Thermal Radiation

→ In Na Vapour lamp

→ thermal radiation is blackbody radiation
→ Giving heat to System and getting radiation
→ thermal equilibrium.

→ Newton – Particle
Einstein – " (photoelectric effect)
Compton – particles
Huggins – Waves (interference
Maxwell – EM theory hence waves.
de Brogli – Matter waves.

An ideal black body has 2 notable frequencies

1) Ideal emitter: at every frequency it emits as much or more thermal energy as any either body at the Same temperature.

2) It is difuse emitter, the energy is radiated istropically independent of direction.

planck's law :- describes the Spectral density of EM radiation emited by a black body at a given temperature T.

B_ν → amount of energy it emits at different radiation frequencies.
It is the power emitted ~~by~~ per unit area of the body per Unit Solid angle of emission per unit frequency.

⇒ at a particular temperature 'T' is given by.

Power emitted per unit area →

$$B_\nu(\lambda,T) = \frac{2h\lambda^3}{c^2} \times \frac{1}{e^{\frac{h\lambda}{K_B T}} - 1}$$

K_B = Boltzmann Constant
c = speed of light
h = planck's Constant.

= h

Rayligh – Jeans law :- (couldn't prove conservatn energy)
Wein's displacement law :- } BBR.
max planck's law

lower frequecies (longer λ)
↓
Rayleigh – Jeans law
higher frequencies (smaller wavelength)
↓
Wein's displacement law.

$$B_\nu(\nu,T) = \frac{2h\nu^3}{c^2} \times \frac{1}{e^{(h\nu/k_BT)} - 1}$$

$$B_\lambda(\lambda,T) = \frac{2hc^2}{\lambda^5} \times \frac{1}{e^{(hc/\lambda k_BT)} - 1}$$

$$B_\lambda(\lambda,T) = \frac{2Ck_BT}{\lambda^4}$$

B_λ = Spectral radiance.

$$B_\nu(\nu,T) = \frac{2\nu^2 k_BT}{c^2}$$ (larger λ & lower ν) → working for

<u>Ultraviolet Catashophe</u> (Rayleigh – Jeans ~~law~~ catashophe).

$\uparrow E = hc/\lambda\downarrow$, $E \to \infty$ so it is breaking the law of conservatn. (ϕ).

modificatn

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \times \frac{1}{e^{hc/\lambda k_BT} - 1}$$

$$e^x = 1 + \frac{x^2}{2!} + \ldots$$

$$e^{hc/\lambda k_BT} = 1 + \frac{hc}{\lambda k_BT}$$

valid for larger λ

$$\boxed{B_\nu(T) = \frac{2h\nu^3}{c^2} \times \frac{1}{e^{h\nu/k_BT} - 1}}$$

$$\frac{1}{e^{hc/\lambda k_BT} - 1} = \frac{1}{hc/\lambda k_BT} = \frac{\lambda k_BT}{hc}$$

$$= \frac{2h\nu^3}{c^2} \times \frac{k_BT}{h\nu} =$$

$$B_\lambda(T) = \frac{2ck_BT}{\lambda^4}$$

$$= \frac{2\nu^2 k_BT}{c^2}$$

Rayleigh

<u>Wein's displacement law</u> :-

$$\lambda_{max} = \frac{b}{T}$$

b – Proportionality constant.
T = temperature.
2.8977 × 10^{-3} m-k.

DANDAPANI

Stopping potential -

E ↑ It will reach other end.

electric dipole approximation

ϕ = work fun^n = $h\nu_0$.

Current ∝ I intensity
Produced by photon

KE ∝ Intensity

→ bcz of high KE photoe⁻ move to -ve polarity ~~for~~ ~~high~~ & cross the Coloumbic force / attract

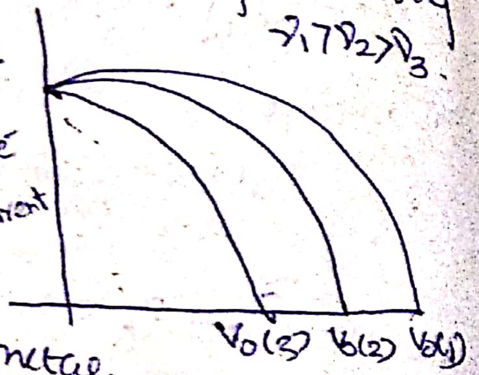
larger KE large distance.

→ A bright light → more photon → more photoe⁻ than dim light

→ Na, no time interval observed in expt

→ high frequency of light → more the energy of photoe⁻.

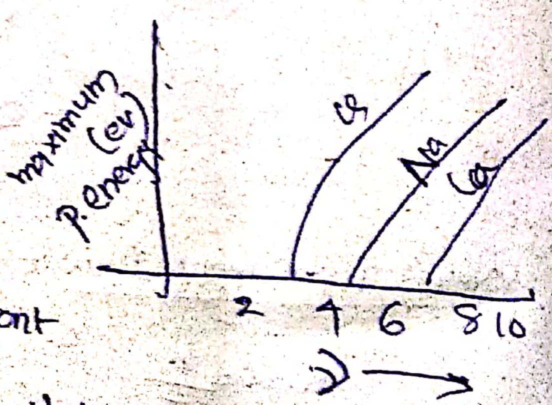
→ Blue light → fast e⁻ than red.



→ Characteristic frequency of a metal

no of e⁻ will be emitted ⇒ ν_0

Quantum theory of light



→ light is not spread as wavefront

↳ Small packets of energy called photons.

→ energy (the whole) concentrated in photons.

→ higher the frequency higher energy

→ $\phi = h\nu$.

$h\nu$ = photon energy.

Radiation thermometer. → helps us to measure thermal energy emitted by a Source.

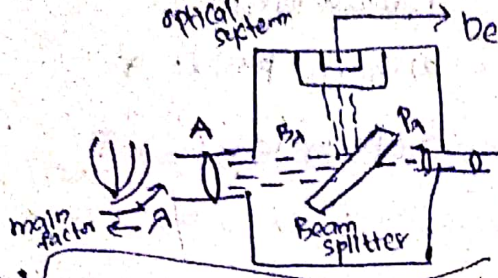
→ using planck's law,

Iron rod → Red → orange → White.

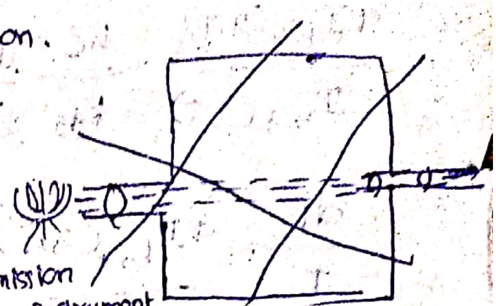
↓

Very longest visible λ → Shortest λ

temperature measurements using radiation.



P_λ = electrical transmission of the medium b/w instrument & target.



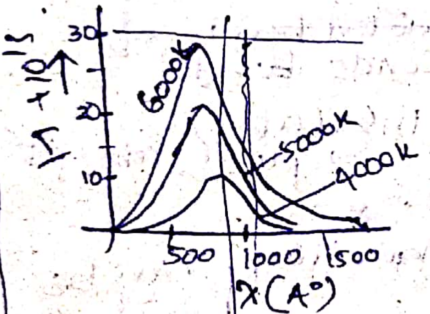
Collect radiation as electrical

BBR → spherical shape → radiation from blackbody $f(r,\theta,\phi)$.

Intensity coming from the BB is spherical & use spherical harmonics to solve that ~~for~~ $I_b = f(r,\theta,\phi)$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \times \frac{1}{e^{hc/\lambda k_B T} - 1}$$

→ planck's law of radiation from black body fixed temp.



area under the curve shows rapidly with the T

Basic idea for radiation thermometer.

1) 10.6 μm at 0°c and 1.5 μm at 2000°c.
2) Visible region (some cases it may lay middle infrared region)
3) Output signal → usually electrical.

$$R_\lambda = \frac{dV}{dE_\lambda}$$

dV → output in response to the radient flux dE_λ

$dV = R_\lambda \, dE_\lambda$

$dV = R_\lambda I_\lambda A B_\lambda P_\lambda \, d\lambda$

$$V = \int_0^\infty R_\lambda I_\lambda A B_\lambda P_\lambda$$ → radiometer measurement equation.

$$I_{b,\lambda}(\lambda,T) = \frac{2hc^2}{\lambda^5} \times \frac{1}{e^{hc/\lambda k_B T} - 1}$$

Differentiate w.r.t. T.

$$\frac{dI_{b,\lambda}(\lambda,T)}{dT} = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{\cancel{e^{hc/\lambda k_BT}-1}} \frac{(e^{hc/\lambda k_BT})^2 \times e^{hc/\lambda k_BT}}{(e^{hc/\lambda k_BT}-1)} \times \frac{hc}{\lambda k_BT}$$

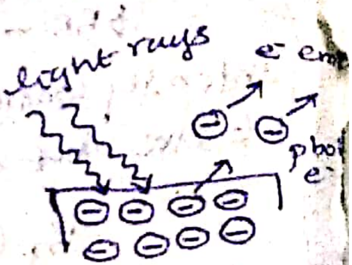
$$dI_{b,\lambda}(\lambda,T) = \frac{2hc^2}{\lambda^6 T^2} \times \frac{1}{e^{hc/\lambda k_BT}-1} \, dT$$

$$\frac{dI_{b,\lambda}(\lambda,T)}{I_{b,\lambda}(\lambda,T)} = \frac{hc}{k_B} \frac{dT}{\lambda T^2}$$

$$\therefore \frac{dT}{T} = \frac{dI_{b,\lambda}(\lambda,T)}{I_b(\lambda,T)} \times \frac{\lambda T}{hc/k_B}$$

What we obtain from Radiation thermometer.
1, wavelength.
2) Shorter possible λ
3) Wavelength vs T.

photoelectric effect

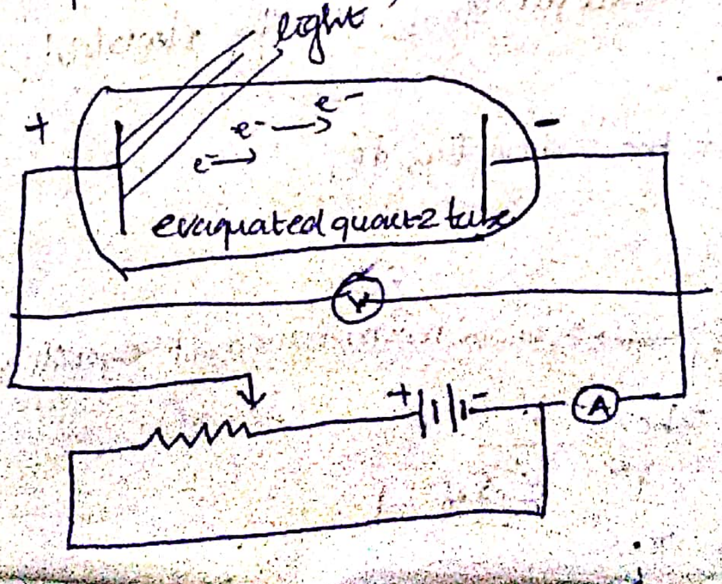


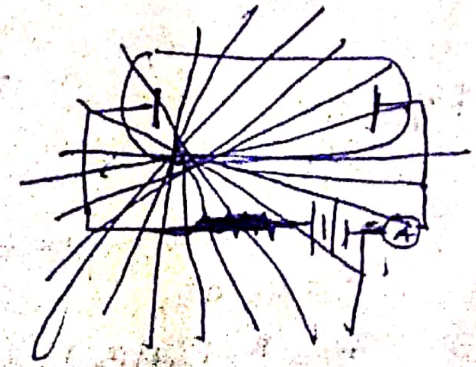
Hamiltonian, $H = H_0 + H'$

Interband transmission, In Semiconductors
when light of ~~aquaequate~~ adequate amt energy is hits on e^- in VB will enter to ~~excited band~~ condn band. - It Crosses band (semiconductors & insulators) → optical absorptn.

Intraband transmission - metals.
VB & CB is crossed & optical conductivity can be measured

Experimental Setup -





ϕ

Cs — 1.9 eV
K = 2.2 eV
Na = 2.3 eV
Li = 2.5 eV.

$h\nu = KE_{max} + \phi_0$.

$h\nu$ = photon energy.

$h\nu = \phi_0$ → min! energy required for an e^- to leave the metal

KE_{max} = maximum photoel energy.

$h\nu = KE_{max} + \phi_0$.

$KE = h(\nu - \nu_0)$

1. What are the energy & momentum of a photon of a red light of wavelength 650nm?
What is the wavelength of a photon of energy 240 eV?

1) $\therefore E = h\nu = \frac{hc}{\lambda}$

$= \frac{6.6\times10^{-34} \times 3\times10^{8}}{650\times10^{-9}}$

$1J = 1.6\times10^{-19} eV$
$1eV = 1.6\times10^{-19} J$
$1J = \frac{1}{1.6\times10^{-19}}$

$= 3.04\times10^{-19} J = \cancel{4.8\times10^{-38}} eV$

$= 1.9 eV$

$P = E/c$
$= 6.3\times10^{-7}$.

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

$= P = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{650\times10^{-9}}$

$= 1.01\times10^{-27}$

2) $E = 240 eV = \frac{hc}{\lambda}$

$\frac{1.6\times10^{-19} \times 240}{1.6\times10^{-19}} = \frac{6.6\times10^{-34} \times 3\times10^{8}}{\lambda}$

$1eV = \frac{1}{1.6\times10^{-19}}$
$\times 240$.

$\lambda =$

$240 \times 1.6\times10^{-19} =$

$\lambda = \frac{6.6\times10^{-34} \times 3\times10^{8} \times 1.6\times10^{-19}}{240}$

$= \cancel{1.32\times10^{-46}} m$

$240 \times 1.6 \times 10^{-19} = hc/\lambda$

$E = hc$

$= 1240eV$

d

$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{240 \times 1.6 \times 10^{-19}}$

d

$= 5.15 \times 10^{-9} m$

$= 515 nm$

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

240eV.

2) The work function of the ~~Constant~~ tungsten metal 4.52eV

a) What is the cutoff wavelength λc for tungsten.

b) What is the maximum kinetic energy of the e when radiation of wavelength 198 nm is used.

c) What is the stopping potential in this case.

$h\nu_0 = \phi_0 = 4.52eV$

a) $h\nu_0 = 4.52eV$

$hc/\lambda_0 = 4.52eV \times 1.6 \times 10^{-19}$

$\lambda_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{4.52 \times 1.6 \times 10^{-19}} = 2.75 \times 10^{-7}$

$= 275 nm.$

b) $KE = h\nu - h\nu_0$

$= h\ \cancel{4.52}$

$1J = 1.6$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 198 \times 10^{-9}} - 4.52 \times \cancel{1.6 \times 10^{-19}}$

$= 6.27 - 4.5$

$\cancel{1 \times 10^{-19}}$

$= 1.75eV$

c) $KE = eV$

$$V = \frac{1.75\ \cancel{eV}}{\cancel{1.6\times10^{-19}}\ \cancel{e}}$$

$$= -1.75eV$$

3) the wavelength of the photoelectric threshold fo Ag. is $3.250\times10^{-10}m$.

Determine the velocity of the e^- ejected from Ag surface By ~~alkaline~~ UV light of λ ~~2.56~~ $2.536\times10^{-10}m$.

$$KE = h(\nu - \nu_0)$$

$$= h\left(\frac{c}{2.536\times10^{-10}} - \frac{c}{3.25\times10^{-10}}\right)$$

$$= 6.6\times10^{-34}\left(\frac{3\times10^{8}}{10^{-10}} \times \frac{1}{2.536} - \frac{3\times10^{8}}{3.25\times10^{-10}}\right)$$

$$= 6.6\times10^{-34}\left(1.18\times10^{18} - 0.92\times10^{18}\right)$$

$$= \cancel{3.696\times10^{18}\times10^{-34}}$$

$$= \cancel{3.69\times10^{-16}} \quad 1.716\times10^{18}\times10^{-34}$$

$$= 1.716\times10^{-16} J$$

~~1 J = 1.6×10^-19~~
~~1 eV~~

$$= \cancel{2.74\times10^{-35}} eV$$

2-7

$$= 1.0725\ eV$$

$$\frac{1}{2}mv^2 = 1.0725$$

$$v = \sqrt{\frac{2\times1.0725}{1.6\times10^{-19}}}$$

$$= \cancel{3.6\times10^{9}} \quad 1.5\times10^{15} m/s.$$

1. An UV light of wavelength 350nm and intensity 1.00 W/m²
is directed at a potassium surface

a) Find the maximum kinetic energy of the following
Photoelectron .

b) If 0.5% of incident photons produce photoelectrons,
how many are emitted per second if the potassium
Surface has an area 1.00cm²? $\times 10^{-4}$

a) $E = hc/\lambda = \frac{6.6\times10^{-34} \times 3\times10^{8}}{350\times10^{-9}}$

$1 eV = 1.6\times10^{-19} J$

$1 J = 1$

$KE = h\nu - h\nu_0$

$= 3.54 - 2.2$

$= 1.34$ eV

b) $n \times 1.34 \times 1.6\times10^{-19} =$

$n_p = \frac{E/t}{E_p} = \frac{1\times10^{-4}}{1.34\times1.6\times10^{-19}}$

$P = E/t$

$= 4.6\times10^{14}$

$= 2.3\times10^{12}$

$m^2c^2c^4$

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

$= \frac{1}{2}mc^2$

$KE + PE$ KE $= \frac{1}{2}mc^2$

m^2c^4

p^2c^2

Scanned by CamScanner

2, Show that photoelectric effect cannot take place with a free electron.

$$E = h\nu \quad -①$$

$$p = \frac{h\nu}{c} \quad -②$$

$$E^2 - p^2c^2 = \cancel{E^2} + 2m\nu\, E mc^2$$

$$\cancel{2h\nu mc^2 = 0}$$

$$E^2 = 2E mc^2$$

$$E \cancel{m} mc^2 = 0$$

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

$$E = h\nu = mc^2$$

$$h\nu = mc^2$$

3) A photon is incident upon a hydrogen atom ejected an e^- of KE 10.7 eV. It is ejected e^- is in first excited state.

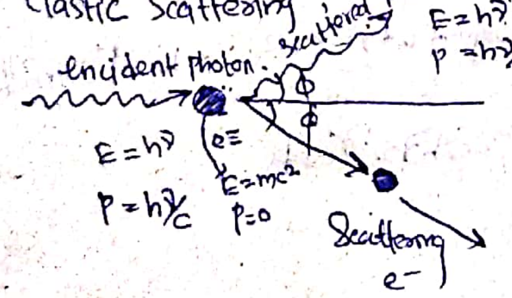
~~Calculated energy~~ how much of the photon.

Calculate the energy of photon how much KE should be imparted to an e^- in ground state,

Compton effect (light matter interaction).

Inelastic Scattering → (KE not conserved) → Arthur Holly Compton discovered

Elastic Scattering

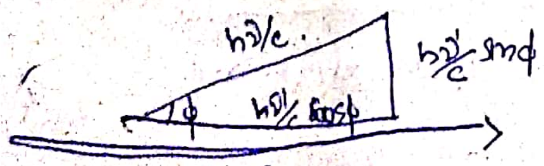


Scattering of e^-.

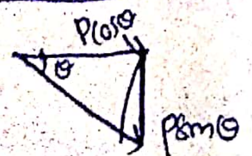
Energy & momentum Conservation.

ν = Initial photon.

$\nu' \Rightarrow$ lower than the initial.



loss in photon energy = Gain in e^- energy.



Vector diagram of the momenta & their Components of incident & scattered photon.

d

$h\nu - h\nu' = KE$ —— ①

d

$E = Pc.$

$P = E/c = h\nu/c$ (Initial photon momentum).

$h\nu'/c$ (Scattering photon momentum).

Initial momentum = Final momentum. (~~+r direction~~)

$h\nu/c + 0 = h\nu'/c \cos\phi + P\cos\theta$ —— ④ ×c

Initial momentum = Final momentum (⊥r direction).

$0 = h\nu'/c \sin\phi - P\sin\theta$ —— (5)

ϕ is the angle b/w direction of the initial & scattered photon

$\theta \to$ angle b/w the direction of initial photon & recoiled e-

$Pc\cos\theta = h\nu - h\nu'\cos\phi.$

$Pc\sin\theta = h\nu'\sin\phi.$

$$p^2c^2 = (h\nu - h\nu'\cos\phi)^2 + h^2\nu'^2\sin^2\phi$$

$$= h^2\nu^2 - 2h^2\nu\nu'\cos\phi + h^2\nu'^2\cos^2\phi + h^2\nu'^2\sin^2\phi$$

$$= h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu'\cos\phi$$

$E = KE + mc^2$

$$E = \sqrt{m^2c^4 + p^2c^2}$$

$$= \sqrt{m^2c^4 + h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu'\cos\phi}.$$

We know

$$(KE + mc^2)^2 = m^2c^4 + p^2c^2$$

$$p^2c^2 = KE^2 + 2mc^2 KE$$

$$KE = h\nu - h\nu'$$

$p^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu') + (h\nu')^2 + 2mc^2(h\nu - h\nu')$

Sub p^2c^2 in (6).

$$2mc^2(h\nu - h\nu') = 2(h\nu)(h\nu')(1-\cos\phi) \quad \text{— (7)}.$$

$\div$ by $2h^2c^2$.

$$\frac{mc}{h}\left(\frac{\nu}{c} - \frac{\nu'}{c}\right) = \frac{\nu}{c}\frac{\nu'}{c}(1-\cos\phi).$$

$\nu/c = 1/\lambda \quad \nu'/c = 1/\lambda'$

$$\frac{mc}{h}\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = \frac{1-\cos\phi}{\lambda\lambda'}$$

$\lambda - \lambda' = \frac{h}{mc}(1-\cos\phi)$.

$\Downarrow$

Compton effect

λ = Initial wave length

λ' = Scattering "

h = planck const.

m = mass of e^-

c = speed of light.

θ = Scattered angle.

Compton Scattering.

$$E = \sqrt{m^2c^4 + p^2c^2}$$

Mass & energy

W' on a object by constant force F', s'.

$W = Fs.$

$KE = F \cdot S.$

F is not constant.

$$KE = \int_0^S F \cdot ds$$

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

$p = \gamma mv$ Relativistic momentum.

$$F = \frac{dp}{dt} = \frac{d}{dt}(\gamma mv) \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

$$KE = \int \frac{d}{dt}(\gamma mv)\, ds = \int_0^v v\, d(\gamma mv) = \int_0^v v\, d\left(\frac{mv}{\sqrt{1-v^2/c^2}}\right)$$

$$\frac{ds}{dt} = v.$$

Integrating by parts.

$$KE = \frac{mv^2}{\sqrt{1-v^2/c^2}} - m\int_0^v \frac{v\,dv}{\sqrt{1-v^2/c^2}}$$

$$= \frac{mv^2}{\sqrt{1-v^2/c^2}} + \left[mc^2\sqrt{1-v^2/c^2}\right]_0^v$$

$$= \frac{mc^2}{\sqrt{1-v^2/c^2}} - mc^2$$

$$KE = \gamma mc^2 - mc^2 = (\gamma - 1)mc^2$$

total energy

$$E = mc^2 + KE$$

$$\Downarrow$$

$$E_0$$

$$E = E_0 + KE$$

$$\Downarrow$$

$mc^2 \rightarrow$ Rest energy.

$$E = \gamma mc^2 = \frac{mc^2}{\sqrt{1-v^2/c^2}}$$

<u>Energy & momentum,</u>

$$E = pc$$

TE, E_0 and momentum of a particle

$$E = \frac{mc^2}{\sqrt{1-v^2/c^2}} \quad \& \quad p = \frac{mv}{\sqrt{1-v^2/c^2}}$$

$$E^2 = \frac{m^2c^4}{1-v^2/c^2} \qquad p^2c^2 = \frac{m^2v^2c^2}{1-v^2/c^2}$$

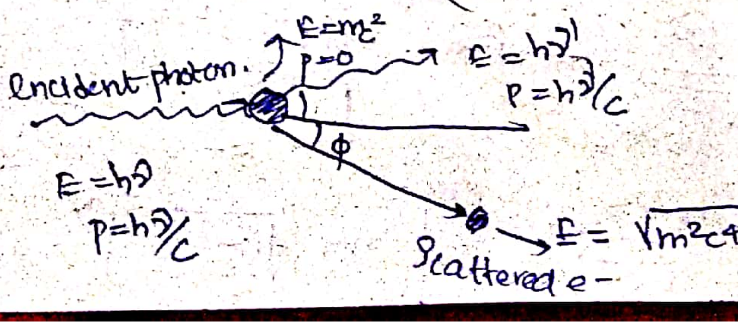
$$E^2 - p^2c^2 = \frac{m^2c^4 - m^2v^2c^2}{1-v^2/c^2} = \frac{m^2c^4\cancel{(1-v^2/c^2)}}{\cancel{1-v^2/c^2}}$$

$$= (mc^2)^2$$

Hence energy of momentum

$$E^2 = (mc^2)^2 + p^2c^2$$

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\theta + p\cos\phi$$



Initial momentum =

Final momentum for the +r directn.

$0 = \frac{h\nu'}{c}\sin\phi - P\sin\theta$ $\phi \Rightarrow$ Angle b/w Initial & Scattered photon.

θ = Initial photon & e^-.

$Pc\cos\theta = h\nu - h\nu'\cos\phi$

$Pc\sin\theta = h\nu'\sin\phi$

$P^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu')\cos\phi + (h\nu')^2$

$E = KE + Mc^2$

$E = \sqrt{m^2c^4 + p^2c^2}$

$KE = h\nu - h\nu'$

$P^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu') + (h\nu')^2 + 2mc^2(h\nu - h\nu')$

$2Mc^2(h\nu - h\nu') = 2(h\nu)(h\nu')(1-\cos\phi)$.

$\div$ by $2h^2c^2$

$$\frac{mc}{h}\left(\frac{\nu}{c} - \frac{\nu'}{c}\right) = \frac{\nu}{c}\cdot\frac{\nu'}{c}(1-\cos\phi).$$

λ = Initial wavelength.

λ' = Scattering wavelength.

h = planck's const

m = mass of e^- object.

c = speed of light

ϕ = Scattering angle

Since $\frac{\nu}{c} = \frac{1}{\lambda}$ & $\frac{\nu'}{c} = \frac{1}{\lambda'}$

$$\frac{mc}{h}\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = \frac{1-\cos\phi}{\lambda\lambda'}$$

Compton effect

$$\boxed{\lambda' - \lambda = \frac{h}{mc}(1-\cos\phi)} \Rightarrow \text{Compton effect}$$

$$\lambda_c = \frac{h}{mc} \Rightarrow \text{Compton wavelength.}$$

$$\lambda' - \lambda = \lambda_c(1-\cos\phi).$$

$\lambda = 400\,nm$.

$\theta = 180°$

$E = ?$

$\lambda_e = \frac{h}{m_e c}$

$\Delta\lambda = 2.43(1-\cos\theta)$

$\Delta\lambda = 4.86$

$\Delta\lambda = 2\lambda_e$.

$\lambda' - \lambda = 4.86$

$\Delta E = \frac{hc}{\lambda} - \frac{hc}{\lambda'}$

$\lambda' = 4.86 + 400$

$= 404.86$

$\Delta E = hc\left(\frac{1}{400} - \frac{1}{404.86}\right) = 6.6\times10^{-34}\times3\times10^{8}\left(\frac{4.86}{\ldots}\right) = 5.9\times10^{-30}$