DUAL NATURE OF RADIATION AND MATTER

NCERT Exercise Solutions

Q.1 Find the (a) maximum frequency – – – – – – – 30 kV electrons.

Sol^n: Given,

Potential of electrons $V = 30\text{ kV} = 30\times10^{3}\text{ V}$

So energy of electron $E = eV$

$= 1.6\times10^{-19}\times 30\times10^{3}$

$= 48\times10^{-16}\text{ J}$

(a) Maximum frequency, $\nu = \frac{E}{h}$ $\quad [\because E = h\nu]$

$\quad\quad$ h → Planck

$= \frac{48\times10^{-16}}{6.63\times10^{-34}}$ $\quad [h = 6.63\times10^{-34}\text{ Js}]$

$\nu = 7.24\times10^{18}\text{ Hz}$. Ans

(b) The minimum wavelength produced by the x-ray

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

$= \frac{3\times10^{8}}{7.27\times10^{18}} = 0.412\times10^{-10}$

or $\lambda = 4.12\times10^{-11}$ Hz

$= 0.0412\times10^{-9}$

$\lambda = 0.041\text{ nm}$

Hence the minimum wavelength is 0.0412 nm Ans

Q.2. Work function of – – – – – – – – – emitted photoelectrons

Sol^n: Given,

Work function, $\phi_0 = 2.14\text{ eV}$

Frequency of light, $\nu = 6\times10^{14}\text{ Hz}$

(a)

$K_{max} = h\nu - \phi_0$

here $h = 6.63\times10^{-34}\text{ Js} = \frac{6.63\times10^{-34}}{1.6\times10^{-19}}\text{ eVs}$

$$K_{max} = \frac{6.63\times10^{-34}\times 6\times10^{14}}{1.6\times10^{-19}} - 2.14$$

$$= \frac{\overset{331}{\cancel{66}}3\times 6}{\cancel{16}\,\cancel{8}\,4}\times10^{-34+14+19} - 2.14$$

$$= \frac{991}{4}\times10^{-1} - 2.14$$

$$= \frac{9.91}{4} - 2.14$$

$$= 2.477 - 2.14$$

$$= 0.337$$

$K_{max} \simeq 0.34\,eV$ Ans

$= 0.34\times1.6\times10^{-19}$ J $\quad [1eV = 1.6\times10^{-19}J]$

$= 0.544\times10^{-19}$

$\simeq 0.54\times10^{-19}$ J Ans

(b) For stopping potential (V_0)

We have $K = eV_0$

$$V_0 = \frac{K}{e} = \frac{0.54\times10^{-19}}{1.6\times10^{-19}}$$

$$= 0.337$$

or $V_0 \simeq 0.34$ V Ans

(c) Maximum speed of emitted photoelectrons (v)

We have

$$K = \frac{1}{2}mv^2$$

or $v^2 = \dfrac{2K}{m}$ $\quad$ [$m \to$ mass of electron]

$$= \frac{2\times0.54\times10^{-19}}{9.1\times10^{-31}} \quad [m_e = 9.1\times10^{-31}\,kg]$$

or $v^2 = 0.118 \times 10^{-19+31}$

$$v^2 = 0.118 \times 10^{12} = 11.8 \times 10^{10}$$
$$v = \sqrt{11.8 \times 10^{10}}$$
$$= 3.435 \times 10^{5}$$
$$\simeq 3.44 \times 10^{5} \ m/s$$

or $v = 344 \ km/s$ <u>Ans</u>

Q.3. The photoelectric cut off - - - - - - emitted?

Soln: Given,

Cut off voltage $V_0 = 1.5 V$

Maximum K.E, $K_{max} = eV_0$

$$= 1.6 \times 10^{-19} \times 1.5$$
$$K_{max} = 2.4 \times 10^{-19} \ J$$ <u>Ans</u>

Q.4. Monochromatic light - - - - - - - of the photon?

Soln: Given,

Wavelength of monochromatic light, $\lambda = 632.8 \ nm$
$= 632.8 \times 10^{-9} m$

Power emitted by laser, $P = 9.42 \ mW$
$= 9.42 \times 10^{-3} W$

(a) The energy of each photon,

$$E = \frac{hc}{\lambda}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$
$$= \frac{6.63 \times 3}{632.8} \times 10^{-34+8+9}$$
$$= \frac{19.89}{632.8} \times 10^{-17}$$

or $\quad E = \frac{19890 \times 10^{-19}}{632.8}$

$E = 3.14 \times 10^{-19}$ J Ans

The momentum of each photon

$p = \frac{h}{\lambda} \qquad [\because \lambda = \frac{h}{p}]$

$= \frac{6.63 \times 10^{-34}}{632.8 \times 10^{-9}}$

$= \frac{6.63}{632.8} \times 10^{-34+9} = \frac{6.63}{632.8} \times 10^{-25}$

$= \frac{663}{632.8} \times 10^{-27}$

$= 1.048 \times 10^{-27}$

$p \simeq 1.05 \times 10^{-27}$ kg ms^{-1} Ans

(c) Momentum of hydrogen atom is the same as the momentum of photon. i.e.

$p = 1.05 \times 10^{-27}$ kg ms^{-1}

by $\quad p = mv$

speed $v = \frac{p}{m} = \frac{\text{momentum}}{\text{mass of hydrogen atom}}$

$= \frac{1.05 \times 10^{-27}}{1.67 \times 10^{-27}} \qquad [m_{\text{hydrogen atom}} = 1.6735 \times 10^{-27} \text{kg}]$

$v = 0.628$ m/s

$\Rightarrow \quad v \simeq 0.63$ m/s Ans

Q.5 In an experiment - - - - - - - Planck constant.

Solⁿ: Given,

The slope of the cut-off voltage (V) verses frequency (ν) of an incident light is

$$\frac{V}{\nu} = 4.12 \times 10^{-15} VS$$

We know

$$h\nu = eV \qquad h \rightarrow \text{Planck's constant}$$

so

$$h = e\frac{V}{\nu}$$

$$= 1.6 \times 10^{-19} \times 4.12 \times 10^{-15}$$

$$h = 6.592 \times 10^{-34}$$

or

$$h \simeq 6.59 \times 10^{-34} JS$$

Ans

Q.6 The threshold frequency - - - - - - - emission.

Solⁿ: Given,

Threshold frequency $\nu_0 = 3.3 \times 10^{14} Hz$

Frequency of incident light $\nu = 8.2 \times 10^{14} Hz$

We know,

$$eV_0 = h(\nu - \nu_0) \qquad V_0 \rightarrow \text{Stopping potential}$$

$$V_0 = \frac{h(\nu - \nu_0)}{e}$$

$$= \frac{6.63 \times 10^{-34}(8.2 \times 10^{14} - 3.3 \times 10^{14})}{1.6 \times 10^{-19}}$$

$$= \frac{6.63 \times 10^{-34} \times 4.9 \times 10^{14}}{1.6 \times 10^{-19}}$$

$$= \frac{32.487 \times 10^{-34+14+19}}{1.6}$$

$$= 20.30 \times 10^{-1} = 2.03V$$

or

$$V_0 = 2.0 \text{ Volt}$$

Ans

Q.7. The work function - - - - - - - -- 330 nm?

Soln: Given,

Work function of the metal $\phi_0 = 4.2\ eV$

Wavelength of incident radiation, $\lambda = 330\ nm$

$= 330 \times 10^{-19} m$

We know,

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

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{\cancel{330}\,110 \times 10^{-9}}$$

$\left[\begin{array}{l} h = 6.63 \times 10^{-34} JS \\ c = 3 \times 10^{8} m/s \end{array} \right.$

$$= \frac{6.63}{110} \times 10^{-34+8+9}$$

$$= \frac{6.63}{110} \times 10^{-17}$$

$$= \frac{663}{110} \times 10^{-19}$$

$$E = 6.027 \times 10^{-19}$$

or $E \simeq 6.0 \times 10^{-19}\ J$

$$= \frac{6 \times 10^{-19}}{1.6 \times 10^{-19}}\ eV$$

$[1 eV = 1.6 \times 10^{-19} J]$

$E = 3.75\ eV$

We can observe,

$3.75\ eV < 4.2\ eV$ (work function)

Therefore no photoelectric emission will take place.

$\Rightarrow$ No because $\nu < \nu_0$

Q.8. Light of frequency ------- electrons?

Soln: Given,

Frequency of incident light, $\nu = 7.21 \times 10^{14}$ Hz

Maximum speed of electron, $v = 6.0 \times 10^{5}$ m/s

Threshold frequency $\nu_0 = ?$

We have,

$$\frac{1}{2}mv^2 = h(\nu - \nu_0)$$

or

$$\nu - \nu_0 = \frac{\frac{1}{2}mv^2}{h}$$

$$= \frac{9.1 \times 10^{-31} \times (6 \times 10^{5})^2}{2 \times 6.63 \times 10^{-34}}$$

$$= \frac{9.1 \times \cancel{36}^{12}}{2 \times \cancel{6.63}_{2.21}} \times 10^{-31+10+34}$$

$$= \frac{9.1 \times \cancel{12}^{6}}{\cancel{2} \times 2.21} \times 10^{13}$$

$$= \frac{54.6}{2.21} \times 10^{13}$$

$$\nu - \nu_0 = 24.7 \times 10^{13} = 2.47 \times 10^{14}$$

so

$$\nu_0 = \nu - 2.47 \times 10^{14}$$

$$= 7.21 \times 10^{14} - 2.47 \times 10^{14}$$

$$\nu_0 = 4.74 \times 10^{14} \text{ Hz}$$

Ans

Q.9. Light of wavelength ------- is made?

Soln: Given,

Wavelength $\lambda = 488$ nm

$= 488 \times 10^{-9}$ m

Stopping potential $V_0 = 0.38\,V$
Work function $\phi_0 = ?$
We have,

$$eV_0 = \phi - \phi_0 \Rightarrow \phi_0 = \phi - eV_0$$

$$\phi_0 = \phi - eV_0$$

$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$\phi_0 = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times488\times10^{-9}} - \frac{\cancel{1.6\times10^{-19}}\times0.38}{\cancel{1.6\times10^{-19}}}$$

$$= \frac{6.63\times3\times10^{-34+8+19+9}}{1.6\times488} - 0.38$$

$$= \frac{19.89\times10^{2}}{1.6\times488} - 0.38$$

$$= \frac{1989}{780.8} - 0.38$$

$$= 2.547 - 0.38$$

$$\phi_0 = 2.167\,eV$$

Ans

Q.10 What is the - - - - - - - - - - - speed of 2.2 m/s?

Solⁿ: (a) Given for bullet,

Mass of bullet $m = 0.040\,kg$
speed $v = 1\,Km/s = 10^3\,m/s$

We have,

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

$$= \frac{6.63\times10^{-34}}{0.040\times10^{3}} = \frac{663}{4.0}\times10^{-37} = 165.7\times10^{-37}$$

or $\lambda = 1.657\times10^{-35} \Rightarrow \lambda \simeq 1.67\times10^{-35}\,m$ Ans

(b) For ball,

$m = 0.060$ kg , $v = 1.0$ m/s

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

$$= \frac{6.63 \times 10^{-34} \times 100}{0.060 \times 1.0}$$

$$= \frac{6.63 \times 10^{-32}}{6.0}$$

$$= 1.105 \times 10^{-32}$$

$$\lambda = 1.1 \times 10^{-32} \text{ m}$$ Ans

(c) Dust particle

$m = 1 \times 10^{-9}$ kg

$v = 2.2$ m/s

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

$$= \frac{6.63 \times 10^{-34}}{1 \times 10^{-9} \times 2.2}$$

$$= \frac{6.63}{2.2} \times 10^{-25}$$

$$= 3.01 \times 10^{-25}$$

$$\lambda \simeq 3.0 \times 10^{-25} \text{ m}$$ Ans

Q.10 Show that the — — — — — — ——— quantum (photon).

Solⁿ: To prove, $\lambda_{EMW} = \lambda_{de\ Broglie}$

For Electromagnetic radiation wavelength of EMW

$$\lambda = \frac{c}{\nu} \quad —(1)$$

From quantum theory, energy of a photon

$$E = pc$$

$$p = \frac{E}{c} = \frac{h\nu}{c}$$

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

put value of p

$$\lambda = \frac{\cancel{h}c}{\cancel{h}\nu} = \frac{c}{\nu} \quad -(2)$$

From (1) and (2)

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

i.e $\lambda_{EM} = \lambda_{de\ Broglie}$

Proved