PHOTO ELECTRIC EFFECT AND WAVE PARTICLE QUALITY
CHAPTER 42

1. λ_1 = 400 nm to λ_2 = 780 nm

   $E = h\nu = \frac{hc}{\lambda}$ h = 6.63×10^{-34} j - s, c = 3×10^8 m/s, λ_1 = 400 nm, λ_2 = 780 nm

   $E_1 = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}} = \frac{6.63 \times 3}{4} \times 10^{-19} = 5 \times 10^{-19}$ J

   $E_2 = \frac{6.63 \times 3}{7.8} \times 10^{-19} = 2.55 \times 10^{-19}$ J

   So, the range is 5×10^{-19} J to 2.55×10^{-19} J.

2. $\lambda = h/p$

   $\Rightarrow P = h/\lambda = \frac{6.63 \times 10^{-34}}{500 \times 10^{-9}}$ J-S = $1.326 \times 10^{-27} = 1.33 \times 10^{-27}$ kg – m/s.

3. $\lambda_1 = 500$ nm $= 500 \times 10^{-9}$m, $\lambda_2 = 700$ nm $= 700 \times 10^{-9}$ m

   $E_1 - E_2$ = Energy absorbed by the atom in the process. = hc $[1/\lambda_1 - 1/\lambda_2]$

   $\Rightarrow 6.63 \times 3[1/5 - 1/7] \times 10^{-19} = 1.136 \times 10^{-19}$ J

4. P = 10 W $\therefore$ E in 1 sec = 10 J % used to convert into photon = 60%

   $\therefore$Energy used = 6 J

   Energy used to take out 1 photon = $hc/\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{590 \times 10^{-9}} = \frac{6.633}{590} \times 10^{-17}$

   No. of photons used = $\frac{6}{\frac{6.63 \times 3}{590} \times 10^{-17}} = \frac{6 \times 590}{6.63 \times 3} \times 10^{17} = 176.9 \times 10^{17} = 1.77 \times 10^{19}$

5. a) Here intensity = I = 1.4×10^3 ω/m^2 Intensity, I = $\frac{\text{power}}{\text{area}} = 1.4 \times 10^3$ ω/m^2

   Let no.of photons/sec emitted = n $\therefore$ Power = Energy emitted/sec = nhc/λ = P

   No.of photons/m^2 = nhc/λ = intensity

   $n = \frac{\text{intensity} \times \lambda}{hc} = \frac{1.9 \times 10^3 \times 5 \times 10^{-9}}{6.63 \times 10^{-34} \times 3 \times 10^8} = 3.5 \times 10^{21}$

   b) Consider no.of two parts at a distance r and r + dr from the source.

   The time interval 'dt' in which the photon travel from one point to another = dv/e = dt.

   In this time the total no.of photons emitted = N = n dt = $\left(\frac{p\lambda}{hc}\right)\frac{dr}{C}$

   These points will be present between two spherical shells of radii 'r' and r+dr. It is the distance of the 1st point from the sources. No.of photons per volume in the shell

   $(r + r + dr) = \frac{N}{2\pi r 2dr} = \frac{P\lambda dr}{hc^2} = \frac{1}{4\pi r^2 ch} = \frac{p\lambda}{4\pi hc^2 r^2}$

   In the case = 1.5×10^{11} m, λ = 500 nm, = 500×10^{-9} m

   $\frac{P}{4\pi r^2} = 1.4 \times 10^3$, $\therefore$ No.of photons/m^3 = $\frac{P}{4\pi r^2}\frac{\lambda}{hc^2}$

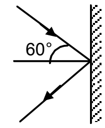
   $= 1.4 \times 10^3 \times \frac{500 \times 10^{-9}}{6.63 \times 10^{-34} \times 3 \times 10^8} = 1.2 \times 10^{13}$

   c) No.of photons = (No.of photons/sec/m^2) $\times$ Area

   $= (3.5 \times 10^{21}) \times 4\pi r^2$

   $= 3.5 \times 10^{21} \times 4(3.14)(1.5 \times 10^{11})^2 = 9.9 \times 10^{44}$.

6. $\lambda = 663 \times 10^{-9}$ m, $\theta = 60°$, $n = 1 \times 10^{19}$, $\lambda = h/p$



$\Rightarrow P = p/\lambda = 10^{-27}$

Force exerted on the wall = $n(mv\cos\theta - (-mv\cos\theta)) = 2n\,mv\cos\theta$.

$= 2 \times 1 \times 10^{19} \times 10^{-27} \times ½ = 1 \times 10^{-8}$ N.

7. Power = 10 W   P → Momentum

$\lambda = \frac{h}{p}$ or, $P = \frac{h}{\lambda}$ or, $\frac{P}{t} = \frac{h}{\lambda t}$

$E = \frac{hc}{\lambda}$ or, $\frac{E}{t} = \frac{hc}{\lambda t}$ = Power (W)

W = Pc/t   or, P/t = W/c = force.

or Force = 7/10 (absorbed) + 2 × 3/10 (reflected)

$= \frac{7}{10} \times \frac{W}{C} + 2 \times \frac{3}{10} \times \frac{W}{C} \Rightarrow \frac{7}{10} \times \frac{10}{3 \times 10^8} + 2 \times \frac{3}{10} \times \frac{10}{3 \times 10^8}$

$= 13/3 \times 10^{-8} = 4.33 \times 10^{-8}$ N.

8. m = 20 g

The weight of the mirror is balanced. Thus force exerted by the photons is equal to weight

$P = \frac{h}{\lambda}$ $E = \frac{hc}{\lambda} = PC$

$\Rightarrow \frac{E}{t} = \frac{P}{t}C$

⇒ Rate of change of momentum = Power/C

30% of light passes through the lens.

Thus it exerts force. 70% is reflected.

∴ Force exerted = 2(rate of change of momentum)

= 2 × Power/C

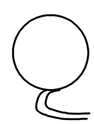
$30\%\left(\frac{2 \times \text{Power}}{C}\right) = mg$

$\Rightarrow$ Power = $\frac{20 \times 10^{-3} \times 10 \times 3 \times 10^8 \times 10}{2 \times 3}$ = 10 w = 100 MW.

9. Power = 100 W

Radius = 20 cm

60% is converted to light = 60 w



Now, Force = $\frac{\text{power}}{\text{velocity}} = \frac{60}{3 \times 10^8} = 2 \times 10^{-7}\text{N}$.

Pressure = $\frac{\text{force}}{\text{area}} = \frac{2 \times 10^{-7}}{4 \times 3.14 \times (0.2)^2} = \frac{1}{8 \times 3.14} \times 10^{-5}$

$= 0.039 \times 10^{-5} = 3.9 \times 10^{-7} = 4 \times 10^{-7}$ N/m^2.

10. We know,

If a perfectly reflecting solid sphere of radius ‘r’ is kept in the path of a parallel beam of light of large aperture if intensity is I,

Force = $\frac{\pi r^2 I}{C}$

I = 0.5 W/m^2, r = 1 cm, C = 3×10^8 m/s

Force = $\frac{\pi \times (1)^2 \times 0.5}{3 \times 10^8} = \frac{3.14 \times 0.5}{3 \times 10^8}$

$= 0.523 \times 10^{-8} = 5.2 \times 10^{-9}$ N.

11. For a perfectly reflecting solid sphere of radius 'r' kept in the path of a parallel beam of light of large aperture with intensity 'I', force exerted = $\frac{\pi r^2 I}{C}$

12. If the i undergoes an elastic collision with a photon. Then applying energy conservation to this collision.
We get, $hC/\lambda + m_0c^2 = mc^2$
and applying conservation of momentum $h/\lambda = mv$
Mass of e = m = $\frac{m_0}{\sqrt{1-v^2/c^2}}$
from above equation it can be easily shown that
V = C   or   V = 0
both of these results have no physical meaning hence it is not possible for a photon to be completely absorbed by a free electron.

13. r = 1 m
Energy = $\frac{kq^2}{R} = \frac{kq^2}{1}$
Now, $\frac{kq^2}{1} = \frac{hc}{\lambda}$ or $\lambda = \frac{hc}{kq^2}$
For max 'λ', 'q' should be min,
For minimum 'e' = 1.6×10^{-19} C
Max $\lambda = \frac{hc}{kq^2} = 0.863 \times 10^3 = 863$ m.
For next smaller wavelength = $\frac{6.63 \times 3 \times 10^{-34} \times 10^8}{9 \times 10^9 \times (1.6 \times 2)^2 \times 10^{-38}} = \frac{863}{4}$ = 215.74 m

14. $\lambda = 350$ nn = 350×10^{-9} m
$\phi = 1.9$ eV
Max KE of electrons = $\frac{hC}{\lambda} - \phi = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{350 \times 10^{-9} \times 1.6 \times 10^{-19}} - 1.9$
= 1.65 ev = 1.6 ev.

15. $W_0 = 2.5 \times 10^{-19}$ J
a) We know $W_0 = h\nu_0$
$\nu_0 = \frac{W_0}{h} = \frac{2.5 \times 10^{-19}}{6.63 \times 10^{-34}} = 3.77 \times 10^{14}$ Hz = 3.8×10^{14} Hz
b) $eV_0 = h\nu - W_0$
or, $V_0 = \frac{h\nu - W_0}{e} = \frac{6.63 \times 10^{-34} \times 6 \times 10^{14} - 2.5 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 0.91 V

16. $\phi = 4$ eV = $4 \times 1.6 \times 10^{-19}$ J
a) Threshold wavelength = λ
$\phi = hc/\lambda$
$\Rightarrow \lambda = \frac{hC}{\phi} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4 \times 1.6 \times 10^{-19}} = \frac{6.63 \times 3}{6.4} \times \frac{10^{-27}}{10^{-9}} = 3.1 \times 10^{-7}$ m = 310 nm.
b) Stopping potential is 2.5 V
$E = \phi + eV$
$\Rightarrow hc/\lambda = 4 \times 1.6 \times 10^{-19} + 1.6 \times 10^{-19} \times 2.5$
$\Rightarrow \lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda \times 1.6 \times 10^{-19}} = 4 + 2.5$
$\Rightarrow \frac{6.63 \times 3 \times 10^{-26}}{1.6 \times 10^{-19} \times 6.5} = 1.9125 \times 10^{-7} = 190$ nm.

17. Energy of photoelectron

$\Rightarrow$ ½ $mv^2 = \frac{hc}{\lambda} - hv_0 = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10^{-7}} - 2.5ev$ = 0.605 ev.

We know KE = $\frac{P^2}{2m} \Rightarrow P^2 = 2m \times KE$.

$P^2 = 2 \times 9.1 \times 10^{-31} \times 0.605 \times 1.6 \times 10^{-19}$

$P = 4.197 \times 10^{-25}$ kg – m/s

18. $\lambda = 400$ nm $= 400 \times 10^{-9}$ m

$V_0 = 1.1$ V

$$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + ev_0$$

$$\Rightarrow \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda_0} + 1.6 \times 10^{-19} \times 1.1$$

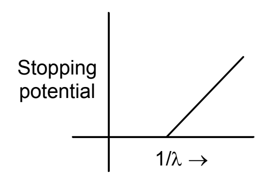
$$\Rightarrow 4.97 = \frac{19.89 \times 10^{-26}}{\lambda_0} + 1.76$$

$$\Rightarrow \frac{19.89 \times 10^{-26}}{\lambda_0} = 4.97 - 17.6 = 3.21$$

$$\Rightarrow \lambda_0 = \frac{19.89 \times 10^{-26}}{3.21} = 6.196 \times 10^{-7} \text{ m} = 620 \text{ nm}.$$

19. a) When $\lambda = 350$, $V_s = 1.45$

and when $\lambda = 400$, $V_s = 1$



$\therefore \frac{hc}{350} = W + 1.45$ …(1)

and $\frac{hc}{400} = W + 1$ …(2)

Subtracting (2) from (1) and solving to get the value of h we get

$h = 4.2 \times 10^{-15}$ ev-sec

b) Now work function = w = $\frac{hc}{\lambda}$ = ev - s

$= \frac{1240}{350} - 1.45$ = 2.15 ev.

c) $w = \frac{hc}{\lambda} = \lambda_{\text{there cathod}} = \frac{hc}{w}$

$= \frac{1240}{2.15}$ = 576.8 nm.

20. The electric field becomes 0 1.2×10^{45} times per second.

$\therefore$ Frequency = $\frac{1.2 \times 10^{15}}{2} = 0.6 \times 10^{15}$

$h\nu = \phi_0 + kE$

$\Rightarrow h\nu - \phi_0 = KE$

$\Rightarrow KE = \frac{6.63 \times 10^{-34} \times 0.6 \times 10^{15}}{1.6 \times 10^{-19}} - 2$

= 0.482 ev = 0.48 ev.

21. $E = E_0 \sin[(1.57 \times 10^7 \text{ m}^{-1})(x - ct)]$

$W = 1.57 \times 10^7 \times C$

$\Rightarrow$ f = $\dfrac{1.57\times10^{7}\times3\times10^{8}}{2\pi}$ Hz W_0 = 1.9 ev

Now $eV_0 = h\nu - W_0$

$= 4.14 \times 10^{-15} \times \dfrac{1.57\times3\times10^{15}}{2\pi} - 1.9$ ev

= 3.105 – 1.9 = 1.205 ev

So, $V_0 = \dfrac{1.205\times1.6\times10^{-19}}{1.6\times10^{-19}}$ = 1.205 V.

22. E $= 100 \sin[(3 \times 10^{15} s^{-1})t] \sin[6 \times 10^{15} s^{-1})t]$

$= 100\ \tfrac{1}{2}\ [\cos[(9 \times 10^{15} s^{-1})t] - \cos[3 \times 10^{15} s^{-1})t]$

The w are 9×10^{15} and 3×10^{15}

for largest K.E.

$f_{max} = \dfrac{w_{max}}{2\pi} = \dfrac{9\times10^{15}}{2\pi}$

$E - \phi_0$ = K.E.

$\Rightarrow hf - \phi_0$ = K.E.

$\Rightarrow \dfrac{6.63\times10^{-34}\times9\times10^{15}}{2\pi\times1.6\times10^{-19}} - 2 = KE$

$\Rightarrow$ KE = 3.938 ev = 3.93 ev.

23. $W_0 = hv - ev_0$

$= \dfrac{5\times10^{-3}}{8\times10^{15}} - 1.6\times10^{-19}\times2$ (Given V_0 = 2V, No. of photons = 8×10^{15}, Power = 5 mW)

$= 6.25 \times 10^{-19} - 3.2 \times 10^{-19} = 3.05 \times 10^{-19}$ J

$= \dfrac{3.05\times10^{-19}}{1.6\times10^{-19}}$ = 1.906 eV.

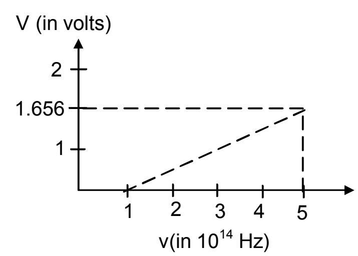
24. We have to take two cases :

Case I … $v_0 = 1.656$

$\nu = 5 \times 10^{14}$ Hz

Case II… $v_0 = 0$

$\nu = 1 \times 10^{14}$ Hz



We know ;

a) $ev_0 = h\nu - w_0$

$1.656e = h \times 5 \times 10^{14} - w_0$ …(1)

$0 = 5h \times 10^{14} - 5w_0$ …(2)

$1.656e = 4w_0$

$\Rightarrow w_0 = \dfrac{1.656}{4}$ ev = 0.414 ev

b) Putting value of w_0 in equation (2)

$\Rightarrow 5w_0 = 5h \times 10^{14}$

$\Rightarrow 5 \times 0.414 = 5 \times h \times 10^{14}$

$\Rightarrow h = 4.414 \times 10^{-15}$ ev-s

25. w_0 = 0.6 ev

For w_0 to be min 'λ' becomes maximum.

$w_0 = \dfrac{hc}{\lambda}$ or $\lambda = \dfrac{hc}{w_0} = \dfrac{6.63\times10^{-34}\times3\times10^{8}}{0.6\times1.6\times10^{-19}}$

$= 20.71 \times 10^{-7}$ m = 2071 nm

26. λ = 400 nm, P = 5 w

E of 1 photon = $\frac{hc}{\lambda} = \left(\frac{1242}{400}\right)$ ev

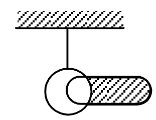
No.of electrons = $\frac{5}{\text{Energy of 1 photon}} = \frac{5 \times 400}{1.6 \times 10^{-19} \times 1242}$

No.of electrons = 1 per 10^6 photon.

No.of photoelectrons emitted = $\frac{5 \times 400}{1.6 \times 1242 \times 10^{-19} \times 10^6}$

Photo electric current = $\frac{5 \times 400}{1.6 \times 1242 \times 10^6 \times 10^{-19}} \times 1.6 \times 10^{-19}$ = 1.6×10^{-6} A = 1.6 μA.

27. λ = 200 nm = 2×10^{-7} m



E of one photon = $\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2 \times 10^{-7}}$ = 9.945×10^{-19}

No.of photons = $\frac{1 \times 10^{-7}}{9.945 \times 10^{-19}}$ = 1×10^{11} no.s

Hence, No.of photo electrons = $\frac{1 \times 10^{11}}{10^4}$ = 1×10^7

Net amount of positive charge 'q' developed due to the outgoing electrons

= $1 \times 10^7 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-12}$ C.

Now potential developed at the centre as well as at the surface due to these charger

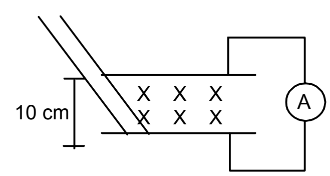
= $\frac{Kq}{r} = \frac{9 \times 10^9 \times 1.6 \times 10^{-12}}{4.8 \times 10^{-2}}$ = 3×10^{-1} V = 0.3 V.

28. ϕ_0 = 2.39 eV

λ_1 = 400 nm, λ_2 = 600 nm

for B to the minimum energy should be maximum

$\therefore$ λ should be minimum.



E = $\frac{hc}{\lambda} - \phi_0$ = 3.105 – 2.39 = 0.715 eV.

The presence of magnetic field will bend the beam there will be no current if the electron does not reach the other plates.

r = $\frac{mv}{qB}$

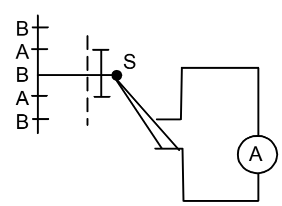
$\Rightarrow$ r = $\frac{\sqrt{2mE}}{qB}$

$\Rightarrow$ 0.1 = $\frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 0.715}}{1.6 \times 10^{-19} \times B}$

$\Rightarrow$ B = 2.85×10^{-5} T

29. Given : fringe width,

y = 1.0 mm $\times$ 2 = 2.0 mm, D = 0.24 mm, W_0 = 2.2 ev, D = 1.2 m



y = $\frac{\lambda D}{d}$

or, $\lambda = \frac{yd}{D} = \frac{2 \times 10^{-3} \times 0.24 \times 10^{-3}}{1.2}$ = 4×10^{-7} m

E = $\frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10}$ = 3.105 ev

Stopping potential eV_0 = 3.105 – 2.2 = 0.905 V

30. ϕ = 4.5 eV, λ = 200 nm

Stopping potential or energy = $E - \phi = \frac{WC}{\lambda} - \phi$

Minimum 1.7 V is necessary to stop the electron

The minimum K.E. = 2eV

[Since the electric potential of 2 V is reqd. to accelerate the electron to reach the plates]

the maximum K.E. = (2+1, 7)ev = 3.7 ev.

31. Given

$\sigma = 1 \times 10^{-9}$ cm^{-2}, W_0 (C_s) = 1.9 eV, d = 20 cm = 0.20 m, λ = 400 nm

we know $\to$ Electric potential due to a charged plate = V = E $\times$ d

Where E $\to$ elelctric field due to the charged plate = σ/E_0

d $\to$ Separation between the plates.

$V = \frac{\sigma}{E_0} \times d = \frac{1 \times 10^{-9} \times 20}{8.85 \times 10^{-12} \times 100}$ = 22.598 V = 22.6

$V_0 e = h\nu - w_0 = \frac{hc}{\lambda} - w_0 = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10^{-7}} - 1.9$

= 3.105 – 1.9 = 1.205 ev

or, V_0 = 1.205 V

As V_0 is much less than 'V'

Hence the minimum energy required to reach the charged plate must be = 22.6 eV

For maximum KE, the V must be an accelerating one.

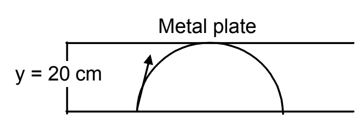
Hence max KE = V_0 + V = 1.205 + 22.6 = 23.8005 ev

32. Here electric field of metal plate = E = P/E_0

$= \frac{1 \times 10^{-19}}{8.85 \times 10^{-12}}$ = 113 v/m

accl. de = ϕ = qE / m

$= \frac{1.6 \times 10^{-19} \times 113}{9.1 \times 10^{-31}}$ = 19.87 $\times 10^{12}$



$t = \frac{\sqrt{2y}}{a} = \frac{\sqrt{2 \times 20 \times 10^{-2}}}{19.87 \times 10^{-31}}$ = 1.41 $\times 10^{-7}$ sec

K.E. = $\frac{hc}{\lambda} - w$ = 1.2 eV

= 1.2 $\times$ 1.6 $\times 10^{-19}$ J [because in previous problem i.e. in problem 31 : KE = 1.2 ev]

$\therefore$ $V = \frac{\sqrt{2KE}}{m} = \frac{\sqrt{2 \times 1.2 \times 1.6 \times 10^{-19}}}{4.1 \times 10^{-31}}$ = 0.665 $\times 10^{-6}$

$\therefore$ Horizontal displacement = $V_t \times t$

= 0.655 $\times 10^{-6} \times 1.4 \times 10^{-7}$ = 0.092 m = 9.2 cm.

33. When λ = 250 nm

Energy of photon = $\frac{hc}{\lambda} = \frac{1240}{250}$ = 4.96 ev

$\therefore$ K.E. = $\frac{hc}{\lambda} - w$ = 4.96 – 1.9 ev = 3.06 ev.

Velocity to be non positive for each photo electron

The minimum value of velocity of plate should be = velocity of photo electron

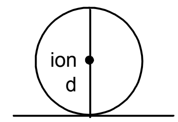
$\therefore$ Velocity of photo electron = $\sqrt{2KE/m}$

$= \sqrt{\dfrac{3.06}{9.1\times10^{-31}}} = \sqrt{\dfrac{3.06\times1.6\times10^{-19}}{9.1\times10^{-31}}}$ = 1.04 × 10^6 m/sec.

34. Work function = ϕ, distance = d

The particle will move in a circle

When the stopping potential is equal to the potential due to the singly charged ion at that point.



$eV_0 = \dfrac{hc}{\lambda} - \phi$

$\Rightarrow V_0 = \left(\dfrac{hc}{\lambda} - \phi\right)\dfrac{1}{e} \Rightarrow \dfrac{ke}{2d} = \left(\dfrac{hc}{\lambda} - \phi\right)\dfrac{1}{e}$

$\Rightarrow \dfrac{Ke^2}{2d} = \dfrac{hc}{\lambda} - \phi \Rightarrow \dfrac{hc}{\lambda} = \dfrac{Ke^2}{2d} + \phi = \dfrac{Ke^2 + 2d\phi}{2d}$

$\Rightarrow \lambda = \dfrac{hc\ 2d}{Ke^2 + 2d\phi} = \dfrac{2hcd}{\dfrac{1}{4\pi\varepsilon_0 e^2} + 2d\phi} = \dfrac{8\pi\varepsilon_0 hcd}{e^2 + 8\pi\varepsilon_0 d\phi}$.

35. a) When λ = 400 nm

Energy of photon = $\dfrac{hc}{\lambda} = \dfrac{1240}{400}$ = 3.1 eV

This energy given to electron

But for the first collision energy lost = 3.1 ev × 10% = 0.31 ev

for second collision energy lost = 3.1 ev × 10% = 0.31 ev

Total energy lost the two collision = 0.31 + 0.31 = 0.62 ev

K.E. of photon electron when it comes out of metal

= hc/λ – work function – Energy lost due to collision

= 3.1 ev – 2.2 – 0.62 = 0.31 ev

b) For the 3rd collision the energy lost = 0.31 ev

Which just equative the KE lost in the 3rd collision electron. It just comes out of the metal

Hence in the fourth collision electron becomes unable to come out of the metal

Hence maximum number of collision = 4.

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