Physics 212E – Chowdary
Classical and Modern Physics
Spring 2005

Objectives for Unit III: Quantum Mechanics

By the end of this unit, students should be able to:

3.0 Relate concepts related to quantum mechanics to real world situations and discuss various applications of the concepts to practical problems in various fields of science, medicine and engineering.

3.1 Describe how classical particles and classical waves behave in single-slit and double-slit experiments. Describe the evidence for wave behavior in the double-slit (and diffraction) experiments along with the aspects of these experiments that indicate particle behavior. Explain how the results of the double-slit experiment change if a detector is placed at one of the slits.

3.2 Relate position and momentum uncertainties using the uncertainty relation. Also relate energy and time uncertainties using the uncertainty relation. Explain the uncertainty relation in terms of classical wave behavior (the “bandwidth theorem”.)

3.3 Describe in your own words how wave function, probability density, and probability are related. From a sketch of a particle’s wave function, determine which regions are most or least likely for locating the particle.

3.4 Given the form of a particle’s wave function, calculate the normalization constant, the probability density, and the probability for finding the particle in small regions (using multiplication) or larger regions (using integration).

3.5 Sketch the allowed wave functions y_n, calculate the corresponding energies E_n, and determine the wavelengths of photons emitted or absorbed in various transitions among energy levels for a particle trapped in a box. Also know the energy levels for a particle in a harmonic oscillator potential.

3.6 Test by direct substitution possible solutions of the Schroedinger equation for the infinite square well, the harmonic oscillator, or other one-dimensional potentials, and determine the value of unknown parameters as well as the energy E.

3.7 Given the potential energy function and energy level, make a qualitatively correct sketch of a one-dimensional wave function, considering number of nodes, variation of wavelength, and concavity of the wave function.

3.8 Determine reflection and transmission coefficients for step barriers, given the barrier’s energy and height along with the energy of the particle. Qualitatively describe how particles can tunnel through a thin barrier.

3.9 Calculate energy levels for a particle in a two- or three-dimensional rectangular box. Describe degeneracy, and distinguish symmetric and accidental degeneracy.

3.10 Discuss in your own words how superposition of quantum states differs from classical systems. Explain some physically observable consequences of the superposition of quantum states. Describe how making a measurement on a quantum state may change the state of the system.

3.11 Given an expression for the superposition state of a quantum system, determine the probability amplitude and probability of finding the system in a specific state. Also calculate expectation values for measured quantities.

3.12 Explain the difference between quantum "spin" and classical angular momentum. Rewrite spin states in terms of different basis states, and calculate probabilities and expectation values for measurements of various spin components or magnitudes.

3.13 Match the two particle types (bosons or fermions) with their spin value (integer or ½ odd integer). Know that bosons 'like' to be in the same state, while two fermions may never be in the same state (the Pauli exclusion principle.)

3.14 Using energy level sketches, describe the following photon-atom interaction processes: absorption, spontaneous emission, and stimulated emission. Describe the role each type plays in the operation of a laser. Explain why a population inversion is necessary for the operation of a laser.

3.15 State in your own words Bohr's three postulates for his model of atoms. Show how these lead to quantization of atomic energies, and determine these energy levels.

3.16 Calculate photon wavelengths given the energy levels for hydrogen-like atoms or ions (i.e., a nucleus and a single electron).

3.17 List the four quantum numbers that arise in the quantum theory of atoms as well as their possible values. Relate each to a spherical coordinate or spin direction, and show how each relates to a measurable physical quantity (energy, angular momentum, etc.).

3.18 Given normalized hydrogen wave-functions, calculate the radial probability density. From this determine both the probability for the electron to be found in various regions away from the nucleus, and the most likely distance from the nucleus.

3.19 Explain how the Pauli exclusion principle and the allowed ranges of quantum numbers leads to the regularity of atoms as displayed in the periodic table. Interpret correctly an atom's electron configuration given in $1s^2\,2s^2\,2p^6\ldots$ notation.

3.20 Explain the connection between angular momentum and magnetic moment in electrons, nucleons, and atoms. Given angular momentum quantum numbers and/or type of particle, calculate magnetic moment.

3.21 Describe the following concepts and applications related to nuclear and electron magnetic resonance: spin flip, magnetic moment, resonance frequency, magnetic resonance spectroscopy and imaging (MRI), microwave astronomy. For a magnetic resonance situation, relate oscillation frequency, applied magnetic field, location in a non-uniform B-field, and magnetic moment.

3.22 Describe Bose-Einstein condensation and explain how Bose-Einstein condensation gives rise to superfluidity and superconductivity. Discuss properties of superfluids and superconductors.

3.23 State the electrical and magnetic effects that define a superconductor, including the Meissner effect. List three external conditions that could be applied to a material so that it ceases to be superconducting. Be able to draw and/or interpret graphs that depict resistance vs. temperature and critical magnetic field vs. temperature for superconductors.