CUA

THE CATHOLIC UNIVERSITY OF AMERICA
DEPARTMENT OF PHYSICS

PHYS 659: Quantum Theory I
Fall 2009

Credit Hours: 4
Classroom: Hannan Hall, Rm 103
Days and hours of class meetings: Tuesday & Thursday, 4-6pm

Instructor contact information:

Dr. Tanja Horn, Assistant Professor
Office: Hannan Hall, Rm 210
Phone: (202) 319-5326
Email: hornt@cua.edu
Web pages: Homework assignments and supplementary material will be posted at:
http://faculty.cua.edu/hornt/Phys659
Office hours: Tue: 12-2pm

Course Content:

This is a first semester of graduate quantum mechanics course. Covered are: theoretical and mathematical formulation of Quantum Mechanics, transformations of states and observables, equations of motion, symmetries and conservation laws, coordinate and momentum representations, basic applications of wave-mechanics, Schroedinger equation and uncertainty principle, harmonic oscillator, theory of angular momentum and rotation group, formation of bound states, and the hydrogen atom.

Required Text:

The text for this course will be: ***Modern Quantum Mechanics*, by J.J. Sakurai, rev. ed. 1994, Addison-Wesley Publishing Company.** The book should be available at the campus bookstore in the PRYZ University Center and perhaps local Border's bookstores. Other good texts are listed below.

Recommended Texts:

- **F. Schwabl, *Quantum Mechanics*** (Concise, well-organized, clear exposition.)
- **C. Cohen-Tannoudji, B. Diu and F. Laloe, *Quantum Mechanics*** (Massive, strong on both fundamentals and applications, excellent for self-study)
- J**.J. Sakurai, *Modern Quantum Mechanics*** (Written by a high-energy theorist, tilted toward the algebraic approach. Nice choice of examples.)
- **L.D. Landau, E.M. Lifschitz, *Quantum Mechanics***, 1958, Addison-Wesley (Practical and fundamental, with many applications and worked problems.)
- **L.I. Schiff, *Quantum Mechanics***, 3rd ed. 1968, McGraw-Hill (A ``standard'' old-fashioned graduate textbook. Contains a lot of material and has a good table of contents.)
- **G. Baym, *Lectures on Quantum Mechanics*** (Informal but sophisticated, very readable, with many applications.)
- **E. Merzbacher, *Quantum Mechanics***, 3rd ed. 1970, Wiley (Another ``standard'' graduate text, with the slant of a nuclear theorist. Strong on scattering theory..)

- **H.A. Bethe and R. Jackiw, *__Intermediate Quantum Mechanics__***, *(*Atomic structure, interaction with radiation, and scattering theory, beyond the usual introductory topics.)
- **R. Shankar, *Principles of Quantum Mechanics*** , 2nd ed. 1994, Plenum Press (Holds the student's hand, verbose, mostly elementary, but has some very nice modern applications.)
- **D.J. Griffiths, *__Introduction to Quantum Mechanics__*** *(*A very well written modern undergraduate text, neatly organized and lucid.)
- **P.A.M. Dirac, *Quantum Mechanics***, 4th ed. 1958, Oxford Univ. Press (An elegant classic.)
- **R.P. Feynman, *__The Feynman Lectures on Physics, vol. III__*** (A ``beginning undergraduate'' text offering insights that keep professors coming back.)
- **A. Messiah, *__Quantum Mechanics__***, 2 vol. 1961, Interscience (Strong on the formal and mathematical aspects of the theory.)
- **J. Preskill, *__Lecture Notes on Quantum Mechanics and Quantum Computation__*** (Notes from a Cal. Tech. course. Includes a nice introduction to the fundamentals of QM.)
- **M. Abramowitz and I. Stegun, *__Handbook of Mathematical Functions__*** (Indispensable for special functions.)
- **Gradshteyn and Ryzhik: *__Table of Integrals, Series, and Products__*** (The best)
- **S. Gasiorowicz, *__Quantum Physics__***, 1974, Wiley
- **M. LeBellac, *__Quantum Mechanics__***, 1st ed. 2006, Cambridge Univ. Press
- **O.L. de Lange, R.E. Raab, *__Operator Methods in Quantum Physics__***, 1991, Oxford Univ. Press

Course Goals:

The focus of this course is the algebraic formulation of quantum theory. During the Fall Semester we will cover chapters 1-4 of Sakurai's textbook supplemented with examples from the recommended texts and class handouts). It is important to read the relevant sections prior to each class as they will complement the lectures; and reading corresponding sections in other textbooks will provide different perspectives on the topics covered in the lectures.

Homework and exams:

- There will be homework problems assigned at regular intervals. Late homework accepted only under dire circumstances. I will grade the homework and provide the solutions on the course webpage. If you know it will be impossible to turn in an assignment on time you must discuss this with me *in advance* of the due date. The homework is an essential part of the course. I believe most of what you learn will come from doing the homework. You are encouraged to discuss the homework with others, but what you finally hand in should be your own work. ***Sources (e.g. textbooks or classmates) should be cited when used heavily in a homework solution.*** __Please make sure you include your name and the homework and course numbers and staple the pages together.__
- There will be one or two mid-term exams and one final exam. The mid-terms will be one hour long, and the final exam two hours. The exams will probably be closed book exams, to provide practice for the qualifying exam. The final exam will be on Dec.
- Homework will count for 20% of your grade, the midterms for 20% each, and the final exam for 40%. I cannot say for sure in advance, but I expect the letter grades to correspond to (roughly) (A) 100-80%, (B) 80-60%, (C) 60-40%.

Expectations and policies

Academic honesty: Academic honesty is expected of all CUA students. Faculty are required to initiate the imposition of sanctions when they find violations of academic honesty, such as plagiarism, improper use of a student's own work, cheating, and fabrication.

The following sanctions are presented in the University procedures related to Student Academic Dishonesty (from http://policies.cua.edu/academicundergrad/integrityprocedures.cfm): "The presumed sanction for undergraduate students for academic dishonesty will be failure for the course. There may be circumstances, however, where, perhaps because of an undergraduate student's past record, a more serious sanction, such as suspension or expulsion, would be appropriate. In the context of graduate studies, the expectations for academic honesty are greater, and therefore the presumed sanction for dishonesty is likely to be more severe, e.g., expulsion. ...In the more unusual case, mitigating circumstances may exist that would warrant a lesser sanction than the presumed sanction."

Please review the complete texts of the University policy and procedures regarding Student Academic Dishonesty, including requirements for appeals, at http://policies.cua.edu/academicundergrad/integrity.cfm and http://policies.cua.edu/academicundergrad/integrity.cfm.

Accommodations for students with disabilities: Any student who feels s/he may need an accommodation based on the impact of a disability should contact the instructor privately to discuss specific needs. Please contact Disability Support Services (at 202 319-5211, room 207 Pryzbyla Center) to coordinate reasonable accommodations for students with documented disabilities. To read about the services and policies, please visit the website: http://disabilitysupport.cua.edu.

Topics to be covered:

- Physical Foundations of Quantum Mechanics
- Vector Spaces and Bra-Ket notation: Chapter 1 of Sakurai
- Operators, Uncertainty Relations, Wave Functions: Sakurai Chapter 1 and 2
- One-dimensional Systems: Sakurai Chapter 2
- Sturm-Liouville equations, Two- and Three-dimensional problems, Bohm-Aharonoff effects: Sakurai Chapter 2
- Angular Momentum, Central Forces, Electromagnetic Fields
- Theory of Angular Momentum: Sakurai Chapter 3
- Symmetries in Quantum Theory: Sakurai Chapter 4

Course Schedule (*with topics covered, minutes, supplements, & homework*):

Date	Topics	HW & supplements
Sept 1	Physical foundations of Quantum Mechanics. For an early account, see Atomic Physics by M. Born (Dover Publ. Co.). For a recent account see the article in Science Magazine by D. Kleppner and R. Jackiw distributed in the class, Classical mechanics and "old" quantum mechanics, Bohr-Sommerfeld Quantization hypothesis.	
Sept 3	Schroedinger equation and standard interpretation, Fourier transforms. Further reading in D. Bohm (conservation based on hydrodynamics), Omnes (consistent histories), Griffith,	First homework posted. Due on Sept 15.

	Gell-mann, Hartle (Bell's inequality).	
Sept 8	Abstract quantum mechanics (representation, operators, basis vectors, normalization, completeness), Formal Bra-Ket notation (adjoint operators, Gram-Schmidt, measurements). Sakurai Chapter 1.2, 1.3	
Sept 10	Operator formalism and usage (matrix representations, Ehrenfest theorem)	
Sept 15	Heisenbergs uncertainty principle, Cauchy-Schwartz inequality, complete sets of commuting observables, Stern-Gerlach experiment, Pauli spin matrices, propagators, Feynman path integral, free particle propagator.	
Sept 17	1-D problems (variational principle, scattering and bound states, WKB methods).	Homework 2 posted. Due on Sept 29.
Sept 22	Scattering/transfer matrix (Ramsauer-Townsend effect), bound states of a well	
Sept 24	Periodic potentials (Bloch theorem), harmonic oscillators (old fashioned and modern way).	
Sept 29	Harmonic oscillator cont., Heisenberg representation for operators, properties of coherent states (Baker-Campbell-Hausdorff forms, Fock representation, Poisson distribution)	
Oct 1	Coherent states cont., semi-classical methods (WKB), Airy functions, asymptotic properties.	Homework 3 posted. Due on Oct 15.
Oct 6	Airy functions cont., continous potentials (WKB method), scattering problems, repulsive barrier potential	
Oct 8	Quantum mechanical propagator, Feynman path integrals, Bohm-Aharonov effect, semi-classical limit of Feynman path integral.	
Oct 13	Review for Exam I	
Oct 15	Exam I	
Oct 20	2-D and 3-D problems, ladder operators, central forces	
Oct 22	Operators in coordinate space, angular momentum and rotation group, translation operators.	Homework 4 posted. Due on Nov 3.
Oct 27	Spherical potentials, radial equation solutions (Bessel functions, construction of Legendre polynomials), spin systems, general angular momentum and addition of angular momentum, Bell's theorem, quantum computation.	
Oct 29	Radial equation solutions cont., hard sphere interactions, Hydrogen atom without spin	
Nov 3	Spinless hydrogen atom cont., review of boundary problems, spin theory, Zeeman effect, spin-orbit coupling, relativistic effects (Thomas precession)	
Nov 5	Hydrogen atom and spin, singlet/triplet states, Clebsch-Gordon coefficients.	Homework 5 posted. Due on Nov. 19.
Nov 10	Perturbation theory, energy levels, hyperfine structure, Lamb shift, Zeeman effect	
Nov 12	Wigner-Eckart theorem, vector operators, irreducible tensors	
Nov 16	Review Exam II	
Nov 19	Exam II	
Nov 24	Wigner-Eckart theorem, projection theorem, anomalous	

	Zeeman effect, Density matrices and operators, von Neumann-Liouville equation, Heisenberg equation of motion, Wigner distribution	
Nov 26	No class, Thanksgiving holiday	
Dec 1	Density matrices, Spin ½ systems, Bell's theorem, EPR paradox.	Homework 6 posted. Due on Dec. 14.
Dec 3	Difference between pure and mixed states, Bell's theorem continued, Quantum teleportation	
Dec 8	Quantum computing, symmetries, conservation laws, time reversal invariance, Entanglement vs. Bell's theorem	
Dec 10	Symmetries, parity, time reversal, charge conjugation, CPT theorem, Pseudoscalar parity operator, spherical harmonics, average dipole moment, NH3, pi mesons	
	Time reversal invariance, anti-unitarity, application of time reversal operator (Kramer's degeneracy)	
Dec 15	Final Exam	