The University of Sydney
AUSTRALIA

School of Physics

PHYS 3960/1/2 Senior Physics (Advanced) Quantum Mechanics Semester 2, 2009

MODULE OUTLINE

This document describes details of the Advanced Quantum Mechanics module and should be read in conjunction with the Senior Physics Handbook.

Lecturer: Joe Khachan
Room: 363 (Physics building)
Tel: (02) 9351 2713
Email: j.khachan@physics.usyd.edu.au

GENERAL GOALS OF THIS MODULE ARE THAT YOU:

- To see that quantum mechanics is much wider than the application of Schrödinger's equation.
- Become familiar with the use of operator methods.
- Be able to relate operator methods to matrix methods.
- Use both of these methods in a number of applications that involve angular momentum such as spectroscopy and quantum computing.
- Become familiar with some approximation methods in applications where solutions in closed form are not tractable.

REFERENCE MATERIAL

There is no text book for this course. There are detailed lecture notes that will be made available through WebCT.

The following textbooks are regarded as good references for this course and are available through the library: *Introductory Quantum Mechanics* (Fourth Edition) by Richard L. Liboff, *Introduction to Quantum Mechanics second edition* by David J. Griffiths Pearson/Prentice Hall 2005*, Quantum Mechanics* by R.W. Robinett, Oxford University Press, 1997. A more mathematical book is by Bransden and Joachain *Introduction to Quantum Mechanics*, Longman Publishers, 1989.

WEB RESOURCES

The lecturer's notes will be available under the University's WebCT environment, which can be accessed from the USYDnet site **intranet.usyd.edu.au**. Access requires a Unikey (Extro account) Username and Password that is issued with your confirmation of enrolment. The University provides computer facilities in the Access Centres **www.usyd.edu.au/su/is/labs/.**

ASSIGNMENTS and ASSESSMENT

Assignments will be set on a weekly basis counting a total of 25 % towards your total assessment for the module. The other 75% comes from the examination at the end of the semester.

ASSUMED KNOWLEDGE

For this module (Advanced Senior Quantum Mechanics) it is assumed that you have passed, at the intermediate level, courses that include: Quantum Mechanics, Differential and Integral Calculus, and Linear Algebra.

LEARNING OUTCOMES

Note that the course is defined by the content of the lectures, which are available online in detailed notes.

THE STATISTICAL INTERPRETATION
(Lecture notes sections 1.1 - 1.2)

- Explain our interpretation of quantum mechanics and how it differs from other possible interpretations.

PROBABILITY, EXPECTATION VALUES, AND OPERATORS
(Lecture notes sections 2.1 – 2.2)

- Explain the meaning of expectation value and use it to derive basic operators such as those for momentum and kinetic energy.

(Lecture notes section 2.3)

- Explain the physical significance of a Hermitian operator and be able to mathematically show whether an operator is Hermitian.

(Lecture notes section 2.4)

- Mathematically obtain the uncertainty associated with an operator.

EIGENFUNCTIONS, EIGENVALUES, AND COMMUTATORS
(Lecture notes Chapter 3)

- Explain the physical significance of an eigenvalues in quantum mechanics.
- Explain the physical significance when two operators commute.
- Be able to calculate the value of a commutation relation.

THE SCHRÖDINGER EQUATION IN THREE DIMENSIONS
(Lecture notes sections 4.1 & 4.2)

- Understand the solution of the Schrödinger equation for the hydrogen atom.
- Understand the origins of the n, l and m_l quantum numbers and the relationship between them.

(Lecture notes section 4.3)

- Be able to write the definition of angular momentum into an operator.
- Show that the operator $\mathbf{L}^2$ has the same form as the differential equation that contains the spherical harmonics of the hydrogen atom.
- Use the properties of the above mentioned differential equation to obtain the mathematical properties of the $\mathbf{L}^2$ and L_Z operations on spherical harmonics.

MATRIX FORMULATION OF QUANTUM MECHANICS
(Lecture notes sections 5.1 – 5.2)

- Be able to apply the orthonormality condition to wave functions.
- Relate Dirac's BraKet notation to their counterparts in integral format.
- Be able to rewrite the orthonormality condition and expectation value in BraKet notation.

(Lecture notes sections 5.3 – 5.5)

- Be able to rewrite an operator equation in terms of a matrix equation.
- Be able to solve a matrix equation for its eigenvalues and eigenvectors.
- Know the relationship between an eigenvector and an eigenfunctions.
- Be able to use raising and lowering operators.

(Lecture notes sections 6.1 – 6.2)

- Extend all the mathematical properties of the angular momentum operator to the spin operator.
- Know how the Pauli spin matrices are related to the matrix representation of the spin operator.

(Lecture notes section 6.3)

- Relate the magnetic dipole moment of an electron to its orbital and spin angular momentum.
- Obtain the energy levels of an electron in a magnetic field.

ADDITION OF ANGULAR MOMENTUM
(Lecture notes Chapter 7 before 7.1)

- Add angular momentum operators of coupled spins and obtain the result of the operation of the total angular momentum operator on an appropriate Ket.
- Explain the physical significance of Clebsch-Gordon coefficients and be able to derive them.

(Lecture notes section 7.1 – 7.4)

- Apply the coupling of angular momentum to the vector model of an atom.
- Show that the fine structure of an atom can arise from the vector model of the atom.
- Apply the selection rules to the electron transitions between the fine structure energy levels.
- Relate the hyperfine structure to the vector addition of the electron and nuclear angular momenta.

PRELUDE TO QUANTUM COMPUTING - BELL'S THEOREM
(Lecture notes Chapter 8)

- Explain the EPR experiment.
- Explain how spin can be measured by a Stern-Gerlach apparatus.
- Be able to write these spin measurements in matrix notation.
- Be able to obtain the correlation coefficient that is used to test the existence of hidden variables.
- Explain the significance of Bell's inequality to hidden variables.
- Explain the significance of the Aspect experiment to hidden variable theories.
- Explain entanglement and its physical significance.

QUANTUM COMPUTING
(Lecture notes sections 9.1 – 9.4)

- Explain the similarities and differences between classical bits and quantum bits (qubits).
- Be able to write quantum gates in both matrix and Dirac notation.
- Be able to use quantum gates to carry out basic quantum computing operations.
- Understand the circuit diagram notation of quantum computation.

(Optional reading of the notes section 9.5)

- (As an option) Understand the Deutsch algorithm.

PERTURBATION THEORY
(Lecture notes Chapter 10 up to and including 10.21)

- Be able to derive and use first and second order perturbation theory.

(Lecture notes sections 10.3 – 10.5)

- Apply perturbation theory to degenerate energy levels.
- Apply degenerate perturbation theory to the Stark effect.

(Lecture notes section 10.6)

- Apply the variational method to the helium atom.

INDISTINGUISHABLE PARTICLES
(Lecture notes Chapter 11)

- Be able to test for the indistinguishability of boson and fermion wave functions.
- Explain how the indistinguishability of fermions leads to the Pauli Exclusion Principle.
- Use the Slater determinant to write down the wave function of a collection of indistinguishable fermions.
- Explain how Bose-Einstein condensation can arise and its physical significance.