BINDURA UNIVERSITY OF SCIENCE EDUCATION
BACHELOR OF SCIENCE EDUCATION DEGREE
PHYSICS PART 2
PH202 (2): QUANTUM PHYSICS 1
DURATION: 3 HOURS

AUG 2024

INSTRUCTIONS:

Answer ALL parts of Section A and any THREE questions from Section B.

Section A carries 40 marks and Section B carries 60 marks.

Electron charge,	$e = 1.60 \times 10^{-19}\, C$
Planck's constant,	$h = 6.63 \times 10^{-34}\, Js$
Mass of an electron,	$m_e = 9.11\, x\, 10^{-31}\, kg$
Acceleration due to gravity,	$g = 9.81\, ms^{-2}$
Permittivity of free space,	$\varepsilon_0 = 8.85 \times 10^{-12}\, Fm^{-1}$
Speed of light,	$c = 3 \times 10^{8}\, ms^{-1}$
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7} T.m/A$,

SECTION A

1. (a)State the 3 postulates of quantum mechanics [3]

(b) What is the de Broglie wavelength of an electron whose mass is 0.51MeV/c^2 energy is 6.0eV? [3]

(c) Distinguish between

(i)Boundstate and unbound state [1]

(ii) Potential step and Potential Barrier [1]

(iii)dispersive and non-dispersive medium in the movement of wave packets [1]

(d) Some ocean waves travel with a phase velocity $V_{phase} = \sqrt{g\lambda/_{2\pi}}$, where g is the acceleration due to gravity. Determine the group velocity of a "wave packet"of these waves? [4]

(e) Using clearly labeled sketch diagrams compare the energy levels of infinite potential well, Harmonic oscillator and hydrogen atom [6]

(f) What is the physical meaning of $\int_{-\infty}^{+\infty} |\psi|^2 dx = 1$? [2]

(g) Compute the wavelength of H_β spectral lines (i.e. the second line of the Balmer Series predicted by Bohr's model of atomic structure). The H_β line is emitted in the transition from n_i = 4 to n_f =2. [4]

(h) The gold foil ($\rho = 19.3 g/cm^3, M = 197 g/mole$) hase a thickness of 2.0×10^{-4}cm. It is used to scatter alpha particles of Kinetic energy $8.0MeV$. What fraction of alpha particles is scattered at angles greater than 90^0? [4]

(i) The first excited state of an iron atom ^{53}Fe collapses to the ground state by emitting a photon of energy 14.4 KeV. If he life time of the excited state is 41ns, Calculate the recoil energy of the atom [4]

(k) An electron is moving along the x-axis with speed $2.05 \times 10^6 m/s$ which can be known with precision at 0.50%. What is the minimum uncertainty with which you can simultaneously measure the position of the electron along the x-axis? [4]

(l) Briefly describe the process of quantum mechanical tunnelling [3]

SECTION B

2. (a) Discuss the statement "*x-ray emission* is the inverse *of photoelectric effect.*" [2]

(b) The work function(Ø) for tungsten metal is 4.52 eV. Calculate

(i) cut-off wavelength λc for tungsten [2]

(ii) maximum kinetic energy of the electrons when radiation of wavelength 198 nm is used. [2]

(iii) Stopping potential in this case. [2]

(c) 1.With aid of an appropriate diagram derive the Compton shift equation

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta).$$ [4]

2. X-ray of wavelength 0.2400nm are compton Scattered and the scattered beam is observed at an angle of 60^0

Relative to the incident beam. Find

(i) the wavelenght of the scattered Xrays [3]

(ii) energy of the scattered photons [3]

(iii) kinetic enery of the scattered electrons [2]

3(a) Describe in words what is meant by normalization of the wave function [2]

(b) A particle which is confined to move in one dimension between O and L is described by the wave function $\psi(x) = Ax(L - x)$

(i) Use the Normalisation condition to determine the constant A [4]

(ii) Derive an expression for the average value (expectation) of position

Of the particle [4]

(iii) Determine the expression for the average values of the kinetic energy

of the particle [4]

(c) For a free particle show that the Schrodinger wave equation leads to the

de Broglie relation $\lambda = \frac{h}{p}$ [6]

4 (a) (i) State the Correspondence principle [2]

(ii) Show that the Bohr Model of the atom does indeed obey

the Correspondence principle [4]

(b) An electron is confined in a region of size of an atom (0.1nm). Calculate

the minimum uncertainty in the momentum of the electron [3]

(c) In a region of space a particle with mass m and zero energy has a

time independent wave function $\psi(x) = Ae^{-x^2/L^2}$ where A and L

are constants Determine the potential energy of the particle [8]

4 (a) State three principles of quantum mechanics [2]

(b) An electron is bound in one-dimensional infinite well of width $1 \times 10^{-10}\mathrm{m}$

Find the energy values in the ground state. [3]

(c) A free particle has initial wave function

$$\psi(x,0) = A\exp - ax^2$$

where A and a are positive real constants.

(i) Normalize $\psi(x,0)$. [3]

(ii) Determine $\psi(x,t)$. [3]

(iii) Find $|\psi(x,t)|^2$. Express your answer in terms of the quantity

$$w \equiv \frac{a}{1+\left(\frac{2\hbar a t}{m}\right)^2}$$ [3]

(iv) Determine $\langle x^2 \rangle$ [6]

5(a) Write Schrödinger's equation for a free particle [2]

(b) (i) Show that the wave function $\psi(x) = Ae^{ikx}$ represents a state for which momentum of the particle has the value $P = \hbar k$ [5]

(ii) Find the kinetic energy of the particle in this state [5]

(c) A spring mass system has a mass equal to 0.10 kg and a spring constant equal to 10 N/m. The system oscillates with amplitude of 0.10 m.

(i) If the energy of the oscillator is quantized what is the quantum number n associated with this energy? [3]

(ii) If the quantum number n changes by unity, what is the fractional change in energy? [3]

(iii) What conclusion do you draw from (ii)? [2]

6. (a) A particle in the infinite square well has the initial wave function

$$\Psi(x,0) = \begin{cases} Ax, & 0 \le x \le a/2, \\ A(a-x), & a/2 \le x \le a. \end{cases}$$

(i) Sketch $\Psi(x,t)$ [3]

(ii) Determine the constant A [4]

(iii) Find $\Psi(x,t)$. [4]

(b) Like the classical wave equation the Schrödinger equation is linear.

Why is this important? [2]

(c) A particle of mass m has the wave function

$$\Psi(x,t) = Ae^{-a[(mx^2/\hbar)+it]}$$

where A and a are positive real constants.

(i) Find A [3]

(ii) For what potential energy function, $V(x)$ is this a solution to the

Schrödinger equation? [4]

END OF EXAM