Chapter 2 (Particle Nature of Light)
Solution of Worksheet

Ans. 1: (a)

Solution: $KE = h\nu - h\nu_0$

So plot of K.E. vs. frequency is a straight line with slope h, i.e. $\theta = \tan^{-1} h$, which is independent of work function.

Ans. 2: (b)

Solution: Stopping potential is the negative potential which stops the emission of $(K.E)_{\max}$ electrons when applied. $\therefore$ Stopping potential $= 4V$.

Ans. 3: (d)

Ans. 4: (d)

Solution: In photoelectric effect, the energy of electron is given as

$$\frac{mv^2}{2} = h\nu - W \quad \Rightarrow \quad 3eV = 8eV - W$$

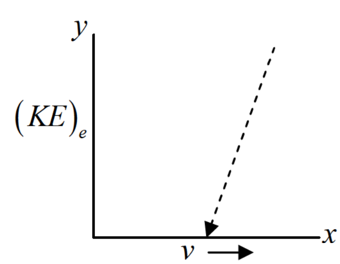
work function $W = (8-3)eV$, $W = 5eV$

Now, if energy corresponding to ν_0 is $8eV$, then energy corresponding to $1.2\nu_0$.

$= 1.2 \times 8eV = 9.6eV$ so, energy of electron = $h\nu' - W = (9.6-5)eV = 4.6eV$

Ans. 5: (c)

Solution: If the threshold frequency ν_0 is given as then $\frac{1}{2}mv^2 = h\nu - h\nu_0$

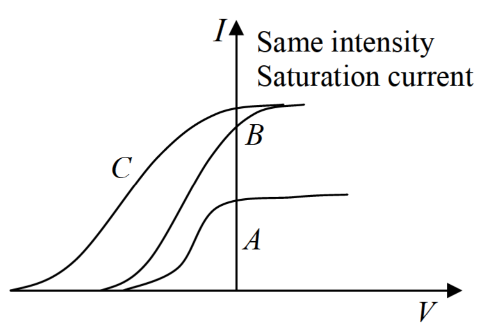


where h is Planck's constant i.e., (KE) of electron $= h\nu - h\nu_0$

thus, y-axis is KE of electron and x-axis is frequency of incident photon.

Ans. 6: (d)

Solution: At stopping potential, photoelectric current is zero.



It is same for A and B.

$\therefore A$ and B will have equal frequencies

Saturation current is proportional to intensity. B and C will have equal intensity.

Option (d) represents correct answer

Ans. 7: (d)

Solution: $T = h\nu - h\nu_0$

$h\nu = 1,241/253.7 = 4.89eV$

$h\nu_0 = 1,241/325 = 3.81eV$

$T = eV = 4.89 - 3.81 = 1.08$

The required potential is $1.08V$

Ans. 8: (d)

Ans. 9: (a)

Solution: $p = \frac{h}{\lambda}, E = \frac{hc}{\lambda}$

Ans. 10: (c)

Solution: $P = \frac{n_r hc}{\lambda_r t} = \frac{n_b hc}{\lambda_b t}$ hence $\lambda_r > \lambda_b \Rightarrow n_r > n_b$

Ans. 11: (c)

Ans. 12: (a)

Ans. 13: (c)

Ans. 14: (b)

Ans. 15: (c)

Solution: $eV_{1s} = h\nu - \phi \Rightarrow \phi = h\nu - eV_{1s}$, $eV_{2s} = h2\nu - \phi, \frac{eV_{2s} = h2\nu - \phi}{eV_{1s} = h\nu - \phi} = \frac{V_{2s}}{V_{1s}} = \frac{2-c}{1-c} > 2$ where $c = \frac{\phi}{h\nu}$

Ans. 16: (b)

Solution: Saturation photo current is proportional to intensity

Frequency will double then maximum kinetic energy will more than double.

Ans. 17: (c)

Solution: Stopping potential will not dependent on intensity .

Ans. 18: (d)

Solution: $i \propto I \propto \frac{1}{r^2}$ so $i \propto \frac{1}{r^2}$

Ans. 19: (c)

Solution: $KE_{\max} = \frac{hc}{\lambda} - \phi$

Ans. 20: (c)

Solution: $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{\sqrt{m}}$

Ans. 21: (b)

Solution 16: $\phi = 4\,eV = 4\times1.6\times10^{-19}J$

(a) Threshold wavelength $=\lambda$

$$\phi=\frac{hc}{\lambda}\Rightarrow\lambda=\frac{hc}{\phi}=\frac{6.63\times10^{-34}\times3\times10^{8}}{4\times1.6\times10^{-19}}=\frac{6.63\times3}{6.4}\times\frac{10^{-27}}{10^{-9}}=3.1\times10^{-7}m=310\,nm$$

(b) Stopping potential is $2.5V$

$$E=\phi+eV$$

$$\Rightarrow\frac{hc}{\lambda}=4\times1.6\times10^{-19}+1.6\times10^{-19}\times2.5\Rightarrow\lambda=\frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda\times1.6\times10^{-19}}=4+2.5$$

$$\Rightarrow\frac{6.63\times3\times10^{-26}}{1.6\times10^{-19}\times6.5}=1.9125\times10^{-7}=190\,nm$$

Ans. 22: (d)

Solution 18: $\lambda = 400\,nm = 400\times10^{-9}\,m$

$$V_0=1.1V$$

$$\frac{hc}{\lambda}=\frac{hc}{\lambda_0}+eV_0$$

$$\Rightarrow\frac{6.63\times10^{-34}\times3\times10^{8}}{400\times10^{-9}}=\frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda_0}+1.6\times10^{-19}\times1.1$$

$$\Rightarrow4.97=\frac{19.89\times10^{-26}}{\lambda_0}+1.76\Rightarrow\frac{19.89\times10^{-26}}{\lambda_0}=4.97-17.6=3.21$$

$$\Rightarrow\lambda_0=\frac{19.89\times10^{-26}}{3.21}=6.196\times10^{-7}m=620\,nm$$

Ans. 23: (c)

Solution: $E=E_0\sin\left[\left(1.57\times10^{7}m^{-1}\right)\left(x-ct\right)\right]$

$$W=1.57\times10^{7}\times C\Rightarrow f=\frac{1.57\times10^{7}\times3\times10^{8}}{2\pi}Hz$$

$$W_0=1.9\,eV$$

Now, $eV_0=h\nu-W_0=4.14\times10^{-15}\times\dfrac{1.57\times3\times10^{15}}{2\pi}-1.9\,eV$

$=3.105-1.9=1.205\ eV$. So, $V_0=\dfrac{1.205\times1.6\times10^{-19}}{1.6\times10^{-19}}=1.205\ V$

Ans. 24: (c)

Solution: $W_0 = 0.6\, eV$

For W_0 to be min 'λ' becomes maximum

$$W_0 = \frac{hc}{\lambda} \text{ or } \lambda = \frac{hc}{W_0} = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.6\times1.6\times10^{-19}} = 20.71\times10^{-7}\, m = 2071\, nm$$

Ans. 25: (a)

Solution: The work function of lithium is $2.5\, eV$. The threshold wavelength is

$$\lambda = \frac{hc}{\varphi} = \frac{\left(4.14\times10^{-15}\, eVs\right)\times\left(3\times10^{8}\, ms^{-1}\right)}{2.5\, eV} = \frac{1242\, eVnm}{2.5\, eV} = 497\, nm$$

This is the required maximum wavelength.

Ans. 26: (d)

Solution: The energy of each photon $= \dfrac{200\, Js^{-1}}{4\times10^{20}\, s^{-1}} = 5\times10^{-19}\, J$

Wavelength $= \lambda = \dfrac{hc}{E} = \dfrac{\left(6.63\times10^{-34}\, Js\right)\times\left(3\times10^{8}\, ms\right)}{\left(5\times10^{-19}\, J\right)} = 4.0\times10^{-7}\, m = 400\, nm$

Ans. 27: (c)

Solution: The light contains two different frequencies. The one with larger frequency will cause photoelectrons with largest kinetic energy. This larger frequency is

$$v = \frac{\omega}{2\pi} = \frac{8\times10^{15}\, s^{-1}}{2\pi}$$

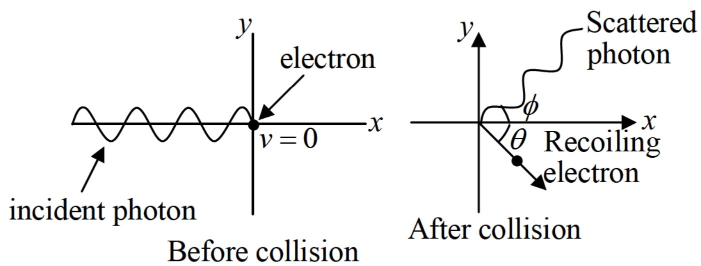
The maximum kinetic energy of the photoelectrons is

$$K_{\max} = hv - \varphi = \left(4.14\times10^{-15}\, eVs\right)\times\left(\frac{8\times10^{15}}{2\pi}s^{-1}\right) - 2.0\, eV$$

$$= 5.27\, eV - 2.0\, eV = 3.27\, eV.$$

Ans. 28: (b)

Solution:



The change in wavelength of scattered photon is given as $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\phi)$ where ϕ is scattered angle. Hence, $\phi = 90^\circ$ (given)

So, $\Delta\lambda = \frac{h}{m_0 c}(1-\cos 90^\circ) = \frac{h}{m_0 c}(1-0) \Rightarrow \Delta\lambda = \frac{h}{m_0 c}$

If λ is wavelength of incident photon then wavelength of photon $= \lambda + \frac{h}{mc}$ (i)

But moment of incident photon mc (given) $\Rightarrow \lambda = \frac{h}{mc}$

So, wavelength of scattered photon $= \frac{h}{mc} + \frac{h}{mc}$ by equation (i) $\lambda_s = \frac{2h}{mc}$

Corresponding momentum $= \frac{h}{\lambda_s}$ Momentum $= \frac{h}{\frac{2h}{mc}} = \frac{1}{2}mc$

Ans. 29: (c)

Solution: This problem can be solved via the Compton Effect equation $\Delta\lambda = \lambda_c(1-\cos\theta)$, where θ is the angle of the scattered photon and $\lambda_c = h/(m_e c)$ is the so-called Compton Wavelength.

In this case, since the particles are protons, one has $\Delta\lambda = \frac{h}{m_p c}$

$$\frac{\Delta\lambda}{\lambda_c} = \frac{\frac{h}{m_p c}}{\frac{h}{m_e c}} = \frac{1}{1840}$$

Ans. 30: (a)

Solution: $\Delta\lambda = \lambda_c(1-\cos\theta)$

When photon scatter in perpendicular direction then $\theta = \frac{\pi}{2} \Rightarrow \Delta\lambda = \lambda_c$

Fractional shift $= \frac{\Delta\lambda}{\lambda} = \frac{\lambda_C}{\lambda}$

Ans. 31: (c)

Solution: $\frac{1}{v'} = \frac{1}{v} + \frac{h}{m_p c^2}(1-\cos\theta)$

$$hv' = \frac{hv}{1+\left(\frac{hv}{m_p c^2}\right)}(1-\cos\theta)$$

$$K.E = h\nu - h\nu' \quad = h\nu - \frac{h\nu}{1+\left(\frac{h\nu}{m_p c^2}\right)(1-\cos\theta)} \qquad \Rightarrow KE = \frac{h\nu}{1+\frac{m_p c^2}{2h\nu}}$$

Ans. 32: (a)

Solution: $\frac{\lambda c}{\lambda} = \frac{hc}{\lambda'} + k$ Where k is kinetic energy

$$k = \frac{hc}{\lambda} - \frac{hc}{(\lambda+\Delta\lambda)} \quad k = \frac{hc\Delta\lambda}{\lambda(\lambda+\Delta\lambda)}$$

Ans. 33: (b)

Solution: $K = \frac{hc}{\lambda} - \frac{hc}{\lambda'} = \frac{hc\Delta\lambda}{\lambda(\lambda+\Delta\lambda)} = \frac{hc}{2\lambda}$ where $\lambda' = \lambda + \Delta\lambda$

MSQ (Multiple Select Questions)

Ans. 34: (a), (b) and (c)

Solution: Consider metal A

Incident energy = work function + Kinetic energy of photoelectrons

$$\therefore 4.25(eV) = W_A + T_A \qquad \text{(i)}$$

Kinetic energy = $\frac{P^2}{2m}$ where $P =$ momentum

$\therefore T_A = \frac{P_A^2}{2m} = \frac{1}{2m}\left(\frac{h}{\lambda_A}\right)^2$, by de Broglie equation $\therefore T_A = \frac{1}{2m}\left(\frac{h}{\lambda_A}\right)^2$ (ii)

Consider metal B

$$4.7 = (T_A - 1.5) + W_B \qquad \text{(iii)}$$

Also $T_B = \frac{1}{2m}\left(\frac{h}{\lambda_B}\right)^2 = \frac{1}{2m}\left(\frac{h}{\lambda_B}\right)^2$ (iv)

From (iv) and (ii), we get

$\frac{T_B}{T_A} = \left(\frac{\lambda_A}{\lambda_B}\right)^2$ or $\frac{T_A - 1.5}{T_A} = \left(\frac{\lambda_A}{\lambda_B}\right)^2$ $[\because T_B = T_A - 1.5]$

or $\frac{T_A - 1.5}{T_A} = \left(\frac{\lambda_A}{2\lambda_A}\right)^2$ $[\because \lambda_B = 2\lambda_A]$

or $4T_A - 6.0 = T_A$ or $3T_A = 6$

$$T_A = 2.00eV \qquad \text{(v)}$$

from (i), $W_A = 4.25 - T_A = 4.25 - 2 = 2.25\,eV$

From (iii),

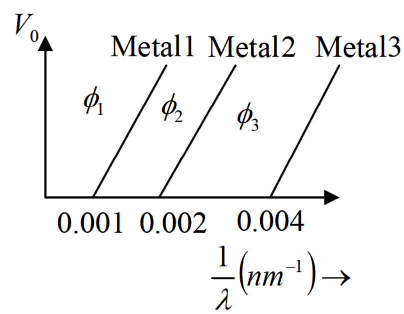
$W_B = 4.7 - (T_A - 1.5) = 4.7 - (2 - 1.5) = 3.95\,eV$ (vii)

Again $T_B = T_A - 1.5 = 2.25 - 1.5 = 0.5\,eV$ (viii)

Option (a), (b), (c) are correct as depicted in equation (vi) (vii) and (v) above

Ans. 35: (a) and (c)

Solution: According to Einstein's equation,



$\frac{hc}{\lambda} - \phi = eV$ where $\phi =$ work function

or $V = \frac{hc}{e\lambda} - \frac{\phi}{e}$ or $V = \left(\frac{hc}{e}\right)\frac{1}{\lambda} - \frac{\phi}{e}$

V and $\left(\frac{1}{\lambda}\right)$ relation represents a straight line.

$\therefore$ Slope of line $= \frac{hc}{e}$ or $\tan\theta = \frac{hc}{e}$

$\therefore$ Option (c) is correct (i)

At $V_0 = 0$

$\phi_1 : \phi_2 : \phi_3 = \frac{hc}{\lambda_{01}} : \frac{hc}{\lambda_{02}} : \frac{hc}{\lambda_{03}} = (0.001\,hc) : (0.002\,hc) : (0.004\,hc) = 1:2:4$

$\therefore$ Option (a) is correct (ii)

Option (b) is obviously incorrect when (a) is correct.

From graph

$\frac{1}{\lambda_{01}} = 0.001\,nm^{-1} \therefore \lambda_{01} = 1000\,nm$ for metal 1.

$\frac{1}{\lambda_{02}} = 0.002\,nm^{-1} \therefore \lambda_{02} = 500\,nm$ for metal 2

$\frac{1}{\lambda_{03}} = 0.004\,nm^{-1} \therefore \lambda_{03} = 250\,nm$ for metal 3.

λ of ultraviolet < 400nm.

The ultraviolet light can be used to emit photoelectrons from metal 1 and metal 2. It cannot emit electrons from metal 3.

Option (d) is incorrect.

Options (a) and (c) are correct.

Ans. 36: (a), (b) and (d)

Solution: (a) According to Einstein's photoelectric equation Incident Energy = work function + Maximum kinetic energy of the photoelectron

or $E = 1.82 + 0.73$

$E = 2.55\,eV$ (i)

(b) Quantum numbers of the two levels:

In case of hydrogen atom, $E = -\left(\frac{13.6}{n^2}\right)$

$\therefore E_1 = -13.6 \ \ eV,\ E_2 = -3.4 \ \ eV$

$E_4 = -0.85\,eV$. The discharge tube contains hydrogen atoms

Since $E_4 - E_2 = -0.85 - (3.4) = 2.55\,eV$ (ii)

Hence the quantum numbers of the two levels involved in the emission of these photons are 4 and 2.

The transition occurs from 4 to 2 (ii)

(c) Change in angular momentum in above transition

$\Delta L = L_2 - L_4$

or $\Delta L = 2\left(\frac{h}{2\pi}\right) - 4\left(\frac{h}{2\pi}\right)$ or $\Delta L = \frac{h}{\pi}$

(d) Recoil speed of the emitting atom: Momentum is conserved in the process

Momentum of hydrogen atom $= mv$

Momentum of emitted photon $= \frac{E}{c}$ $\therefore$ $mv = \frac{E}{c}$

or $v = \frac{E}{mc}$ or $v = \frac{2.55 \times 1.6 \times 10^{-19}}{(1.67 \times 10^{-27})(3 \times 10^8)}$

or $v = 0.814\ m/s$

$\therefore$ Recoil speed of emitting atom $0.814 m/s$

Ans. 37: (a), (c) and (d)

Solution: The stopping potential for shorter wavelength is 3.95 volt i.e., maximum kinetic energy of photoelectrons corresponding to shorter wavelength will be $3.95\,eV$. Further energy of incident photons corresponding to shorter wavelength will be in transition from $n = 4$ to $n = 3$.

$$E_{4\to 3} = E_4 - E_3 = \frac{-(13.6)(3)^2}{(4)^2} - \left[\frac{-(13.6)(3)^2}{(3)^2}\right] = 5.95\,eV$$

Now from the equation, $K_{\max} = E - W$

We have, $W = E - K_{\max} = E_{4\to 3} - K_{\max} = (5.95 - 3.95)eV = 2\,eV$

Longer wavelength will correspond to transition from $n = 5$ to $n = 4$. From the relation

$$\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The longer wavelength, $\frac{1}{\lambda} = (1.094\times 10^7)(3)^2\left(\frac{1}{16} - \frac{1}{25}\right)$ or $\lambda = 4.514\times 10^{-7}\,m = 4514\,\overset{0}{\mathrm{A}}$

Energy corresponding to this wavelength,

$$E = \frac{12375\,eV}{4514\,\overset{0}{A}} = 2.74\,eV$$

$\therefore$ Maximum kinetic energy of photoelectrons

$K_{\max} = E - W = (2.74 - 2)eV = 0.74\,eV$ or the stopping potential is 0.74 volt

Ans. 38: (a), (d)

Solution: For threshold frequency $hf = 2\times 1.6\times 10^{-19} \Rightarrow f = \frac{2\times 1.6\times 10^{-19}}{6.6\times 10^{-34}} = 4.9\times 10^{15}\,\sec^{-1}$

$$K_{\max} = \hbar\omega - W$$

For given wave maximum kinetic energy is for highest ω so $\omega = 12.56\times 10^{15}\,\sec^{-1}$

$$\hbar\omega = \frac{6.6\times 10^{-34}\,J\,s\times 12.56\times 10^{15}\,s^{-1}}{2\pi} = \frac{82.8\times 10^{-19}\,J}{6.28\times 1.6\times 10^{-19}}eV = 8.24\,eV$$

$$K_{\max} = \hbar\omega - W \Rightarrow 8.24\,eV - 2\,eV = 6.24\,eV$$

Ans. 39: (c), (d)

Solution: Suppose the photoelectric effect does take place with a free electron due to the absorption of a photon of energy T. The photoelectron must be ejected with energy in the incident direction. Energy and momentum conservation give $T = h\nu$

$$P = h\nu / c$$

Equation (1) can be written as the relativistic relation connecting momentum and kinetic energy

$$T^2 = c^2p^2 = T^2 + 2Tmc^2$$

Using (1) and (2) in (3), we get

$$2h\nu . mc^2 = 0$$

Neither h nor mc^2 is zero. We thus end up with an absurd situation. This only means that both energy and momentum can not be conserved for photoelectric effect with a free electron.

Ans. 40: (a), (b), (c), (d)

Solution: $T_A = 4.25 - W_A$ (i)

$T_B = 4.7 - W_B$ (ii)

$$\frac{T_A}{T_B} = \frac{P_A^2}{P_B^2} = \frac{\lambda_B^2}{\lambda_A^2} = 4 \quad \text{(iii)}$$

$T_B = T_A - 1.5$ (iv)

Solving the above equations,

$T_A = 2eV$ and $T_B = 0.5\,eV$

$W_A = 2.25eV$ and $W_B = 4.2\,eV$

Ans. 41: (a), (b)

Ans. 42: (a), (b), (c)

Ans. 43: (b), (d)

Ans. 44: (a)

Ans. 45: (b)

Ans. 46: (a), (c), (d)

Ans. 47: (a), (c), (d)

Solution: (a) Here intensity $= I = 1.4\times10^3\,\omega/m^2$ Intensity, $I = \dfrac{\text{power}}{\text{area}} = 1.4\times10^3\,\omega/m^2$

Let number of photons / sec emitted $= n$ $\therefore$ Power = Energy emitted / sec $= \dfrac{nhc}{\lambda} = P$

Number of photons / $m^2 = \dfrac{nhc}{\lambda} =$ intensity

$$n = \frac{\text{intensity}\times\lambda}{hc} = \frac{1.9\times10^3\times5\times10^{-9}}{6.63\times10^{-34}\times3\times10^8} = 3.5\times10^{21}$$

(b) Consider number 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 $= \dfrac{dv}{e} = dt$

In this time the total number of photons emitted $= N = ndt = \left(\dfrac{p\lambda}{hc}\right)\dfrac{dr}{C}$

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 source. Number 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 $=1.5\times10^{11}m,\ \lambda=500\,nm,\ =500\times10^{-9}\,m$

$\frac{P}{4\pi r^2}=1.4\times10^3$, $\therefore$ Number of photons / m^3 $=\frac{P}{4\pi r^2}\frac{\lambda}{hc^2}$

$$=1.4\times10^3\times\frac{500\times10^{-9}}{6.63\times10^{-34}\times3\times10^8}=1.2\times10^{13}$$

(c) Number photons = (Number of photons/sec/ m^2) $\times$ Area

$$=\left(3.5\times10^{21}\right)\times4\pi r^2$$

$$=3.5\times10^{21}\times4(3.14)\left(1.5\times10^{11}\right)^2=9.9\times10^{44}$$

Ans. 48: (a), (b), (c), (d)

Solution: $W_0=2.5\times10^{-19}J$

(a) We know $W_0=h\nu_0$

$$\nu_0=\frac{W_0}{h}=\frac{2.5\times10^{-19}}{6.63\times10^{-34}}=3.77\times10^{14}\,Hz=3.8\times10^{14}\,Hz$$

(b) $K_{\max}=h\nu-W_0$

or, $K_{\max}=6.63\times10^{-34}\times6\times10^{14}-2.5\times10^{-19}=0.91eV=0.91\times1.6\times10^{-19}J=1.46\times10^{-19}J$

(c) $\lambda=500nm\equiv\nu=6\times10^{14}\,Hz$

$K_{\max}=6.63\times10^{-34}\times6\times10^{14}-2.5\times10^{-19}=0.91eV$

(d) $K_{\max}=eV\Rightarrow V=0.91V$

Ans. 49: (a), (b), (c), (d)

Solution: (a) The energy of each photon is

$$E=\frac{hc}{\lambda}=\frac{\left(4.14\times10^{-15}eVs\right)\times\left(3\times10^8ms^{-1}\right)}{500\,nm}=\frac{1242\,eVnm}{500\,nm}=2.48\,eV$$

(b) In one second, $10\,J$ of energy passes through any cross section of the beam. Thus, the number of photons crossing a cross section is $n=\frac{10J}{2.48\,eV}=2.52\times10^{19}$

This is also the number of photons falling on the surface per second and being absorbed.

(c) The linear momentum of each photon is $p = \frac{h}{\lambda} = \frac{hv}{c}$

The total momentum of all the photons falling per second on the surface is

$$= \frac{nhv}{c} = \frac{10J}{c} = \frac{10J}{3\times10^{8}\,ms^{-1}} = 3.33\times10^{-8}\,Ns$$

(d) As the photons are completely absorbed by the surface, this much momentum is transferred to the surface per second. The rate of change of the momentum of the surface, i.e., the force on it is $F = \frac{dp}{dt} = \frac{3.33\times10^{-8}}{1\,s} = 3.33\times10^{-8}\,N$

Ans. 50: (a), (b), (c), (d)

Solution: The kinetic energy of the most energetic electrons is

$$K = \frac{hc}{\lambda} - \varphi = \frac{1242\,eV\,nm}{450\,nm} - 2.0\,eV \;= 0.76\,eV = 1.2\times10^{-19}\,J$$

The linear momentum $= mv = \sqrt{2mK}$

$$= \sqrt{2\times\left(9.1\times10^{-31}\,kg\right)\times\left(1.2\times10^{-19}\,J\right)} = 4.67\times10^{-25}\,kgms^{-1}$$

When a charged particle is sent perpendicular to a magnetic field, it goes along a circle of radius

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

Thus, $\quad 0.20\,m = \frac{4.67\times10^{-25}\,kg\,m\,s^{-1}}{\left(1.6\times10^{-19}\,C\right)\times B}$

or, $\quad B = \frac{4.67\times10^{-25}\,kg\,m\,s^{-1}}{\left(1.6\times10^{-19}\,C\right)\times\left(0.20\,m\right)} = 1.46\times10^{-5}\,T$

Ans. 51: (a) and (b)

Ans. 52: (b) and (c)

Solution: According to Compton scattering formula, the difference in wavelength of the scattered λ' and incident λ photon is $\lambda' - \lambda = \frac{\hbar}{mc}(1-\cos\theta)$, where θ is the scattering angle. In our case, $\theta = 90^{0}$ and $\lambda' - \lambda = \frac{\hbar}{mc}$. But $E = \frac{\hbar c}{\lambda}$, so $E' = \frac{\hbar c}{\lambda'}$, where E' is the energy of the scattered photon. Thus, $\frac{\hbar c}{E'} - \frac{\hbar c}{E} = \frac{\hbar}{mc}$, from which $E' = \frac{E\cdot mc^{2}}{E+mc^{2}}$.

Energy of recoil electron $E - E' = E - \frac{E.mc^2}{E+mc^2} = \frac{E^2 + E.mc^2 - E.mc^2}{E+mc^2} = \frac{E^2}{E+mc^2}$

Ans. 53: (a) and (b)

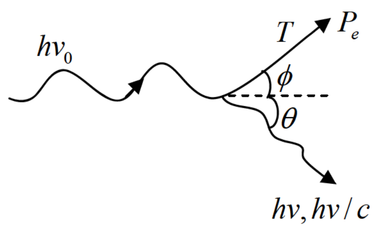
Ans. 54: (a), (c), (d)

Solution: (a) Let $E = h\nu$ be the energy of the scattered photon and $h\nu / c$ be its momentum

Energy conservation gives $h\nu_0 = h\nu T$ (1)

where T is the electron's kinetic energy.

Balancing momentum along and perpendicular to the direction of incidence



$$h\nu_0 / c = h\nu \cos\theta / c + P_e \cos\varphi \quad (2)$$

$$0 = h\nu \sin\theta / c + P_e \sin\varphi \quad (3)$$

where P_e is the electron momentum

Re-arranging (2) and (3) and squaring

$$P_e^2 \cos^2\varphi = \left(\frac{h\nu_0}{c} - \frac{h\nu\cos\theta}{c}\right)^2 \quad (4)$$

$$P_e^2 \sin^2\varphi = \left(\frac{h}{c}\nu\sin\theta\right)^2 \quad (5)$$

Add (4) and (5) and using the relativistic equation

$$c^2 P_e^2 = T^2 + 2Tmc^2 = h^2\left(\nu_0^2 + \nu^2 - 2\nu_0\nu\cos\theta\right) \quad (6)$$

Eliminating T between (1) and (2) and simplifying we get

$$E = E_0 / \left[1 + \alpha\left(1 - \cos\theta\right)\right] \quad (7)$$

(c) $T = E_0 - E = E_0 - E_0 / \left[1 + \alpha\left(1 - \cos\theta\right)\right] = T = \dfrac{\alpha E_0\left(1 - \cos\theta\right)}{1 + \alpha\left(1 - \cos\theta\right)}$

(8)

(d) From (2) and (3), we get

$$\cot\varphi = \left(\nu_0 - \nu\cos\theta\right) / \nu\sin\theta$$

With the aid of (7), and re-arranging we find $\tan\left(\theta / 2\right) = \left(1 + \alpha\right)\tan\varphi$ (9)

NAT (Numerical Answer Type)

Ans. 55: 6.24

Solution: $K_{\max} = \hbar\omega - W$

For given wave maximum kinetic energy is for highest ω so $\omega = 12.56\times10^{15}\ \text{sec}^{-1}$

$$\hbar\omega = \frac{6.6\times10^{-34}\,J\text{s}\times12.56\times10^{15}\,s^{-1}}{2\pi} = \frac{82.8\times10^{-19}\,J}{6.28\times1.6\times10^{-19}}eV = 8.24eV$$

$$K_{\max} = \hbar\omega - W \Rightarrow 8.24eV - 2eV = 6.24eV$$

Ans. 56: 4 eV

Solution: The kinetic energy of photoelectron is given as

$$KE = h\nu - W$$

where $\nu \rightarrow$ frequency of incident photon $W \rightarrow$ work function of the substance $h \rightarrow$ Planck constant

Now, $h\nu_0 = 8eV, KE = 2eV$

So, work function $=(8-2)eV$ $W = 6eV$

Now, if $h\nu_0 = 8eV \Rightarrow 1.25h\nu_0 = 10eV$

Thus, $h\nu = 10eV, W = 6eV$ $\Rightarrow$ Kinetic energy $= h\nu - W = 10eV - 6eV = 4eV$

Ans. 57: $1.775eV$

Solution: The maximum wavelength λ of a photon which can emit electron from a metal is known as threshold wavelength of the metal. The energy corresponding to this threshold wavelength is equal to work function of the metal. Hence, Work function = Threshold energy

$$\Rightarrow \quad = \frac{hc}{\lambda_0} = \frac{6.624\times10^{-34}\times3\times10^8}{7000\times10^{-10}} = \frac{12375}{7000}eV = 1.775eV$$

Ans. 58: 310

Solution: $\lambda_{\max} = \dfrac{hc}{\text{work function}}$

$$\therefore \lambda_{\max} = \frac{\left(6.63\times10^{-34}\right)\times\left(3\times10^8\right)}{4\times1.6\times10^{-19}} \quad \text{or } \lambda_{\max} = 310\times10^{-9}\,m$$

Ans. 59: 5.5

Solution: Energy of photon in $eV = \dfrac{12375}{\lambda\left(\overset{0}{A}\right)}$

$\therefore E_1 = \frac{12375}{4144} eV = 2.99 \ \ eV$, $E_2 = \frac{12375}{4972} eV = 2.49 eV$, $E_3 = \frac{12375}{6216} eV = 1.99 eV$

work function $= 2.3 eV$

First two wavelengths have energies great than work function of metallic surface. Hence they can eject photoelectrons.

Total intensity $= 3.6 \times 10^{-3} Wm^{-2}$

Number of wavelengths = 3

Intensity per wavelength $= \frac{3.6 \times 10^{-3}}{3} = 1.2 \times 10^{-3} \ \ Wm^{-2}$ Area $= 10^{-4} \ \ m^2$

$\therefore$ Energy falling per second $= \left(1.2 \times 10^{-3}\right) \times 10^{-4} = 1.2 \times 10^{-7} \ J/S$

$\therefore$ Let number of photons of first wavelength $= n_1$ and number of photons of second wavelength $= n_2$

$\therefore \ n_1 = \frac{1.2 \times 10^{-7}}{2.99 \times \left(1.6 \times 10^{-19}\right)} = 2.5 \times 10^{11}$ $\quad n_2 = \frac{1.2 \times 10^{-7}}{2.49 \times 1.6 \times 10^{-19}} = 3.0 \times 10^{11}$

$\therefore$ Total photons per second $= (2.5 + 3.0)10^{11} = 5.5 \times 10^{11}$ $\therefore$ Each capable photon ejects an electron

$\therefore$ Photoelectrons liberated in sec 5.5×10^{11}

Ans. 60: (a) 6.25, (b) 0, (c) 5

Solution: (a) Incident energy $E = 10.6 eV = 10.6 \times \left(1.6 \times 10^{-19}\right) J = 16.96 \times 10^{-19} J$

$$\frac{\text{Energy incident}}{\text{area} \times \text{time}} = 2 \ \ W/m^2$$

$$\therefore \frac{\text{Number of incident photons}}{\text{area} \times \text{time}} = \frac{2}{16.96 \times 10^{-19}} = 1.18 \times 10^{18}$$

$$\therefore \ \frac{\text{Incident photons}}{\text{time}} = \left(1.18 \times 10^{18}\right) \times \text{area}$$

$$= 1.18 \times 10^{18} \times \left(1.0 \times 10^{-4}\right) = 1.18 \times 10^{14}$$

$$\therefore \frac{\text{Number of photoelectrons}}{\text{time}} = \left(\frac{0.53}{100}\right) \times \left(1.18 \times 10^{14}\right) \Rightarrow n = 6.25 \times 10^{11} \qquad \text{(ii)}$$

Minimum energy = zero

Maximum energy $= E_1 - \text{work function}$

or $\quad K_{\max} = (10.6 - 5.6) eV$ or $K_{\max} = 5.0 eV$ (iii)

Ans. 61: 4.67

Solution: $k=\frac{hc}{\lambda}-\phi=\frac{1240\,eV\,nm}{450}-2eV=0.76eV=1.2\times10^{-19}J$

Momentum $p=\sqrt{2mk}=\sqrt{2\times\left(9.1\times10^{-31}\right)\times\left(1.2\times10^{-19}\right)}=4.67\times10^{-25}kg\ m/s$

$$=\frac{m_0}{\sqrt{1-0.8^2}}0.8^2c^2-\frac{m_0}{\sqrt{1-0.6^2}}0.6^2c^2=m_0\times0.62c^2$$

$$\Delta W=0.62c^2$$

Ans. 62: 4

Solution: Stopping potential is the negative potential which stops the emission of $(K.E)_{\max}$ electrons when applied.

$\therefore$ Stopping potential = 4 volt

Ans. 63: 6.15

Solution: The velocity of Solution: According to Einstein's equation, kinetic energy of the photoelectron

$$T=hv-hv_0 \qquad \text{(i)}$$

where v is the frequency of the incident photon and v_0 is the threshold frequency.

$$\lambda=2,536\times10^{-10}m=253.6nm$$

Corresponding energy $E=hv=1,241/253.6\,eV=4.894\,eV$

$$\lambda_0=3,250\times10^{-10}m=325nm,\ E=hv_0=1,241/325=3.818eV$$

$T=4.894-3.818=1.076eV$ hence kinetic energy is in electron volt so there is not any need to solve the problem by special relativity so

$$T=1/2mv^2=mc^2v^2/2c^2=0.511\times10^6\times v^2/2c^2=1.076$$

where $v=2.05\times10^{-3}c=6.15\times10^5ms^{-1}$

Ans. 64: 264

Solution: $hv_0=W=4.7\,eV$

$$\lambda_0=1,241/4.7=264\,nm$$

Ans. 65: 1.77

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

$\therefore$ Energy used $=6J$

Energy used to take out 1 photon $=\frac{hc}{\lambda}=\frac{6.63\times10^{-34}\times3\times10^8}{590\times10^{-9}}=\frac{6.633}{590}\times10^{-17}$

Number of photons used $=\dfrac{6}{\dfrac{6.63\times 3}{590}\times 10^{-17}}=\dfrac{6\times 590}{6.63\times 3}\times 10^{17}=176.9\times 10^{17}=1.77\times 10^{19}$

Ans. 66: 1.6

Solution: $\lambda = 350\,nm = 350\times 10^{-9}\,m$

$\phi = 1.9\,eV$

Max K.E. of electrons $=\dfrac{hc}{\lambda}-\phi=\dfrac{6.63\times 10^{-34}\times 3\times 10^{8}}{350\times 10^{-9}\times 1.6\times 10^{-19}}-1.9=1.65\,eV=1.6\,eV$

Ans. 67: 4.2

Solution: Energy of photoelectron

$\Rightarrow \dfrac{1}{2}mv^2=\dfrac{hc}{\lambda}-hv_0=\dfrac{4.14\times 10^{-15}\times 3\times 10^{8}}{4\times 10^{-7}}-2.5\,eV=0.605\,eV$

We know K.E. $=\dfrac{P^2}{2m}\Rightarrow P^2=2m\times \text{K.E.}$

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

$P=4.197\times 10^{-25}\,kg\text{-}m/s$

Ans. 68: 0.48

Solution 20: The electric field becomes 01.2×10^{45}

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

$hv=\phi_0+KE\Rightarrow hv-\phi_0=KE\Rightarrow KE=\dfrac{6.63\times 10^{-34}\times 0.6\times 10^{15}}{1.6\times 10^{-19}}-2=0.482\,eV=0.48\,eV$

Ans. 69: 3.93

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

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

The values of w are 9×10^{15} and 3×10^{15}

For largest K.E. $f_{\max}=\dfrac{w_{\max}}{2\pi}=\dfrac{9\times 10^{15}}{2\pi}$

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

$\Rightarrow \dfrac{6.63\times 10^{-34}\times 9\times 10^{15}}{2\pi\times 1.6\times 10^{-19}}-2=K.E.\Rightarrow K.E.=3.938\,eV=3.93\,eV$

Ans. 70: 1.9

Solution: $W_0 = h\nu - eV_0$

$$= \frac{5\times10^{-3}}{8\times10^{5}} - 1.6\times10^{-19}\times 2 \text{ (Given } V_0 = 2V\text{, No. of photons } = 8\times10^{15}\text{, Power } = 5\,mW\text{)}$$

$$= 6.25\times10^{-19} - 3.2\times10^{-19} = 3.05\times10^{-19}\,J = \frac{3.05\times10^{-19}}{1.6\times10^{-19}} = 1.906\,eV$$

Ans. 71: 1.6

Solution: The energy of each photon is

$$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\,Js)\times(3\times10^{8}\,ms^{-1})}{(632.8\times10^{-9}\,m)} = 3.14\times10^{-19}\,J$$

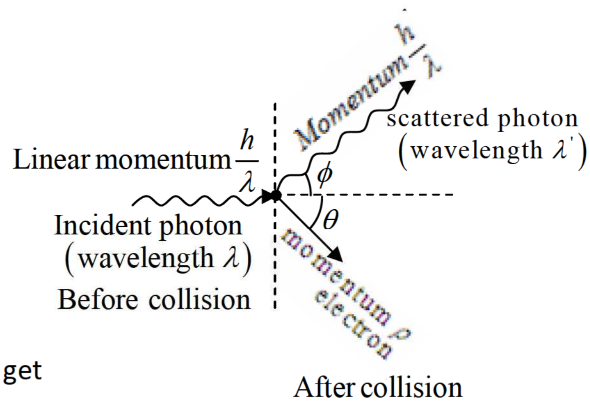
The energy of the laser emitted per second is $5\times10^{-3}\,J$. Thus, the number of photons emitted per second $= \frac{5\times10^{-3}\,J}{3.14\times10^{-19}\,J} = 1.6\times10^{16}$

Ans. 72: 2.4

Solution: Applying the conservation law of linear momentum along the horizontal and vertical component, we have

Horizontal $\frac{h}{\lambda} = \frac{h}{\lambda'}\cos\phi + p\cos\theta$ (i)

Vertical component $\frac{h}{\lambda'}\sin\phi = p\sin\theta$ (ii)



By equation $\lambda = \frac{h}{2mc}$; $\phi = 180^\circ$

Putting these values in equations (i) and (ii), we get

$$\Rightarrow \quad 2mc = \frac{h}{\lambda'}\cos180^\circ + p\cos\theta \quad \Rightarrow 2mc = p\cos\theta - \frac{h}{\lambda'} \qquad \text{(iii)}$$

by equation (ii) $\Rightarrow 0 = p\sin\theta$ By equations (iii) and (ii), we get $p = \frac{12mc}{5}$

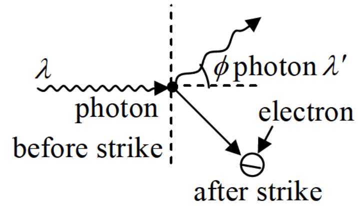
Ans. 73: 3.14

Solution: In Compton effect the range in wavelength is given as $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\phi)$ where $m_0 =$ electron rest mass, $\phi =$ scattering angle.

The maximum energy is transferred to electron, if $\Delta\lambda$ is maximum

i.e., $(1-\cos\phi)$ is maximum $\Rightarrow \phi = 180^\circ$ Thus, scattering angle is 180° or π.

Ans. 74: 2.4



Solution: When a photon of wavelength λ strike a stationary electron

The wavelength of the photon increases. This effect is known as Compton Effect.

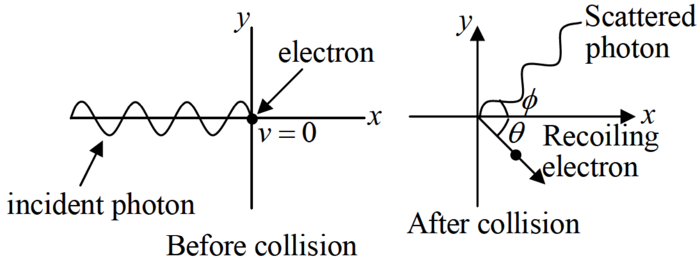
The change b wavelength is given as $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\phi)$

The change in wavelength does not depend on the energy of the incident photon.

Here, $\phi = 90^\circ$ $\quad \Delta\lambda = \frac{h}{m_0 c}\left(1-\cos 90^\circ\right) = \frac{h}{m_0 c} = 2.4\times 10^{-12} m$

Ans. 75: $0.5mc$

Solution:



The change in wavelength of scattered photon is given as

$\Delta\lambda = \frac{h}{m_0 c}(1-\cos\phi)$, where ϕ is scattered angle

As, $\quad \phi = 90^\circ$ (given), so $\Delta\lambda = \frac{h}{mc}\left(1-\cos 90^\circ\right) = \frac{h}{mc}(1-0) = \frac{h}{mc}$

Now, if λ is wavelength of incident photon,

then wavelength of photon $= \lambda + \frac{h}{mc}$ (i)

But moment of incident photon is mc (given), so $\lambda = \frac{h}{mc}$

so, wavelength of scattered photon $= \frac{h}{mc} + \frac{h}{mc}$ by equation (i)

$\Rightarrow \bar{\lambda} = \frac{2h}{mc}$ and corresponding momentum $= \frac{h}{\bar{\lambda}} = \frac{mc}{2}$

Momentum $= \frac{h}{2h/mc} = \frac{1}{2}mc$, $\qquad \therefore\ \Delta p = mc - \frac{mc}{2} = \frac{mc}{2}$

Ans. 76: 2.64

Solution: Fractional shift in frequency is

$$\Delta v / v_0 = \frac{1}{1+\dfrac{Mc^2}{2hv_0 \sin^2\left(\dfrac{\theta}{2}\right)}}$$

$$hv_0 = E_\gamma = 1,241/\lambda_{nm} = 1,241/0.1 = 12,410eV = 0.01241MeV$$

Put $\theta = 180^0$ and $MC^2 = 938.3\,MeV$ to obtain

$$\left(\Delta v / v_0\right)_{\max} = \frac{1}{1+\dfrac{938.3}{2\times 0.01241}} = 2.645\times 10^{-5}$$

Ans. 77: 0.03

Solution: The energy of scattered photon will be

$$hv = hv_0 / \left[1+\alpha\left(1-\cos\theta\right)\right]$$

For $hv_0 = 30keV, \alpha = hv_0 / mc^2 = 30/511 = 0.0587$ and $\theta = 30^0$

We find $hv = 29.766keV$

Therefore the kinetic energy of the electron

$$T = 30.0 - 29.766 = 0.234\,keV$$

The velocity $v = \left(2T/m\right)^{1/2} = c\left(2T/mc^2\right)^{1/2} = c\left(2\times 0.234/511\right)^{1/2} = 0.03c$

Ans. 78: 0.3

Solution: For Compton scattering, if λ_0 and λ are the wavelength of the incident photon and scattered photon,

$$\Delta\lambda = \lambda - \lambda_0 = \frac{h}{mc}\left(1-\cos\theta\right) = 0.02425\left(1-\cos 60^0\right)\overset{0}{\mathrm{A}} = 0.01212\,\overset{0}{\mathrm{A}}$$

Therefore, $\lambda_0 = \lambda - 0.01212 = 0.312 - 0.012 = 0.3\,\overset{0}{\mathrm{A}}$

Ans. 79: 0.48

Solution: The change in wavelength in Compton scattering is

$\Delta\lambda = \dfrac{h}{mc}\left(1-\cos\theta\right)$ where θ is the scattering angle. $\Delta\lambda$ will be maximum for $\theta = 180^0$ in which case $\Delta\lambda\left(\max\right) = 2h/mc = 0.48A^0$