yuri.gartstein@utdallas.edu
Office hours: M 2:00-3:30 pm			Extra class hours: As needed		
Web communication and access to course materials: https://webct.utdallas.edu					

COURSE OBJECTIVES

This course will be dealing with the subjects that frequently fall under the name of "Advanced quantum mechanics", hence some of the titles in the list of suggested books. Alternatively, it could probably be called something like "Introduction into the methods of quantum field theory". Be apprised, however, that this is certainly not a course of the modern quantum field theory or even of the quantum electrodynamics. The truly beautiful notions and concepts we will be discussing have been established a long time ago and became since a common language used in condensed matter physics, statistical mechanics and high-energy physics. A high-energy electron hits a target and a bunch of particles is produced as a result of collision. A photon is absorbed in a semiconductor producing an electron-hole pair that contributes to the photocurrent. How does one describe quantum-mechanical systems where particles are being created and annihilated? That is where the language of second (or field) quantization becomes natural. We will see how the notion of photons results from quantization of the familiar classical electromagnetic field and how phonons in solids are related to the familiar sound waves. Some other topics will include particles and antiparticles in relativistic quantum mechanics, elements of scattering theory and basics of omnipresent Feynman diagrams...

While studying elements of formalism, the focus in this course will be on "physics", that is, on how the formalism works and helps us understand actual physical processes. The instructor shares the sentiment eloquently expressed by John Ziman: "Nothing is more repellent to normal human beings than the clinical succession of definitions, axioms and theorems..." Upon completion of the course, the instructor would like to have students clearly understand basic principles, be able to see relationships between ideas, and, most importantly, be "fluent" in using principles and ideas in "calculating" properties of simpler systems.

EVALUATION AND GRADING POLICY

In accordance with the course objectives, conceptual understanding and ability to apply principles to actual problem solving are the key to high grades. The final grade will be comprised of contributions from the homework (~60%), the course project (~20%) and the final exam (~20%). Your consistent effort during the whole semester is evidently highly valued.

Homeworks are expected to be done by the due date, however an extra time may be given to submit improved versions. The homework may include not only problems but also some self-study topics. It is **required** that homeworks are submitted not handwritten but typed. While, admittedly, this may be somewhat more time-consuming in the beginning, the instructor is confident that students will benefit in the long run. On a technical side, it will help you keep records and simplify the editing process. More importantly, this should assist in your developing skills for scientific exposition of your results. Your conceptual logic and approaches (where you are starting from, where you are going and how) would be most valued. I do not specify the format of your output, whether you prefer to work with LaTeX or Word based systems.

The course project is an individual topic/problem given by the instructor that a student would have an ample time to prepare using various resources with the final delivery in the form of a short paper and a presentation to the class. The exam is open book or take-home; in all cases, however, a student should be able to explain his/her solution.

Every attempt will be made to give students an opportunity to improve their standing. That includes the possibility of individual make-up test(s) at the end of the semester. A proactive student's position is encouraged and your feedback is always welcome.

The integrity of students' behavior matters - working in groups is encouraged but it is the individual understanding of the subject and results that will be tested. All special student needs should be reported within first two weeks of the course. Communication of all grades and announcements will be through WebCT.

Last but not least, I strongly feel that satisfaction one gets from the learning accomplishments makes "grades" a much less sensitive issue. My general position is that "I am not here to make your life harder but to help you learn". I would like to invite all students to have more fun from learning and worry less about grading.

BOOKS AND RESOURCES

There is a lot of wonderful books on modern quantum field theory (especially useful for those with further interests in high-energy physics), which are not listed here. If you happen to have one of them, that should be sufficient for many purposes and there may be no need to purchase more. Listed below are some texts that I feel could (for various reasons) be attractive to students and from which I am planning to borrow many materials. No priority is intended in the sequence of the books and any editions (including inexpensive ones) will work. Some of the topics like non-relativistic scattering theory are traditionally treated in "ordinary" textbooks on quantum mechanics, and I am not quoting them here.

1. **F. Schwabl, "Advanced Quantum Mechanics"** (Springer). This book may turn out to be a very nice compromise between the size, comprehensiveness and thoroughness. Schwabl and Greiner have also texts on "elementary" quantum mechanics which may serve as good complements to "advanced" counterparts.
2. **J.M. Ziman, "Elements of Advanced Quantum Theory"** (Cambridge). In addition to anything else, you, like myself, may find Ziman's and Lipkin's books stylistically and pedagogically "entertaining".
3. **W. Greiner, "Quantum Mechanics. Special Chapters"** (Springer). A wonderful set of thorough textbooks on various aspects of quantum mechanics written by Greiner, only three of which are listed here.
4. **W. Greiner, J. Reinhardt, "Field Quantization"** (Springer).
5. **W. Greiner, "Relativistic Quantum Mechanics"** (Springer).
6. **J.J. Sakurai, "Advanced Quantum Mechanics"** (Addison-Wesley). A well-known text with emphasis on quantum theory of radiation, Dirac's equation and quantum electrodynamics.
7. **H.J. Lipkin, "Quantum Mechanics"** (North-Holland).
8. **H. Haken, "Quantum Field Theory of Solids"** (North-Holland). A nice didactic treatment of non-relativistic ideas that could be especially useful for those with interests in condensed matter applications.

Whenever needed and possible, the instructor will make his resources available to students.

HIGH-LEVEL DESCRIPTION OF THE COURSE

This brief description is intended just to give you a glimpse of **some** of the subjects we will be talking about (not necessarily in the same order and to different depths). More detailed subject listings will be available online as we proceed along.

NON-RELATIVISTIC MANY-PARTICLE SYSTEMS

Identical particles and symmetry of many-particle wave functions; Bosons and fermions; Occupation number representation and Fock space; Creation and annihilation operators; Field operators and field equations; Systems of free bosons and free fermions, correlation functions; Interactions and Hartree-Fock approximation; Quasi-particles; Attraction of fermions and BCS model of superconductivity; Repulsion of bosons and Bogoliubov model of superfluidity.

CANONICAL QUANTIZATION OF WAVE EQUATIONS

A single harmonic oscillator with creation and annihilation operators; Coupled oscillators, phonons;

Classical field theory; Lagrangian, Hamiltonian and wave equations; Canonical quantization; Schrödinger equation and second quantization.

PHOTONS AND INTERACTION OF RADIATION WITH MATTER

Maxwell equations, gauges and Lagrangian of the electromagnetic field; Coulomb gauge and quantization of the transverse field: photons; Emission, absorption and scattering of light by atoms and condensed systems; Reality of vacuum fluctuations: Casimir force.

RELATIVISTIC WAVE EQUATIONS AND THEIR QUANTIZATION

Relativistic covariance; Klein-Gordon and Dirac equations and their free solutions; Particles and antiparticles; Non-relativistic limit and spin-orbit coupling; Lagrangians and quantization of relativistic wave equations; Micro-causality and spin-statistics theorem.

NON-RELATIVISTIC SCATTERING THEORY

Wave packets and their scattering; Scattering amplitudes, phase shifts and cross-section; Optical theorem; S- and T-matrices; Born series and Born approximation; Inelastic and resonance scattering; Scattering by the Coulomb potential.

INTERACTING FIELDS AND PERTURBATION THEORY

Nonlinear Lagrangians; Interaction of electrons with the radiation field: Quantum electrodynamics; Time evolution, Heisenberg and interaction representations; S-matrix; Perturbation expansions and Feynman graphs; Simple scattering processes; Dyson's equation; Self-energy and renormalization.