UNIVERSITY OF RUHUNA
BACHELOR OF SCIENCE (GENERAL) DEGREE LEVEL III (SEMESTER I)
EXAMINATION – NOVEMBER 2021

Subject: PHYSICS
Course Unit: PHY 3114

Part II Time: 02 hours & 30 minutes

Answer FIVE (05) Questions only.

(All symbols have their usual meaning)

Planck's constant, $h = 6.626 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23} JK^{-1}$
Avogadro's number, $N_A = 6.022 \times 10^{23}$
Mass of an electron, $m_e = 9.1 \times 10^{-31}$ kg
Speed of light, $c = 3 \times 10^8$ ms^{-1}
Charge of the electron $= 1.602 \times 10^{-19}$ C
1 eV $= 1.602 \times 10^{-19}$ J
1 a.m.u $= 1.66 \times 10^{-27}$ kg

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1. While sitting in front of a colour TV with a 25 kV picture tube potential, you have an excellent chance of being irradiated with X-rays.

   (a) Describe, briefly the process that produces a possible X-ray flux?

   [04 marks]

   (b) Calculate the shortest wavelength of X-rays come out from the tube (i.e. X-rays with highest energy).

   [08 marks]

   (c) Assume that a rock salt (NaCl) crystal X-ray diffraction was taken using x-rays of wavelength equivalent to in part (b) above. Calculate the interplanar spacing for (2 0 0) planes and Bragg angle for a first order reflection maximum from these planes for the shortest wavelength of X-rays.

   [13 marks]

   Note: The molecular weight of NaCl is 5.845×10^{-2} kgmol^{-1} and density of NaCl is 2.165×10^3 kgm^{-3}. Consider that the number of atoms in the NaCl unit cell is 4.

2. The electrical conductivity of a metal can be written as $\sigma = \frac{ne^2\tau}{m}$, where τ is the collision time of electrons in the metal and n is the electron density.

(a) Describe, briefly, what is meant by the electrical conductivity of a metal. Show that the electrical conductivity depends on the mobility of the electrons in a metal.

[06 marks]

(b) If the collision time of the electron is 0.2 ns, calculate the mobility of the electron.

[04 marks]

(c) Calculate the electrical conductivity of the metal if the electron density is 10^{19} m^{-3}.

[04 marks]

(d) What is meant by resistivity? Find the resistivity of the metal.

[06 marks]

(e) If a moving electron in a metal has an effective mass (m*) equivalent to 0.1 times the mass of a free electron (m_e), what would be the average time between the successive collisions?

[05 marks]

3. The mean number of molecules per unit volume with the speed in the range between v and $v + dv$ is given by Maxwell speed distribution,

$$F(v)dv = 4\pi n \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}} dv.$$

(a) Using the speed distribution, show that the mean speed of a monatomic ideal gas molecule confined within a container of volume V and in equilibrium at absolute temperature T is $\sqrt{\frac{8kT}{m\pi}}$.

[06-marks]

(b) Also, show that the most probable speed of a gas molecule in this container is $\sqrt{\frac{2kT}{m}}$.

[10-marks]

(c) Hence show that the mean speed of an ideal gas molecule exceeds the most probable speed by about 12.8 % .

[04-marks]

(d) If the mass of one mole of gas is 16×10^{-3} kg , calculate the average speed of a gas molecule at 27 °C.

[05-marks]

Note: $\int_0^\infty e^{-\alpha x^2} x^3 dx = \frac{1}{2\alpha^2}$

4.

(a) Explain the statistics (at least 4 different characteristics) obeyed by a system of particles under

(i) Bose-Einstein and

[04-marks]

(ii) Fermi-Dirac distributions.

[04-marks]

(b) Consider N identical particles in volume V in equilibrium at absolute temperature T. If there is no interaction between particles show that the average number of particles in state s is given by $\bar{n}_s = -\frac{1}{\beta}\frac{\partial \ln z}{\partial \varepsilon_s}$. Here, z is the partition function of the system and ε_s is the energy of the particle in state s.

[08-marks]

(c) Consider a system of four identical particles that obey Bose-Einstein statistics. Assume that each particle can be in any of the three quantum states s = 1, 2 and 3. In a table, list all possible quantum states of this system of particles.

[09-marks]

5.

(a)

(i) State the de Broglie equation for matter waves.

[03 marks]

(ii) Calculate the de Broglie wavelength of an electron having a kinetic energy of 1000 eV.

[04 marks]

(iii) Compare the result in part (ii) with the wavelength of x-rays having the same energy.

[03 marks]

(b)

(i) State Heisenberg's uncertainty principle in mathematical form, describing each term.

[03 marks]

(ii) A bullet of mass 0.03 kg is moving with a velocity 500 ms^{-1}. The speed is measured up to an accuracy of 0.02%. Calculate the uncertainty in the measurement of position of the bullet.

[05 marks]

(iii)Describe the result in part (ii)

[02 marks]

(c)

(i) Write down the mathematical forms of phase velocity and group velocity.

[02 marks]

(ii)The waves on the surface of water travel with a phase velocity $v_p = \sqrt{g\lambda/2\pi}$, where g is the acceleration due to gravity and λ is the wavelength of the wave. Show that the group velocity of a wave packet comprised of these waves is $v_p/2$.

[03 marks]

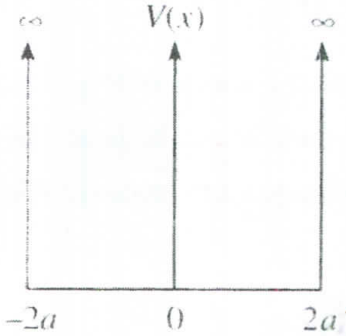
6.

(a) Write down the general 1-D expression of time-independent Schrodinger equation. Describe what each term represents.

[04 marks]

(b) A particle of mass m is confined to a 1-dimentional infinite potential well of width $4a$ specified by $V(x) = \begin{cases} 0 \ ; \ -2a \leq x \leq 2a \\ \infty \ ; otherwise \end{cases}$

as shown in the figure.



(i) Show that the energy eigenvalues are givens by $E_n = \frac{\pi^2\hbar^2}{32\, ma^2}n^2 \quad ; n = 1,2,3, ...$

[08 marks]

(ii) Find corresponding eigen functions (Normalization is not required).

[04 marks]

(c) If the particle specified in part (b) is an electron and the width of the potential well is 1Å,

(i) Calculate the separation between the two lowest energy levels.

[03 marks]

(ii) Calculate the frequency and the wavelength of the photon corresponding to a transition between these two levels.

[04 marks]

(iii) In what region of the electromagnetic spectrum does this frequency/wavelength fall?

[02 marks]

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