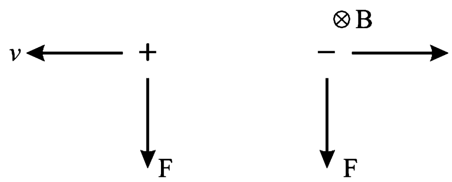
Chapter-25 : Dual Nature of Radiation and Matter

1. **(a)** In discharge tube cathode rays (a beam of negative particles) and canal rays (positive rays) move opposite to each other. They will experience a magnetic force in the same direction, if a normal magnetic field is applied.



2. **(c)** de-Broglie wavelength of a material particle at temperature T is given by

$$\lambda = \frac{h}{\sqrt{2mkT}}, \text{ where k is Boltzmann's constant}$$

$\Rightarrow \quad \lambda \propto \frac{1}{\sqrt{T}}$

$\therefore \quad \frac{\lambda_2}{\lambda_1} = \sqrt{\frac{T_1}{T_2}}$

or, $\frac{\lambda_2}{\lambda_1} = \sqrt{\frac{1200}{300}} = 2$

$\therefore \quad \lambda_2 = 2\lambda_1 = 2\lambda$

3. **(b)** $eV_1 = h\nu_1 - h\nu_0$

$eV_2 = h\nu_2 - h\nu_0$

$V_2 - V_1 = \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$

$= 12400\left(\frac{1}{3000} - \frac{1}{4000}\right) = 1.03\text{ eV}$

4. **(b)** Here the velocity of electron increases, so as per Einstein's equation mass of the electron increases, hence the specific charge $\left(\frac{e}{m}\right)$ decreases.

5. **(d)**

6. **(c)** de-Broglie's relation, $\lambda = \frac{h}{p}$

momentum $p = \sqrt{2mE}$

$\Rightarrow \lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mK}} \quad (\because E = K)$

7. **(b)** The momentum of a photon is $p = \frac{h}{\lambda}$

8. **(a)** Gain in K.E. $= qV = (1.6 \times 10^{-19} \times 1)\text{ J} = 1\text{ eV}$

9. **(b)** The number of photoelectrons emitted is proportional to the intensity of incident light.
Saturation current $\propto$ intensity.

10. **(d)** $E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4000 \times 10^{-10}} = 4.95 \times 10^{-19}\text{ J}$

11. **(a)** A photoelectric cell converts light into electricity.

12. **(d)** From Equation $K.E = h\nu - \phi$
slope of graph of K.E and ν is h (Plank's constant) which is same for all metals

13. **(c)** The stopping potential is equal to maximum kinetic energy.

14. **(a)** In the Davisson and Germer experiment, the velocity of electrons emitted from the electron gun can be increased by increasing the potential difference between the anode and filament.

15. **(d)** $W = 3.3\text{ eV}$

$h\nu_0 = 3.3 \times 1.6 \times 10^{-19}\text{ J}.$

$\nu_0 = \frac{3.3 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 0.796 \times 10^{15}\text{ Hz}$

$= 7.96 \times 10^{14}\text{ Hz} \simeq 8 \times 10^{14}\text{ Hz}$

16. **(a)** $\lambda = 667 \times 10^{-9}\text{ m}, P = 9 \times 10^{-3}\text{ W}$

$P = \frac{Nhc}{\lambda}$, N= No. of photons emitted/sec.

$N = \frac{9 \times 10^{-3} \times 667 \times 10^{-9}}{6.6 \times 10^{-34} \times 3 \times 10^8}$

$= \frac{9 \times 6.67 \times 10^{-10}}{3 \times 6.6 \times 10^{-26}} \simeq 3 \times 10^{16}\text{ / sec}$

17. **(a)** Energy emitted/sec by $S_1, P_1 = n_1 \frac{hc}{\lambda_1}$

Energy emitted/sec by $S_2, P_2 = n_2 \frac{hc}{\lambda_2}$

$\therefore \quad \frac{P_2}{P_1} = \frac{n_2}{n_1} \cdot \frac{\lambda_1}{\lambda_2} = \frac{1.02 \times 10^{15}}{10^{15}} \cdot \frac{5000}{5100} = 1.0$

18. **(d)** $K_{max} = \frac{hc}{\lambda} - W = \frac{hc}{\lambda} - 5.01 = \frac{12375}{\lambda(\text{in Å})} - 5.01$

$= \frac{12375}{2000} - 5.01 = 6.1875 - 5.01 = 1.17775 \simeq 1.2\text{ V}$

19. **(a)** Retarding potential depends on the frequency of incident radiation but is independent of intensity.

20. **(a)** The de-Broglie's wavelength associated with the moving electron, $\lambda = \frac{h}{P}$
Now, according to problem

$\frac{d\lambda}{\lambda} = -\frac{dp}{P}$

$\frac{0.5}{100} = \frac{P}{P'}$

$P' = 200\,P$

21. **(a)** Give that, only 25% of 200W converter electrical energy into light of yellow colour

$\left(\frac{hc}{\lambda}\right) \times N = 200 \times \frac{25}{100}$

Where N is the No. of photons emitted per second, h = plank's constant, c = speed of light

$N = \frac{200 \times 25}{100} \times \frac{\lambda}{hc}$

$= \frac{200 \times 25 \times 0.6 \times 10^{-6}}{100 \times 6.2 \times 10^{-34} \times 3 \times 10^8} = 1.5 \times 10^{20}$

22. **(c)** $n \to 2$ to $n \to 1$

$E = 10.2\text{ eV}$

$kE = E - \phi$

$Q = 10.20 - 3.57$

$h\upsilon_0 = 6.63\text{ eV}$

$\upsilon_0 = \frac{6.63 \times 1.6 \times 10^{-19}}{6.67 \times 10^{-34}} = 1.6 \times 10^{15}\text{ Hz}$

23. **(d)** As λ is increased, there will be a value of λ above which photoelectrons will be cease to come out so photocurrent will become zero.

24. **(b)** Given : work function of metal $\phi = 2.28\text{ eV}$
Wavelength of light $\lambda = 500\text{ nm} = 500 \times 10^{-9}\text{m}$

$$KE_{max} = \frac{hc}{\lambda} - \phi = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{5 \times 10^{-7}} - 2.82$$

$KE_{max} = 2.48 - 2.28 = 0.2\ eV$

$$\lambda_{min} = \frac{h}{p} = \frac{h}{\sqrt{2m(KE)_{max}}}$$

$$= \frac{\frac{20}{3} \times 10^{-34}}{\sqrt{2 \times 9 \times 10^{-31} \times 0.2 \times 1.6 \times 10^{-19}}} = 2.80 \times 10^{-9}\ nm$$

$\therefore\ \lambda \geq 2.8 \times 10^{-9}\ m$

25. (c) Work function, $W_0 = \frac{hc}{\lambda_0}$

In electron volt,

$$W_0(\text{in eV}) = \frac{hc}{e\lambda_0} = \frac{12375}{\lambda_0(\text{Å})}$$

$$\therefore\ \lambda_0(\text{Å}) = \frac{12375}{W_0(eV)}$$

$\Rightarrow$ For metal A, $\lambda_0 = \frac{12375}{3.2} = 3867\text{Å}$

For metal B, $\lambda_0 = \frac{12375}{1.9} = 6513\text{Å}$

$\because$ Incident wavelength (λ) < threshold wavelength λ_0 for both the metals, hence photoelectrons will emit for both.

26. (b) $K_{1_{max}} = h\nu_1 - \phi = 1 - 0.5 = 0.5\ eV$

$K_{2_{max}} = 2.5 - 0.5 = 2.0\ eV$

Thus $K_{1_{max}} : K_{2_{max}} = 0.5 : 2 = 1 : 4$

27. (a) $\because\ \lambda_0 = \frac{hc}{\phi}$

$$\therefore\ (\lambda_0)_{sodium} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2 \times 1.6 \times 10^{-19}} = 6188\ \text{Å}$$

$$\because\ \lambda_0 \propto \frac{1}{\phi} \Rightarrow \frac{(\lambda_0)_{sodium}}{(\lambda_0)_{copper}} = \frac{(\phi)_{copper}}{(\phi)_{sodium}}$$

$$\Rightarrow (\lambda_0)_{copper} = \frac{2}{4} \times 6188 = 3094\ \text{Å}$$

To eject photo-electrons from sodium the longest wavelength is 6188 Å and that for copper is 3094 Å. Hence for light of wavelength 4000 Å, sodium is suitable.

28. (a) $E_k = E - \phi_0 = 6.2 - 4.2 = 2.0\ eV$,

$E_k = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}\ J$

29. (b) $\lambda_0 = \frac{c}{v_0} = \frac{3 \times 10^8}{5 \times 10^{14}} = 6 \times 10^{-7}\ m = 6000\text{Å}$

30. (d) $\frac{1}{2}mv^2 = \frac{hc}{\lambda} - \phi$ and

$$\frac{1}{2}mv'^2 = \frac{hc}{(3\lambda/4)} - \phi = \frac{4hc}{3\lambda} - \phi$$

Clearly, $v' > \sqrt{\frac{4}{3}}v$

31. (d) $$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\frac{(4m_p) \times (2e) \times (800)}{(m_p) \times (e) \times (100)}} = 8$$

$$\Rightarrow \lambda_\alpha = \frac{\lambda_p}{8} = \frac{\lambda_0}{8}$$

32. (a) By using, $\frac{hc}{\lambda} = W_0 + \frac{1}{2}m\upsilon^2$

$$\Rightarrow \frac{hc}{400 \times 10^{-9}} = W_0 + \frac{1}{2}m\upsilon^2 \qquad ...(i)$$

and, $$\frac{hc}{250 \times 10^{-9}} = W_0 + \frac{1}{2}m(2\upsilon)^2 \qquad ...(ii)$$

On solving (i) and (ii)

$$\frac{1}{2}m\upsilon^2 = \frac{hc}{3}\left[\frac{1}{250 \times 10^{-9}} - \frac{1}{400 \times 10^{-9}}\right] \qquad ...(iii)$$

From equation (i) and (iii), $W_0 = 2hc \times 10^6 J$

33. (b) $E = W_0 + eV_0$

For hydrogen atom, $E = +13.6\ eV$

$\therefore\ +13.6 = 4.2 + eV_0$

$$\Rightarrow V_0 = \frac{(13.6 - 4.2)eV}{e} = 9.4V$$

Potential at anode = – 9.4 V

34. (c) By using $E = W_0 + K_{max}$

$E = \frac{12375}{5000} = 2.475\ eV$ and $K_{max} = eV_0 = 1.36\ eV$

So $2.475 = W_0 + 1.36 \Rightarrow W_0 = 1.1\ eV$

35. (b) $E = W_0 + K_{max}$ ...(i)

$\Rightarrow hf = W_A + K_A$ ...(ii)

and $2hf = W_B + K_B = 2W_A + K_B$ $\quad \left(\because \frac{W_A}{W_B} = \frac{1}{2}\right)$

Dividing equation (i) by (ii)

$$\frac{1}{2} = \frac{W_A + K_A}{2W_A + K_B} \Rightarrow \frac{K_A}{K_B} = \frac{1}{2}$$

36. (a) $\lambda = 400\ nm$, $hc = 1240\ eV.nm$, K.E. = 1.68 eV

We know that $\frac{hc}{\lambda} - W = K.E \Rightarrow W = \frac{hc}{\lambda} - K.E$

$$\Rightarrow W = \frac{1240}{400} - 1.68 = 3.1 - 1.68 = 1.42\ eV$$

37. (b)

38. (d) V = 3000 volt.

$$\frac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$\therefore\ v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 3000}{9.1 \times 10^{-31}}}$$

$= 32.6 \times 10^6 = 3.26 \times 10^7\ m/s.$

39. **(a)** The energy of each photon $= \dfrac{200}{4\times10^{20}} = 5\times10^{-19}$ J

Wavelength $= \lambda = \dfrac{hc}{E} = \dfrac{(6.63\times10^{-34})\times(3\times10^{8})}{5\times10^{-19}}$

$\Rightarrow \lambda = 4.0\times10^{-7} = 400\,\text{nm}$

40. **(c)** $V_0 = \dfrac{hc}{e\lambda} - \dfrac{\phi_0}{e}$,

$$2.4 = \frac{hc}{6000\times10^{-10}e} - \frac{\phi_0}{e} \quad \text{....(i)}$$

$$V_0 = \frac{hc}{4000\times10^{-10}e} - \frac{\phi_0}{e} \quad \text{....(ii)}$$

Eq. (i) – Eq.(ii)

$$2.4 - V_0 = \frac{hc}{e}\left[\frac{1}{6000\times10^{-10}} - \frac{1}{4000\times10^{-10}}\right]$$

$$2.4 - V_0 = \frac{6.62\times10^{-34}\times3\times10^{8}}{10^{-7}\times1.6\times10^{-19}}\left[\frac{4-6}{24}\right]$$

$$V_0 = 2.4 + \frac{6.62\times10^{-34}\times3\times10^{8}}{12\times10^{-7}\times1.6\times10^{-19}}$$

$V_0 = 2.4 + 1.03 = 3.43$ V

41. **(c)** $K_{max} = E - W_0$

$\therefore\ T_A = 4.25 - (W_0)_A$ .... (i)

$T_B = (T_A - 1.5)$

$= 4.70 - (W_0)_B$ .... (ii)

Equation (i) and (ii) gives

$(W_0)_B - (W_0)_A = 1.95\,eV$

De Broglie wave length $\lambda = \dfrac{h}{\sqrt{2mK}} \Rightarrow \lambda \propto \dfrac{1}{\sqrt{K}}$

$$\Rightarrow \frac{\lambda_B}{\lambda_A} = \sqrt{\frac{K_A}{K_B}} \Rightarrow 2 = \sqrt{\frac{T_A}{T_B - 1.5}} \Rightarrow T_A = 2eV$$

From equation (i) and (ii)

$W_A = 2.25\,eV$ and $W_B = 4.20\,eV$

42. **(b)** $\lambda_{photon} = \dfrac{hc}{E}$ and $\lambda_{electron} = \dfrac{h}{\sqrt{2mE}}$

$$\Rightarrow \frac{\lambda_{photon}}{\lambda_{electron}} = c\sqrt{\frac{2m}{E}} \Rightarrow \frac{\lambda_{photon}}{\lambda_{electron}} \propto \frac{1}{\sqrt{E}}$$

43. **(c)** K.E. $= 2E_0 - E_0 = E_0$ (for $0 \le x \le 1$)

$$\Rightarrow \lambda_1 = \frac{h}{\sqrt{2mE_0}}$$

K.E. $= 2E_0$ (for $x > 1$) $\Rightarrow \lambda_2 = \dfrac{h}{\sqrt{4mE_0}}$

$$\Rightarrow \frac{\lambda_1}{\lambda_2} = \sqrt{2}.$$

44. **(c)** $\dfrac{hc}{e\lambda} - \phi = eV$

$$V = \frac{hc}{e\lambda} - \frac{\phi}{e}$$

For plate 1 : $\dfrac{\phi_1}{hc} = 0.001$ **Plate 2 :** $\dfrac{\phi_2}{hc} = 0.002$ **Plate 3 :** $\dfrac{\phi_3}{hc} = 0.004$

$\phi_1 : \phi_2 : \phi_3 = 1 : 2 : 4$

For plate 2, threshold wavelength

$$\lambda = \frac{hc}{\phi_2} = \frac{hc}{0.002hc} = \frac{1000}{2} = 500\ nm$$

For plate 3, threshold wavelength

$$\lambda = \frac{hc}{\phi_3} = \frac{hc}{0.004hc} = \frac{1000}{2} = 250\ nm$$

since violet colour light λ is 400 nm, so $\lambda_{violet} < \lambda_{threshold}$ for plate 2

so, violet colour light will eject photo-electrons from plate 2 and not from plate 3.

45. **(a)** For one photocathode

$$hf_1 - W = \frac{1}{2}mv_1^2 \quad \text{....(i)}$$

For another photo cathode

$$hf_2 - W = \frac{1}{2}mv_2^2 \quad \text{....(ii)}$$

Subtracting (ii) from (i) we get

$$(hf_1 - W) - (hf_2 - W) = \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2$$

$$\therefore\ h(f_1 - f_2) = \frac{m}{2}(v_1^2 - v_2^2)$$

$$\therefore\ v_1^2 - v_2^2 = \frac{2h}{m}(f_1 - f_2)$$

46. **(b)** By using $h\nu - h\nu_0 = K_{max}$

$\Rightarrow h(\nu_1 - \nu_0) = k_1$ ... (i)

And $h(\nu_2 - \nu_0) = k_2$ ... (ii)

$$\Rightarrow \frac{\nu_1 - \nu_0}{\nu_2 - \nu_0} = \frac{k_1}{k_2} = \frac{1}{k},\ \text{Hence } \nu_0 = \frac{k\nu_1 - \nu_2}{k-1}.$$

47. **(b)** Stopping potential $= \dfrac{1}{e}\left[\dfrac{hc}{\lambda} - \phi\right]$ where

$$hc = 1240\text{eV–nm} = \frac{1}{e}\left[\frac{1240}{200} - 4.7\right] = \frac{1}{e}[6.2 - 4.7]$$

$$= \frac{1}{e}\times1.5eV = 1.5\text{V}$$

But $V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{ne}{r}$

$$\therefore\ n = \frac{Vr(4\pi\varepsilon_0)}{e} = \frac{1.5\times10^{-2}}{9\times10^{9}\times1.6\times10^{-19}}$$

$\therefore\ n = 1.04\times10^{7}$

Comparing it with $A\times10^{z}$ we get, $z = 7$

48. **(d)** The electron ejected with maximum speed v_{max} are stopped by electric field E = 4N/C

After travelling a distance $d = 1m$

$$\frac{1}{2}mv_{max}^2 = eEd = 4eV$$

The energy of incident photon $= \frac{1240}{200} = 6.2$ eV

From equation of photo electric effect

$$\frac{1}{2}mv_{max}^2 = h\nu - \phi_0$$

$\therefore \ \phi_0 = 6.2 - 4 = 2.2$ eV

49. (a) The energy possessed by photons of wavelength 550 nm is $\frac{1240}{550} = 2.25$ eV

The energy possessed by photons of wavelength 450 nm is $\frac{1240}{450} = 2.76$ eV

The energy possessed by photons of wavelength 350 nm is $\frac{1240}{350} = 3.54$ eV

For metal plate *p* : $\phi_p = 2\,eV$.

All the wavelengths are capable of ejecting electrons. Therefore, the current is maximum. Also as the work function is lowest in *p*, the kinetic energy of ejected electron will be highest and therefore, the stopping potential is highest.

For metal plate *q* : $\phi_q = 2.5\,eV$.

Photons of wavelength 550 nm will not be able to eject electrons and therefore, the current is smaller than *p*. The work function is greater than *q* therefore the stopping potential is lower in comparison to *p*.

For metal plate *r* : $\phi_r = 3\,eV$

Only wavelength of 350 nm will be able to eject electrons and therefore, current is minimum. Also the stopping potential is least.

50. (b) For electron and positron pair production, minimum energy is 1.02 MeV.

Energy of photon is given

$$1.7 \times 10^{-3} J = \frac{1.7 \times 10^{-13}}{1.6 \times 10^{-19}} = 1.06 \text{ MeV.}$$

Since energy of photon is greater than 1.02 MeV.
so electron positron pair will be created.