Thursday 17th February 2005

Quantum Physics: Aims and Objectives

Aim

To provide an introduction to quantum phenomena and wave mechanics.

Objectives

On completion of this course, students will:

- Be able to write down the equation of a travelling wave in real and complex form; know the definitions of the angular frequency ω and the wave vector k in terms of the frequency f and wavelength λ; know the meanings of the terms *amplitude* and *intensity* applied to waves; know the theory of the two-slit diffraction experiment.
- Know the Planck equation, $E = h\nu = \hbar\omega$, and the de Broglie equation, $p = h/\lambda = \hbar k$.
- Be aware of the following experimental evidence in favour of the existence of photons satisfying the Planck and de Broglie equations:
  (a) Detection of individual photons (by photography and other means).
  (b) The photo-electric effect and Einstein's interpretation of it in terms of quantised photons satisfying the Planck equation.
  (c) How the results of Compton scattering, pair production and pair annihilation experiments support the de Broglie equation.
- Be aware of the evidence from diffraction experiments that particles such as electrons, neutrons and He atoms can behave like waves satisfying the Planck and de Broglie equations.
- Know the term *dispersion relation* and be able to write down the dispersion relations $\omega = ck$ for photons and $\omega = \hbar k^2/2m$ for non-relativistic massive particles.
- Be able to explain how atomic spectra point to the existence of discrete allowed energy orbits.
- Know the Bohr theory of the atom and be able to explain how this theory accounts for the spectra of hydrogenic atoms. Understand how the Bohr quantisation condition relates to the de Broglie relation.
- Appreciate the conceptual difficulty of reconciling the results of the two-slit diffraction experiment with the existence of photons and other quantum mechanical particle-waves.
- Understand the terms *wave function*, *probability amplitude* and *probability density*. Know how these are related to one another.

- Be able to write down the wave function of a travelling wave and to relate the wave vector k and angular frequency ω to the momentum and energy of the particle.
- Be familiar with the idea of a wave packet. Know what is meant by *normalising* a wave function. Know (without mathematical proof) that wave packets may be obtained by superposing plane waves of different wavelengths.
- Have a qualitative understanding of how the properties of wave packets lead to the position-momentum and energy-time uncertainty principles. Appreciate the relationship between the uncertainty principle and diffraction.
- Be able to write down the standing waves that fit into a square well with infinitely high walls. Understand that the discrete set of standing-wave solutions implies a discrete set of quantised energy levels (analogy with harmonics on a violin string). Be aware that similar but more difficult calculations predict/reproduce atomic spectra, shell structure and the periodic table. Know (without mathematical proof) that a general bound state is a superposition of standing waves.
- Be able to write down the time-independent Schrödinger equation and to show that it is satisfied by travelling waves and by standing waves in a square well with infinitely high walls.
- Know that the results of subatomic experiments are probabilistic in nature, and that the wavefunction immediately after a measurement of the energy is the solution of the time-independent Schrödinger equation corresponding to the measured energy level.
- Be familiar with the idea of an evanescent wave and understand how evanescent waves lead to tunnelling. Be able to estimate the probability of tunnelling through a potential barrier (using decay rate of evanescent wave only). Be able to describe the physics underlying scanning tunnelling microscopy.