Objectives for Material to be Learned from Unit 3

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

3.1 (Continuing objective) Describe applications of the concepts of quantum mechanics to everyday "real-life" situations.

3.2 Describe how wavefunction, probability density, and probability are related. Be able to interpret and calculate probability and probability per length both graphically and algebraically. From a sketch of a particle's wavefunction, determine in which regions it is most or least likely to be found.

3.3 Use Heisenberg's uncertainty relation to: (a) relate spreads in position, momentum and velocity; (b) determine the minimum average kinetic energy for a confined particle; and (c) give an explanation for the stability of atoms.

3.4 Test by direct substitution possible solutions of the 1-D Schrödinger equation.

3.5 For a particle in an infinite square well potential, draw the allowed wavefunctions ψ_n and express them mathematically. From the wavefunction, use Schrödinger's equation to calculate the corresponding energies E_n.

3.6 Describe and plot wavefunctions for a finite square well potential. Discuss the significance of a non-zero wavefunction in regions where $E < U$. Use these ideas to explain quantum mechanical tunneling.

3.7 Explain the band structure that typically describes quantum energy levels in extended systems.

3.8 Relate the emitted or absorbed photon energies, wavelengths and frequencies to the energy levels of various systems. Explain fluorescent and phosphorescent behavior.

3.9 Express the state of a quantum system in terms of state vectors. Explain what is meant by the state being "normalized."

3.10 Explain what is meant by a measurement on a quantum state and the meaning of "collapse of the state." Given a superposition state, determine the possible results of a measurement of, for example, energy or a spin component and compute the probabilities of obtaining various possible results.

3.11 Describe aspects of quantum mechanical "spin" that can't be explained classically.

3.12 Given a spin state written in one basis, write the same spin state in a different basis. For example, given a spin $|\psi\rangle$ state in the $|\pm z\rangle$ basis, be able to express the same state in the $|\pm x\rangle$ basis.

3.13 Construct two-particle states from single-particle states for classical, distinguishable particles, and for indistinguishable fermions and bosons. Show that two fermions cannot be in the same state and that bosons "like" to be in the same state.

3.14 Match the two particle types (bosons or fermions) with their spin value (integer or $\frac{1}{2}$-odd integer). Apply the Pauli exclusion principle to systems with multiple fermions and relate this principle to the Periodic Table of the Elements.

3.15 Describe the basic properties of lasers, superconductors, and superfluids, and how these processes originate from bosons affinity for being in the same state. Describe stimulated emission and explain why a population inversion is necessary for the operation of a laser.

3.16 Test solutions for the hydrogen atom in the three-dimensional Schrödinger Equation.

3.17 Write down and relate the possible values of the principal quantum number n, the orbital quantum number l, and the magnetic quantum number m_l for states of an electron in the hydrogen atom. Calculate the energy E_n, angular momentum magnitude $|\vec{L}|$, and z-component of angular momentum L_z using these quantum numbers.

3.18 Relate the conductivity (or lack thereof) of a solid to the band structure of its energy levels. Use simple "$k_B T$" approximations to determine how the conduction properties depends on the temperature.

3.19 Explain doping and describe "n-type" and "p-type" semiconductors. Explain how p-n junctions produce diode and transistor behavior, concentrating in particular on the behavior of the depletion zone. Explain how light-emitting diodes work, and calculate the wavelength/frequency of LED emission, based on the band structure of the semiconductor.

3.20 Identify whether a given two-particle state is separable or entangled. For separable states, obtain the separate single-particle states.

3.21 For a given two-particle state, calculate the probabilities associated with a particle-2 measurement given the result of a particle-1 measurement.

3.22 Describe the EPR paradox and Bell's inequality and their implications for locality and the completeness of quantum states.