UNIT VII

DUAL NATURE OF MATTER AND RADIATION

Weightage Marks : 14

TOPICS TO BE COVERED

Dual nature of radiation, Photoelectric effect Hertz and Lenard's observations; Einstein's photoelectrical equation, Particle nature of light.

Mattre waves-wave nature of particles, de-broglie relation Davisson Germer experiment.

KEY POINTS

- Light consists of individual photons whose energies are proportional to their frequencies.
- A photon is a quantum of electromagnetic energy :

  Energy of photon

$$E = h\nu = \frac{hc}{\lambda}$$

  Momentum of a photon

$$= \frac{h\nu}{c} = \frac{h}{\lambda}$$

  Dynamic mass of photon

$$= \frac{h\nu}{c^2} = \frac{h}{c\lambda}$$

  Rest mass of a photon is zero.

- *Photoelectric effect :* Photon of incident light energy interacts with a single electron and if energy of photon is equal to or greater than work function, the electron is emitted.
- Max. Kinetic energy of emitted electron $= h(\nu - \nu_0)$ Here ν_0 is the frequency below which no photoelectron is emitted and is called threshold frequency.
- A moving body behaves in a certain way as though it has a wave nature having wavelength,

$$\lambda = \frac{h}{mv}.$$

QUESTIONS

VERY SHORT ANSWER QUESTIONS (1 Mark)

1. What is the rest mass of photon?
2. A good mirror reflects 80% of light incident on it. Which of the following is correct.
   (a) Energy of each reflected photon decreases by 20%.
   (b) Total no. of reflected photons decreases by 20%. Justify your answer.
3. Why in a photocell the cathode is coated with alkali metals.?
4. Name the phenomenon which shows quantum nature of electromagnetic radiation.
5. Write Einstein's photoelectric equations and specify each term.
6. Which of the following radiations is more effective for electron emission from the surface of sodium?
   (i) Microwave
   (ii) Infrared
   (iii) Ultraviolet.
7. A metal emits photoelectrons when red light falls on it. Will this metal emit photoelectrons when blue light falls on it?

8. Name any two phenomena which show the particle nature of radiation.

9. The photoelectric cut off voltage in a certain photoelectric experiment is 1.5V. What is the max kinetic energy of photoelectrons emitted?

10. What is the de-Broglie wavelength of a 3 kg object moving with a speed of 2m/s?

11. What factors determine the maximum velocity of the photoelectrons from a surface?

12. What is the stopping potential applied to a photocell, in which electrons with a maximum kinetic energy of 5.6 eV are emitted. **Ans. :** 5.6 V

13. Work functions of caesium and lead are 2.14 eV and 4.25 eV respectively. Which of the two has a higher threshold wavelength?

Ans. : Work function, $\phi_0 = h\nu_0 = h\frac{c}{\lambda_0}$ *or* $\lambda_0 \propto \frac{1}{\phi_0}$

Hence caesium has a higher threshold wavelength for photoelectric emission.

14. What is the de-Broglie wavelength of a neutron at absolute temperature T K ?

Ans. :

$$\lambda = \frac{h}{\sqrt{2m_n E_k}} = \frac{h}{\sqrt{2m_n \frac{3}{2} k_B T}} = \frac{h}{\sqrt{3m_n k_B T}}$$ $K_B \rightarrow$ Boltzmann's Constant

SHORT ANSWER QUESTIONS (2 Mark)

1. Write one similarity and one difference between matter wave and an electromagnetic wave.

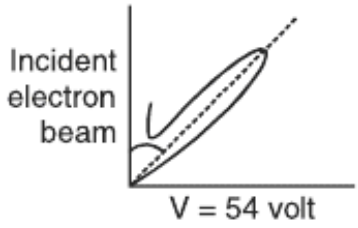
2. Does a photon have a de Broglie wavelength? Explain.

3. A photon and an electron have energy 200 eV each. Which one of these has greater de-Broglie wavelength?

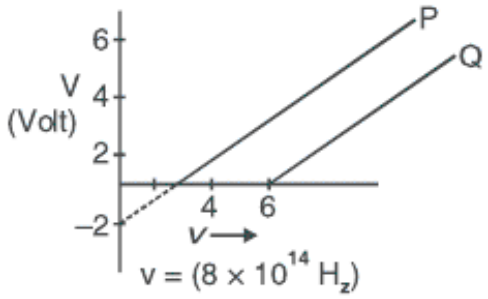
4. The work function of the following metal is given Na = 2.75 eV, K = 2.3 eV, Mo = 4.14 eV, Ni = 5.15 eV which of these metal will not give a photoelectric emission for radiation of wave length 3300 A° from a laser

source placed at 1m away from the metal. What happens if the laser is brought nearer and placed 50 cm away.

5. Name the experiment for which the followings graph, showing the variation of intensity of scattered electron with the angle of scattering, was obtained. Also name the important hypothesis that was confirmed by this experiment.



6. In a photoelectric effect experiment the graph between the stopping potential V and frequency of the incident radiation on two different metals P and Q are shown in Fig. :



(i) Which of the two metals has greater value of work function?

(ii) Find maximum K.E. of electron emitted by light of frequency $\nu = 8 \times 10^{14}$ Hz for metal *P*.

7. Do all the photons have same dynamic mass? If not, why?

8. Why photoelectrons ejected from a metal surface have different kinetic energies although the frequency of incident photons are same?

9. Find the ratio of de-Broglie wavelengths associated with two electrons 'A' and 'B' which are accelerated through 8V and 64 volts respectively.

10. The photoelectric current at d istances r_1 and r_2 of light source from photoelectric cell are I_1 and I_2 respectively. Find the value of $\frac{I_2}{I_1}$.

Ans. : $I \propto \frac{I}{r^2} \Rightarrow \frac{I_2}{I_1} = \left(\frac{r_1}{r_2}\right)^2$

11. How does the maximum kinetic energy of emitted electrons vary with the increase in work function of metals?
Ans. : $KE_{max} = h\nu - W_0 \Rightarrow KE_{max}$ decreases with increase in W_0.

SHORT ANSWER QUESTIONS (3 Marks)

1. Explain the working of a photocell? Give its two uses.
2. Find the de Broglie wavelength associated with an electron accelerated through a potential difference V.
3. What is Einstein's explanation of photo electric effect? Explain the laws of photo electric emission on the basis of quantum nature of light.
4. If kinetic energy of thermal neutron is $\frac{3}{2}kT$ then show that de-Broglie wavelength of wav es associated with a thermal neutron of mass m at temperature T kelvin is $\frac{h}{\sqrt{3mkT}}$ where k is boltz mann constant.
5. Explain Davisson and Germer e xperiment to v erify the wav e nature of electrons.
6. Explain the effect of increase of (i) frequency (ii) intensity of the incident radiation on photo electrons emitted by a metal.
7. X-rays of wave length λ fall on a photo sensitive surface emitting electrons. Assuming that the work function of the surface can be neglected, prove that the de-Broglie wavelength of electrons emitted will be $\sqrt{\frac{h\lambda}{2mc}}$.
8. A particle of mass M at rest decays into two particles of masses m_1 and m_2 having v elocities V_1 and V_2 respectively. Find the r atio of de-broglie Wavelengths of the two particles. **Ans. :** 1 : 1

NUMERICALS

1. Ultraviolet light of wavelength 350 nm and intensity 1W/m^2 is directed at a potassium surface having work function 2.2eV.

   (i) Find the maximum kinetic energy of the photoelectron.

   (ii) If 0.5 percent of the incident photons produce photoelectric effect, how many photoelectrons per second are emitted from the potassium surface that has an area 1cm^2.

   $$E_{K\max} = 1.3\ eV;\ n = 8.8 \times 10^{11}\ \frac{\text{photo electro n}}{\text{second}}$$

2. A metal surface illuminated by 8.5×10^{14} Hz light emits electrons whose maximum energy is 0.52 eV the same surface is illuminated by 12.0×10^{14} Hz light emits elections whose maximum energy is 1.97eV. From these data find work function of the surface and value of Planck's constant. [Work Function = 3ev]

3. An electron and photon each have a wavelength of 0.2 nm. Calculate their momentum and energy.

   (i) 3.3×10^{-24} kgm/s

   (ii) 6.2 keV for photon

   (iii) 38eV for electron

4. What is the (i) Speed (ii) Momentum (ii) de-Broglie wav elength of an electron having kinetic energy of 120eV?
   [**Ans. :** (a) 6.5×10^6 m/s; (b) 5.92×10^{-24} kg m/s; (c) 0.112 nm.]

5. If the frequency of incident light in photoelectric e xperiment is doubled then does the stopping potential become double or more than double, justify? (More than double)

6. A proton is accelerated through a potential difference V.Find the percentage increase or decrease in its deBroglie wavelength if potential difference is increased by 21%. (9.1%)

7. For what Kinetic e nergy of a n eutron will t he associated de Broglie wavelength be 5.6×10^{-10}m?

Ans. : $\sqrt{2m_n \times K.E.} = \frac{h}{\lambda} \Rightarrow K.E. = \left(\frac{h}{\lambda}\right)^2 \times \frac{1}{2m_n}$

$$= \left(\frac{6.6251\times\ 0^{-34}}{5.61\times\ 0^{-10}}\right)^2 \frac{1}{21\times .671\times 0^{-27}} = 3.351\times 0^{-21} J$$

8. A nucleus of mass M initially at rest splits into two fragments of masses $\frac{M}{3}$ and $\frac{2M}{3}$. Find the ratio of de Broglie wavelength of the fragments.

Ans. : Following the law of conservation of momentum,

$$\frac{M}{3}v_1 + \frac{2M}{3}v_2 = 0 \quad \text{or} \quad \left|\frac{M}{3}v_1\right| = \left|\frac{2M}{3}v_2\right|$$

$$\lambda = \frac{h}{mv} \Rightarrow \left|\frac{\lambda_1}{\lambda_2}\right| = \left|\frac{2\frac{M}{3}v_2}{\frac{M}{3}v_1}\right| \qquad \left|\frac{\lambda_1}{\lambda_2}\right| = \left|\frac{2v_2}{v_1}\right|$$

9. An electron and a proton are possessing same amount of K.E., which of the two have greater de-Broglie, wavelength? Justify your answer.

Ans. : $E_e = \frac{1}{2}m_e v_e^2$ and $E_p = \frac{1}{2}m_p v_p^2$

$$\Rightarrow v_e m_e = \sqrt{2E_e m_e} \text{ and } m_p v_p = \sqrt{2E_p m_p}$$

But. $E_e = E_p \Rightarrow \frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}} > 1$

$\therefore \lambda_e > \lambda_p$.

ANSWERS

1 MARK QUESTIONS

1. Zero
2. (b) Total no. of reflected photons decreases by 20%.
3. Lower work function sensitive to visible light.

4. Photoelectric effect.

6. Ultraviolet (maximum frequency).

7. Yes, it will emit photoelectrons.

8. Photoelectric effect, Compton effect.

9. 2.3×10^{-19} eV

10. 1.1×10^{-34} m

11. (a) frequency of incident radiation.

    (b) Work function of surface.

2 MARKS QUESTIONS

7. No.

$$m = \frac{E}{c^2} = \frac{h\nu}{c^2}$$

$\Rightarrow$ m depends on frequency of photon.

8. Because electrons lose their energy in collision. And energy is different for different electrons.

9. $2\sqrt{2}$