University of New South Wales – School of Physics
PHYS3210 Quantum Mechanics - Session 1, 2011
Lecturer: Dr Vincent Smith

Brief Syllabus:
Fundamental principles; the Hydrogen atom; angular momentum; stationary and time-dependent perturbations; semi-classical radiation theory; variational methods; systems of particles; the Helium atom; matrix formulation.

Assumed Knowledge:
The courses assume familiarity with the material covered in PHYS2040, Quantum Physics. Some familiarity with multivariable calculus and differential equations is assumed. Any student without these prerequisites should consult the lecturer prior to enrolment.

Course Goals:
Quantum Mechanics is the fundamental theory of matter at the atomic level, and provides an accurate description of atoms and assemblies of atoms, as well as of subatomic physics. Quantum effects also manifest themselves in macroscopic phenomena such as magnetism and superconductivity. This course aims to provide physics graduates with a working knowledge of the subject, including both a familiarity with its conceptual basis and also the mathematical skills needed to carry out calculations/predictions for real systems. Specific issues to be discussed include:
- The fundamental postulates of Quantum Mechanics (in the form of "Wave Mechanics" based on the Schroedinger equation).
- Working with operators, expectation values, eigenvalues and eigenfunctions
- The hydrogen atom, angular momentum operators, conserved quantities and "quantum numbers".
- Methods to analyse systems which do not have closed-form analytic solutions.
- How to understand transitions between quantum states, and how to calculate selection rules and transition rates.
- Systems of indistinguishable particles, multi-electron atoms and the periodic table.

Why is Quantum Mechanics Important?
Quantum Theory represents certainly the greatest revolution in our understanding of the physical world since the times of Newton and Maxwell. All Physics graduates, irrespective of their future career directions, need to have an understanding and appreciation of this subject. Quantum aspects are becoming more and more important in leading-edge technology, and in many diverse research fields. A teacher of Physics cannot hope to answer the questions of students who are exposed to quantum ideas, often without adequate explanation, unless they have studied the subject in some depth.

Quantum Mechanics provides a correct and complete (as far as we know) description of the material world. The theory was developed by many people, beginning in the mid-1920s and essentially complete by the 1950s. At UNSW, this material is taught in a sequence of courses from Level 2 to Level 4.

Although the basic framework was complete by 1950, Quantum Mechanics remains vigorous on a number of fronts, such as:
- in fundamental research, via extension to Field Theory, Particle Physics and Quantum Gravity.
- through application of QM principles in research in nuclear, atomic and molecular physics, and in condensed matter.
- through recent developments in fields like Quantum Optics which allow single quantum states to be realized and manipulated in the laboratory. Fundamental ideas about entangled states, quantum measurement, and quantum computing can now be tested and refined.
- in developing technology, involving nanostructure electronic devices, where electrons no longer behave semi-classically.

How to Succeed - Strategies for Learning:
Many (most?) students find Quantum Mechanics difficult. There are two quite distinct reasons for this. We are all wedded to a conceptual view of the natural world, based on macroscopic phenomena and objects. Thus, it is difficult to accept that electrons are neither "waves" nor "particles", but can only be described imperfectly in words and require a mathematical description. It is hard to avoid the picture of electron "spin" in terms of a little ball spinning about an axis, false though this is.

The other difficulty that students have is with mathematics. Some do not have enough practice or confidence; others find the mathematics dry and formal. The mathematics is necessary, but it is a means to an end, not an end in itself!

The subject does not require students to memorize large numbers of facts, or complicated mathematical expressions. However, it is necessary to recognize the techniques needed to derive various important results, and to formulate solutions to problems. For this reason, a set of Tutorial Problems is provided. Students should work through these, either individually or in groups. Worked solutions are provided on the Web – these should be consulted after you have attempted the problems. Some of these problems will be discussed in lectures to illustrate important points.

Assessment:
2 hour written examination 70%
Three assignments 20% In-session exam 10%
One of the assignments will involve computer-based work. Some software is available in the 3rd Year Laboratory.

Textbooks:
S. M. McMurray, "Quantum Physics" (Addison-Wesley, 1994)
S. Gasiorowicz, "Quantum Physics" (Wiley, 1996)

Useful Reference Books:
There are at least 20-30 good books which cover the material of this course. Some which you may find useful include:
A.P. French & E. F. Taylor, "An Introduction to Quantum Physics" (Van Nostrand Reinhold, 1979) *- good on conceptual aspects*
R. Eisberg & R. Resnick "Quantum Physics of Atoms, Molecules, Solids, Nuclei & Particles" (Wiley, 1974)
- brief on some topics, good for a wide range of applications
W. Greiner "Quantum Mechanics: An Introduction" (Springer 1994)
- great on detailed explanations; also includes a final chapter (brief) on 'conceptual and philosophical' problems.
E. Merzbacher "Quantum Mechanics", 3rd Ed (Wiley 1998)
- somewhat advanced; for those with mathematical inclinations.

Computational Quantum Mechanics:
Modern computers can be a great aid in understanding and learning Quantum Mechanics. Visualizing a complex wavefunction or watching a wavepacket scatter off a potential sure beats writing a complex expression in terms of Airy or Bessel functions.
Many modern books, eg. McMurray or Serway, Moses and Moyer "Modern Physics" come with associated computer software. There are at least two books which focus exclusively on this:
S. Brandt & H. D. Dahmen, "Quantum Mechanics on the Personal Computer" (Springer 1995) - a Mac version also exists
J. Hiller, I. Johnston & D. Styer, "Quantum Mechanics Simulations" (Wiley 1995- CUPS series).
However, computers are a tool, and should be used as such.

Extension Reading:
P. Davies & J. Brown, Eds. "The Ghost in the Atom" (Cambridge, 1993)
- a discussion of issues to do with the 'meaning' of quantum mechanics, and interviews with a number of leading physicists.
A. Rae "Quantum Physics: Illusion or Reality?" (Cambridge, 1994)
- a non-technical discussion of conceptual issues
G. Milburn "The Feynman Processor" (Allen & Unwin, 1998)
- entangled states, teleportation and quantum computing
B. d'Espagnat "Veiled Reality An Analysis of Present-Day Quantum Mechanical Concepts" (Addison-Wesley, 1995)
- an in-depth and technical analysis of quantum measurement theories and the foundations of quantum mechanics.