3/1/2019

Thermal Radiation

Radiation due to heat

Irrespective of temperature, there will be electromagnetic radiation depends on the object.

→ Eg: Em from Na will e⁻ excite goes from one energy level to higher energy level. [Night time animals eyes glow - em radiation]

→ Perfect black body → Thermal equilibrium.

→ Classical mechanics inadequate to say that, equilibrium of a system at a constant temp

Newton – particle

Einstein – Photoelectric effect(γ)

Compton – (γ scattering) particles

Huygens → waves (interference)

Maxwell → EM theory hence waves.

Louis de Broglie → Matter waves.

at low temperature, the peak for Intensity will be low.

Ideal black body

→ Ideal emitter:

1) at every frequency, it emits as much or more thermal energy as any other body at the same temperature.

2) → It is diffuse emitter. the energy is radiated ~~is~~ isotropically emit em radiation, independent of direction.

Pb → high radiation

(as along the distance, feels the radiation)

Plank's law

In vacuum $I \propto \lambda$

If not vacuum $I \propto (\nu)$

→ Describe the spectral density of electromagnetic radiation emitted by a black body at a given temperature 'T'.

we can't use classical mechanics for ~~calculation~~ finding E of system (duality of matter)

→ B → amount of energy

It emits at different radiation frequencies.

→ It is the power emitted per unit area of the body, per unit solid angle of emission, per unit frequency.

→ ν at temperature 'T' is given by

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

$$= \frac{1}{e^{h\nu/k_BT} - 1}$$

k_B – Boltzman.

h – planck's constant

C – speed of light

→ when we keep a system in vaccum (Isolated). there will be radiation.

9/01/2019

What is the need of Black body radiation.

1) Rayleigh – Jeans law

2) Wein's displacement law.

Black body

↓

Emits electromagnetic radiation.

B_ν → Power emitted per unit area per unit

$B_\nu(\nu, T)$

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

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

lower vies (longer λ)

↓

Rayleigh Jean law

higher vies (smaller λ)

↓

Wein's Approximation

Rayleigh Jeans law

↓ For large λ,

↓ It wouldn't prove the conservation of energy.

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

Can't use for ↓ λ, ...

B_λ — Spectral radiation

c — Speed of light

K_B — Boltzmann constant

$I \propto \frac{1}{\lambda^4}$

T — Temp

$$B_\nu(T) = \frac{2\nu^2 K_B T}{c^2}$$

This law is for large wavelengths (lower ν).

(i) Ultraviolet Catastrophe.

$\Downarrow$

(i) Rayleigh Jeans (Catastrophe)

$\rightarrow$ classical physics.

Both have problem with lower λ, $\uparrow \nu$.

Catastrophe — ?

" Black body emits radiation at all frequency range."

It can't hold to amount of energy (Law of conservation of energy is not holding).

$\lambda \rightarrow 0$, $E \rightarrow \infty (\nu \rightarrow \infty)$.

Rayleigh Jeans

$\lambda = c/\nu$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda K_B T}} - 1}$$

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

$$e^{\frac{hc}{\lambda K_B T}} = 1 + \frac{hc}{\lambda K_B T}.$$

$$\frac{1}{e^{\frac{hc}{\lambda K_B T}} - 1} = \frac{1}{\frac{hc}{\lambda K_B T}} = \frac{\lambda K_B T}{hc}$$

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

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

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

$2h\nu^3$

$$= \frac{2h\nu^3}{c^2} \cdot \frac{K_B T}{h\nu}$$

$\frac{2h\nu^3}{c^2} \cdot \frac{\lambda K_B T}{hc}$

$$B_\nu(T) = \frac{2\nu^2 K_B T}{c^2}$$

$\frac{2h\nu^3 \lambda K_B T}{c^2 hc}$

Wein's displacement law.

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

b — Proportionality Constant

$\frac{2h\nu^3}{c^2} \cdot \frac{K_B T}{h\nu}$

B.B.R curve at each peak inversely proportional to T.

$b = 2.8977729 \times 10^{-3}$ m-K

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

photoelectric effect.

$\lambda \propto \nu$.

$\lambda \propto \frac{1}{T}$.

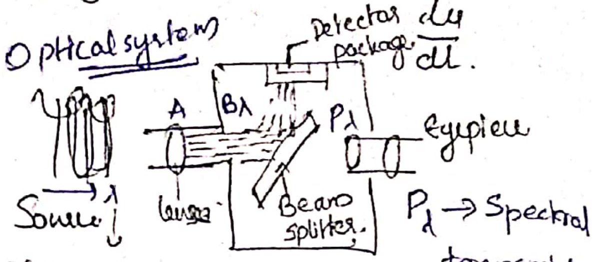
RMILUXGr

$\lambda \rightarrow \nu$

$\Delta\lambda$ is there while $\uparrow T$.

So displacement $\Delta\lambda$.

→ Temperature measurements using Radiation.



$P_\lambda \rightarrow$ Spectral transmission of the medium

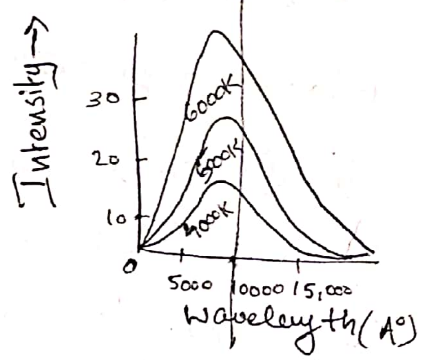
(Main factor)

+ Black body emits radiation all around the body. (Spherical in shape.)

→ $I_b = f(r, \theta, \phi)$ → spherical co-ordinates.

Use of planck's law for this

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



Area under the curve grows rapidly with temperature (Area ↑, T↑)

→ Basic ideas for radiation thermometer (c

1) 10.6 μm at 0°c and 1.3μm at 2000°c.

2) Visible region.

10/1/2019

Radiation thermometer (How it works)

1. Temperature Sensor
2. Converting the same in numbers.

(The above 2 laws, Rayleigh's and wein's we can apply for radiation thermometer.)

In Red hot → Red Orange (very longer) (visible λ)
↓
White (shortest wavelength.

→ Device which measure the thermal energy emitted by a Source

→ Using Planck's law. (to get the temp corresponding to the energy)

Some times near ~~and~~ and of middle infrared region

Use temperature to produce

3) Output signal

(usually it will be electrical)

between instrument and target

R_λ (Response) after going through eyepiece, it independent only on λ.

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

(Initial λ was original wavelength)

$dV \rightarrow$ output in response to the radiant flux dE_λ'

$$dV = R_\lambda . dE_\lambda$$

$$dV = R_\lambda I_\lambda AB_\lambda P_\lambda d\lambda$$

$$\boxed{V = \int_0^\infty R_\lambda I_\lambda AB_\lambda P_\lambda}$$

Radiometer measurement equations

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

Differentiate w.r.to T.

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

Differentiate w.r.to T.

$$\frac{dI_{b,\lambda}}{dT} = \frac{2hc^2}{\lambda^5} \cdot \frac{d}{dT}\left(\frac{1}{e^{\frac{hc}{\lambda K_B T}} - 1}\right)$$

$$= \frac{2hc^2}{\lambda^5}\left[\frac{1 \times \left(e^{\frac{hc}{\lambda K_B T}}\right) \times \frac{hc}{\lambda K_B T^2}}{\left(e^{hc/\lambda K_B T} - 1\right)^2}\right]$$

$$= \frac{2hc^2}{\lambda^5}\left[\frac{\frac{-hc}{\lambda K_B T^2} \times e^{\frac{hc}{\lambda K_B T}}}{\left(e^{hc/\lambda K_B T} - 1\right)^2}\right]$$

$$= \frac{-2h^2c^3}{\lambda^6 K_B T^2} \cdot \frac{1}{\left(e^{\frac{hc}{\lambda K_B T}} - 1\right)} \cdot \frac{e^{\frac{hc}{\lambda K_B T}}}{\left(e^{\frac{hc}{\lambda K_B T}} - 1\right)}$$

$$= \frac{-2h^2c^3}{\lambda^6 K_B T^2} \cdot \frac{1}{\left(e^{\frac{hc}{\lambda K_B T}} - 1\right)} \left(\frac{1}{1 - e^{\frac{-hc}{\lambda K_B T}}}\right)$$

$$\frac{dI_{b,\lambda}}{I_{b,\lambda}} = \frac{hc}{K_B T^2 \lambda}\left('' \right)$$

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

$$\boxed{\frac{dT}{T} = \frac{d I_{b,\lambda}(\lambda,T)}{I_{b,\lambda}(\lambda,T)} \times \frac{\lambda T}{\frac{hc}{k_B}}}$$

error in the above part

1) $\frac{\text{Vis}}{\text{Wavelength}}$

2) Shortest possible wavelength.

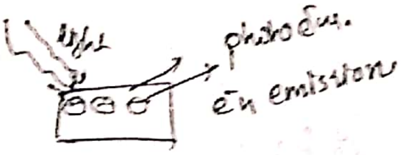
3) Wavelength vs. temp

4)

16/1/2019 → Franklin-Hertz experiment

→ (before photoelectric effect)

→ Photoelectric effect



Why semiconductors, we can't use in this experiment.

Optical expt → photon ($h\nu$)

$$H = H_0 + H'$$

→ Optical phenomenon

→ Even in semiconductors

→ Inter band transition
(e⁻s can cross the barrier)
In semiconductors and insulators.
Where in metals, there is no band gap, e⁻s can ~~switch~~ move without having a barrier.

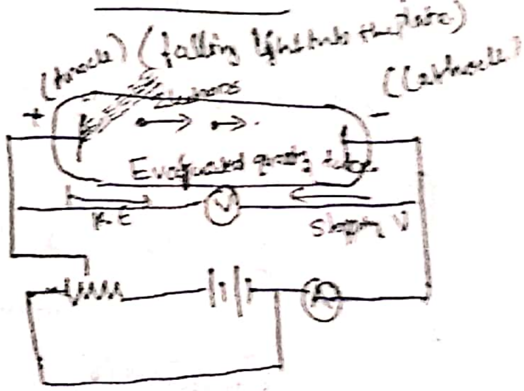
→ Intraband transition (metals.)

CSIR

In semiconductors and in insulators, optical absorption,

In metal, optical conductivity (only in metals).

Experimental set up.



→ All e⁻s emitted from the Anode won't ~~go~~ reach the Cathode

→ e⁻s already negatively charged how it goes to cathode. (−ve charge).

→ Threshold energy (work function)
for the metal plate to emit
ems — ($h\nu_0$). (lossing its K.E)

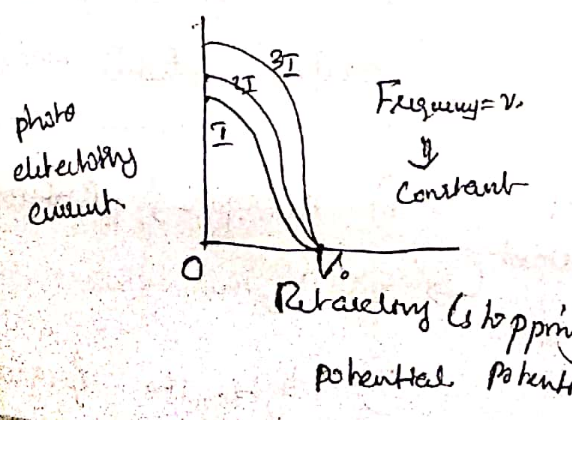
stopping potential ;
→ there is a potential
difference between anode
and cathode (not constant
potential).

→ Frequency should be high
for moving ems from anode to
cathode (E↑). So there is
a probability for em to move

→ stopping potential.
↓
Potential difference
minimum for to move the ems

→ If Intensity of light is less, the
propability of ems to move
is very less.

→ Electric dipole approximation
(perturbation to the system.)
↓
It is just to disturb ems,
by giving high intensive light.



Current
→ produced ∝ Intensity,
by photoelectron
→ (by classical physics).

→ ems take the energy till
& crossing the binding energy
before moving
↳ workfunction (for emitting)
$\phi = h\nu_0$..

→ E ∝ Intensity of the
radiation.

→ time difference will be
there between two
ems. Some ems lags
~~...~~ time and
collision happens
→ K.E

17/1/2017 photoelectric effect

Still with energy is larger
enough, ems will comes out
and use the energy to
travel to other well
eventhough other well
is -vely charged

(same for all)

→ If the energy is not sufficient to travel, the e⁻s gets collapsed

→ Work function will be different for different metals

→ No time interval observed in expt. (There is a minute time (difference) interval for e⁻s to come out).

→ $10^{-6} W/m^2$

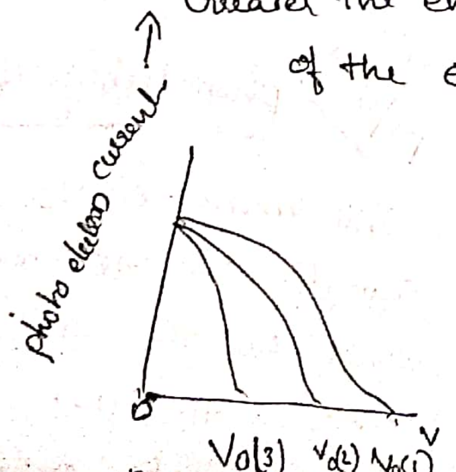
→ A layer of sodium 1 atom thick $1m^2$ → 10^{-25} W.

→ A bright light → more photoelectrons will come than dim light

→ More intense light

↓

Greater the energy of the e⁻s.



Light intensity = constant

$\nu_1 > \nu_2 > \nu_3$.

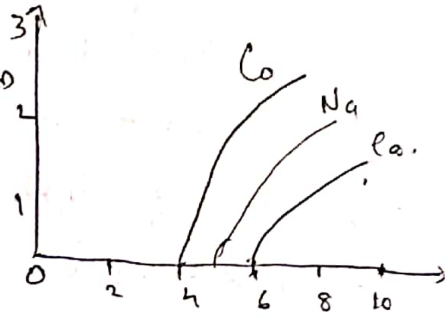
Even though the intensity of light is different, the kinetic energy of the e⁻s will be same.

→ Higher the ν of light → more the energy of photons.

→ Blue light (ν ↑) → results in fast e⁻s than red.

→ characteristic frequency of a metal no e⁻s will be emitted.

→



Quantum theory of Na

→ Light is not spread as wavefront → small packets called photons

→ 1) energy → photons.

→ 2) 'ν'

3) Higher the frequency

greater the frequency.

→ photo ēns (energy transfer to the metal ēns).

$\phi = h\nu_0$

→ Cs → 1.9 eV (Half of the energy to pull the ēn out.)

K → 2.2 eV

Na → 2.3 eV

Li → 2.5 eV.

→ $h\nu = KE_{max} + \phi$

→ $h\nu$ → photon energy.

→ KE_{max} → maximum photo electron energy (which is proportional to stopping potential.)

ϕ → minimum energy required for an ēn to leave the metal.

$h\nu = KE_{max} + h\nu_0$

$KE_{max} = h\nu - h\nu_0$

$$\boxed{K.E_{max} = h(\nu - \nu_0)}$$

→ Stopping V ↑ -ve, then the ēns get collapsed easily (Eventually the current won't increase)

Stopping V (energy form) which will act as the barrier for the K.E energy coming bez of the hν of the light So it won't allow ēns to travel if it act as a barrier.

→ Energy to depend on the frequency of the light

23/1/2019 $\boxed{P = \frac{E}{c}}$

1. What are the energy and momentum of a photon of a red light of wave length 650nm.?

$\lambda = 650nm$.

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

2. What is the wavelength of a photon of energy 2.40 eV?

$-27+8-9+9$

1 a) $E = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{650 \times 10^{-9}}$

$= 3 \times 10^{-26+7} = 3 \times 10^{-19} J$

$= 3.058 \times 10^{-19} J$

$= \frac{3 \times 10^{-19}}{1.6 \times 10^{-19}} = \frac{30}{16} \approx 2 eV$

$= 1.9 eV$

$16 \overline{)30}$ 1.
16
140

16 × 9 = 135

Q.
1(b)

$P = \frac{h \times c}{\lambda \times c} \quad \frac{6.626\times10^{-34}}{65\times10^{-7}}$

$= \frac{E}{c} \quad 1.01\times10^{-27}$

$= 1.01\times10^{-27}$ kgm/s

$E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

$P = \frac{E}{c}$

$= \frac{1.9\times1.6\times10^{-19}}{3\times10^{8}}$

$= 1.013\times10^{-27}$ kgm/s

Q. $E = 2.40\,eV$

2.

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

$= \frac{6.626\times10^{-34}\times3\times10^{8}}{2.40\times1.6\times10^{-19}}$

$= 5.17\times10^{-7}$

$= 517$ nm

2) The work function of tongston metal 4.52 eV

a) what is the cut off wavelength (λ_c) for tongsten?

b) What is the mam. K.E of e^- when recall attom of wavelegth 198nm is used

c) What is the stopping potential in this case

a) $\phi = h\nu_0 = \frac{hc}{\lambda_0} = 4.52\times1.6\times10^{-19}$

$\lambda_0 = \frac{6.626\times10^{-34}\times3\times10^{8}}{4.52\times1.6\times10^{-19}} = 275$ nm

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

$$= \frac{6.626\times10^{-34}\times3\times10^{8}}{198\times10^{-9}\times1.6\times10^{-19}} - 4.52\,eV$$

$$= 6.27 - 4.52 = \underline{\underline{1.75\,eV}}$$

c) $\text{stopping potential} = \frac{1.75\,eV}{e} = \underline{\underline{1.75\,V}}$

3) The wavelength of the Photoelectric threshold ~~for~~ Ag is $\underline{3.250\times10^{-10}\,m}$. Determine the velocity of the electron ejected from Silver surface by ultraviolet light of wavelength $2.536\times10^{-10}\,m$.

~~$\lambda = 325\,nm$~~

$\underline{\underline{\lambda = 0.325\,nm}}$

Kinetic energy $= h\nu - h\nu_0$

$$= \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

$$= \frac{6.626\times10^{-34}\times3\times10^{8}}{0.2536\times10^{-9}} - \frac{6.626\times10^{-34}\times3\times10^{8}}{0.325\times10^{-9}}$$

$$= 7.83\times10^{-16} - 6.116\times10^{-16}$$

$$= 1.714\times10^{-16}\,J$$

$$= 1.071\times10^{3}\,eV$$

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

$v = \sqrt{2K/m}$

$v = 1.95\times10^{7}\,m/s$

$$v = \sqrt{\cancel{2m\,K.E.}} = \sqrt{\frac{\cancel{2\times1.071\times10^{3}\times}}{2\times1.714\times10^{-16}\times9.1\times10^{-31}}}$$

$$= \cancel{1.37\times10^{15}} = \sqrt{\;} = \cancel{1.79\times10^{-23}}\,m/s$$

~~$v = 1.76\times10^{-23}$ m/s~~

24/1/2019

1. An ultraviolet light of wavelength 350nm, and intensity $1.00\,W/m^2$ is ~~also~~ directed at a potassium surface.

a) Find the maximum kinetic energy of the photoelectrons.

b) If 0.5 percent of incident photons produce photoelectrons, how many are emitted per second if the potassium surface has an area $1.00\,cm^2$?

ϕ for $K = 2.2\,eV$.

$\lambda = 350\,nm$.

a) $h\nu = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\times3\times10^{8}}{350\times10^{-9}}$

$E = 3.55\,eV - 2.2\,eV$

$= 1.35\,eV$

$= 2.16\times10^{-19}\,J$

b) Area $= 1.00\,cm^2$

$\frac{0.5}{100}\times n$

Intensity $= 1.00\,W/m^2$

Power $= 1.00\,W/m^2 \times 10^{-4}\,m^2$

$= 10^{-4}\,W$

$= 1\times10^{-4}\,W$

$\frac{n}{t} \rightarrow ?$

0.5

Power $= 1\times10^{-4}\times\frac{0.5}{100}$

Area $= 1.00\,cm^2$

~~$1e = 1.6\times10^{-19}\,J$~~

K.E $= 2.16\times10^{-19}\,J$

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

Area $= 1.00\,cm^2$

$= 10^{-4}\,m^2$

b) $I = \frac{nh\nu}{A} = E/A$

$$n = \frac{IA}{h\nu}$$

$$= \frac{1 \times 10^{-4} \times 350 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^{8}}$$

$$= 1.76 \times 10^{14} \times \frac{0.5}{100}$$

$$= \underline{\underline{8.8 \times 10^{11} \text{ e/ns}}}$$

$2mE = m^2v^2$

$T^2 = c^2p^2 = T^2 + 2 \cdot 1 \, mv^2 mc^2$

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

$\rightarrow T^2 = T^2 + 2Tmc^2$

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

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

$T^2 +$

$$\underline{\underline{T^2 = c^2p^2 = T^2 + 2Tmc^2}}$$

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

$E = h\nu$

$P = h\nu/c = E/c$

Assume that photoelectric effect take place with a free electron.

$$T^2 = c^2p^2 = T^2 + 2Tmc^2 \quad (1)$$

$$T^2 = \frac{c^2 \cdot h^2\nu^2}{c^2} = T^2 + 2Tmc^2$$

$(h\nu)^2 = E^2 = T^2 + p^2c^2$

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

$c^2p^2 = c^2 \times m^2v^2$

$= c^2 \times m^2v^2$

$= c^2 mv^2 \times \frac{2m}{2}$

$= c^2 T$

$$\underline{T^2 = 2mc^2T.}$$

$P = \sqrt{2mE}.$

$p = \sqrt{2mE}.$

$\frac{p^2}{2m} = E = T$

$p^2 = 2mT.$

$E = \frac{p^2}{2m}$

$p^2 = 2mE = 2mT.$

$T^2 = c^2p^2 = c^2 \times 2mT$

$$\underline{\underline{T^2 = 2mTc^2 = p^2c^2}}$$

$p^2c^2 = 2mTc^2$

$p^2c^2 = 2mTc^2$

$= 2mc^2 h\nu$

$T = 2mc^2$

$T - 2mc^2 = 0,$

$h\nu - 2mc^2 = 0,$

$2h\nu mc^2 = .$

K.E = 10.7 eV

$E = h\nu.$

$K.E = h\nu - \phi$

$h\nu = K.E + \phi$

$K.E = -2.15 \times 10^{-2}$

5/2/2019

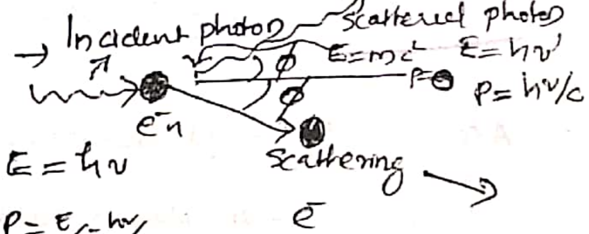
→ Compton Effect

(Light matter interaction) opposite to (photoelectric effect).

3. A photon is incident upon a Hydrogen atom ejects an electron of K.E 10.7eV If the ejected e^- is first excited state. Calculate the energy of the photon $h\nu$. How much K.E should be imported to an electron is ground state?

→ Inelastic scattering (K E is not conserved)

→ Elastic Scattering



→ 1st experiment in 1925.

→ Arthur Holly Compton.

K.E of photon less b/z it hits e^- and imported to e^- (e^- scatters)

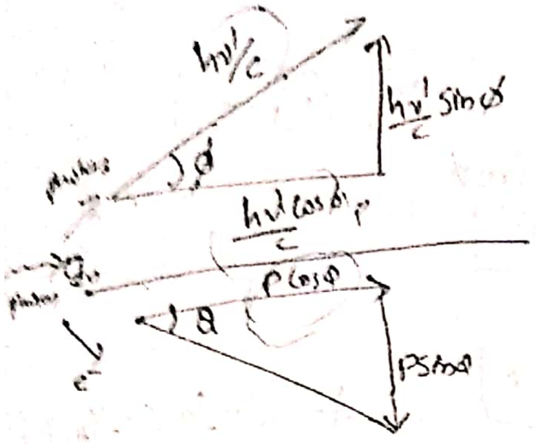
λ of photon ↑ ($\downarrow E = \frac{hc}{\lambda\uparrow}$)

→ Scattering of e^-

Scattering of ēn

Energy (of ēn) and momentum conservations.

→ Momentum is not conserved. But how?



Vector diagram of the momentum and their components of incident & scattered photons.

ν → Initial photon

ν' → lower than the initial

Loss in photon energy = gain in ēn energy

→ $h\nu - h\nu' = K.E$ —(1) (energy loss)

$E = pc$ (2)

→ $p = E/c = h\nu/c$ —(3)

(Initial photon momentum)

→ Scattered photon momentum. $h\nu'/c$

For E → first o then lead to P.

Initial momentum = Final momentum

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\phi + p\cos\theta \quad —(4)$$

Initial momentum = Final momentum (+y direction)

$$0 = \frac{h\nu'\sin\phi}{c} - p\sin\theta \quad \rightarrow (5)$$

ϕ → angle between the direction of the initial and the scattered photon.

θ → angle between the direction of the initial and the scattered ēn.

→ Multiply (4) & (5) by c, $p = E/c$

$$h\nu = h\nu'\cos\phi + pc\cos\theta$$

$$h\nu = h\nu'\cos\phi + E\cos\theta$$

(6) — $pc\cos\theta = h\nu - h\nu'\cos\phi$

Then

(7) — $pc\sin\theta = h\nu'\sin\phi$

(6)^2 + (7)^2 ⇒ $p^2c^2 = (h\nu - h\nu')^2\cos^2\phi + (h\nu'\sin\phi)^2$

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

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

$$p^2c^2 = h^2\left[\nu^2 - 2\nu\nu'\cos\phi + \nu'^2\right]$$

$$p^2c^2 = h^2\left[\nu^2 + \nu'^2 - 2\nu\nu'\cos\phi\right]$$

$\Downarrow$

Substitute for E

$$E = K.E + Mc^2 \quad —(1)$$

$$E = \sqrt{M^2c^4 + p^2c^2} \quad —(2)$$

We know

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

$$p^2c^2 = K.E^2 + 2mc^2KE$$

$$K.E = h\nu - h\nu'.$$

$$p^2c^2 = (h\nu)^2 - 2(h\nu)(h\nu') + (h\nu_1)^2 + 2Mc^2(h\nu - h\nu')$$

Sub p^2c^2 in (6)

$$2Mc^2(h\nu - h\nu') = 2(h\nu)(h\nu')(1-\cos\phi) \quad —(7)$$

$\div$ by $2h^2c^2$ → after $\checkmark$

$$\frac{mc}{h}\left(\frac{\nu}{c} - \frac{\nu'}{c}\right)$$

$$= \frac{\nu}{c}\frac{\nu'}{c}(1-\cos\phi)$$

$$\frac{\nu}{c} = \frac{1}{\lambda} \quad \frac{\nu'}{c} = \frac{1}{\lambda'}$$

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

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

$\Downarrow$

Compton effect

λ → initial λ

λ' → scattering

h → planck's const

m → mass of e^-

c → speed of light

ϕ → scatter angle

Mass and energy

7/2/2017

W on a object by a constant force F and s.

$$W = Fs.$$

giving a force $K.E = Fs$

$W \to K.E$

F is not constant.

$\rightarrow K.E = \int_0^S F.ds$

1) $\rightarrow K.E = \frac{1}{2} mv^2$

$P = \gamma mv$

$F = \frac{dP}{dt}$

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

$= \frac{d}{dt}(\gamma mv)$ Relativistic momentum.

$KE = \int_0^S \frac{d}{dt}(\gamma mv)\, ds$

$= \int_0^v v\, d.\left(\frac{mv}{\sqrt{1 - v^2/c^2}}\right)$

Integrating by parts.

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

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

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

$K.E = \gamma mc^2 - mc^2$

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

Total Energy

$E = mc^2 + K.E$

$\Updownarrow$

E_0

$E = E_0 + K.E$

$\Downarrow$

$mc^2 \rightarrow$ Rest energy

$E = \gamma mc^2$

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

Energy and momentum

$E = pc$.

$\rightarrow TE, E_0$ and momentum of a particle

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

$\rightarrow P = \frac{mv}{\sqrt{1 - v^2/c^2}}$

Square it

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

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

Subtract the two

$E^2 - p^2c^2 = m^2c^2 \left[\ \right]$

$\frac{m^2c^4 - m^2v^2c^2}{1 - v^2/c^2}$

$= \frac{m^2c^4\left[1 - v^2/c^2\right]}{1 - v^2/c^2}$

$= (m^2c^4)^2$

Hence Energy and momentum

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

$\lambda_c = \frac{h}{mc} \Rightarrow$

$\rightarrow \lambda_e = \frac{6.626\times10^{-34}}{511\times10^{3}\times3\times10^{8}}$

$= 4.3\times10^{-8}\,m$

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

Compton wavelength

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

$m_e = E/c^2 \quad eV/c^2$

$m_e \Rightarrow eV/c^2 \quad 511\,keV/c^2$

+ photon is ~~trying to~~ hits with electron free (continuous)

In photoelectric effect

photon with metal

↓ not uniform). continuous

upto to classical

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

$= \frac{h}{mv}$

$= \frac{h}{mc}$

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

$= \frac{h}{511\,keV/c^2 \times c}$

$= \frac{hc}{511\,keV}$

$= \frac{6.6\times10^{-34}\times3\times10^{8}}{511\times10^{3}}$

λ_e

h in "J" ↓ Convert to eV

$= \frac{3.89\times10^{-31}}{1.6\times10^{-19}}$

$= 2.43\times10^{-12}\,m$

13/2/2019

$\theta = 30^\circ$, ϕ

Shift in λ,

$\Delta\lambda = \lambda_c(1-\cos\phi)$

$= \frac{h}{m_e c}(1-\cos\phi)$.

? → For x ray — 300 keV

30°

$h = 6.6261\times10^{-34}\,Js$

$c = 2.9979\times10^{8}\,m/s$

$eV = 1.6022\times10^{-19}\,J$.

$E = \frac{1}{2}mv^2 \Rightarrow kg\,m^2/s^2$

$\rightarrow J s \Rightarrow kg\,m^2/s / m/s \cdot kg$

$\lambda_e = \frac{h}{m_e c} = \frac{6.626\times10^{-34}}{9.0\times10^{-31}\times3\times10^{8}}(1-\cos30)$

$= 3.3\times10^{-13}\,m$

$= 0.33\,pm$

$\lambda' - \lambda = \lambda_e(1 - \cos\theta)$

$= 2.43 \times 10^{-12}(1 - \cos 30)$

$= 3.25 \times 10^{-13}$

minimum shift

$\Delta\lambda = 0 \qquad \theta = 0^\circ$

maximum shift

$\theta = 180^\circ$

$\Delta\lambda = 2 \times 2.43$

→ $\theta = 60^\circ$

$\Delta\lambda = 2.43(1 - \cos 60)$

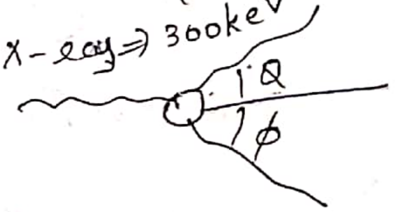
$= 2.43\left(\frac{1}{2}\right)$

$= 1.2$

$E' = h\nu'$

$= h \cdot \frac{c}{\lambda'}$

→ X-ray ⇒ 300keV



$\frac{hc}{\lambda} = 300\ keV$

$\lambda = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{300 \times 10^{3} \times 1.6 \times 10^{-19}}$

$= 4.1375 \times 10^{-12}$

$\Delta\lambda = \lambda' - 4.13 \times 10^{-12}$

$= 3.25 \times 10^{-13}$

$= .325 \times 10^{-12}$

$\lambda' = 4.13 \times 10^{-12} + .325 \times 10^{-12}$

$= 4.4625 \times 10^{-12}$

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

$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{4.46 \times 10^{-12}}$

$= 4.45 \times 10^{-14}$

$= 278.403\ keV$ for photon

$\Delta E = 300 - 278.4 = 21.6\ keV$

used by e^-.

$E = hc/\lambda_e$

14/2/2019

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

$\lambda = 400nm \qquad \theta = 180^\circ$

$E' = ?$

$\lambda = 400nm.$

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

$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{4 \times 10^{-7} \times 1.6 \times 10^{-19}}$

$E = 3.10\ eV$

$\Delta\lambda = \lambda_e(2) = 2\lambda_e$

$\Delta\lambda = 2 \times 2.43$

$= 4.86 \times 10^{-12}$

$\lambda' = \lambda + 4.85\times10^{-12}$ $\quad \lambda' - \lambda = 2\lambda_e$

$\lambda' = 400\times10^{-9} + 4.85\times10^{-12}$

$= 4\times10^{2}\times10^{3}\times10^{-12} + 4.85\times10^{-12}$

$= 4\times10^{5}\times10^{-12} + 4.85\times10^{-12}$

$= 4\times10^{5}\times10^{-12}$

$= 4\times10^{-7}m$

$E' = \frac{hc}{\lambda'} = \frac{6.62\times10^{-34}\times3\times10^{8}}{4\times10^{-7}\times1.6\times10^{-19}}$

$= 3.10\ eV$

$\lambda' - \lambda = 2\lambda_e$

$\Delta E = \frac{hc}{\Delta\lambda} = hc\left[\frac{1}{\lambda'-\lambda}\right]$

$\Delta E = \frac{12.40\times4.86}{400\times400\times10^{6}}$ $\rightarrow keV$

$= 3.76\times10^{-8}\ keV$ $= 3.76\times10^{-5}$ $= 37.6\ \mu eV$

$E = \frac{1240\ keV}{400\times10^{3}}$

$= \cancel{0.015}\ 3.1\times10^{-3}$

$= 3.1\ eV$

$\Delta\lambda = \cancel{\lambda\lambda}$

$\Delta\lambda = 2\lambda_e$

? $\lambda = 0.24nm$

Longest λ'?

$\lambda' - \lambda = 2\lambda_e$

$\lambda' = \lambda + 2\lambda_e$

$\lambda' = 0.24\times10^{-3} + 4.85\times10^{-12}$
$\times10^{-12}$

$= 244.85\ pm$

Cat which
$180° \rightarrow$ longer λ)

$E_e = ?$

$E_e = \frac{6.626\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}}\left[\frac{1}{\cancel{244.85\times10^{-12}}\ 240\times10^{-12}}\right]$

$E_e = 1.24\times10^{-6}\times10^{12}\left[\frac{1}{240} - \frac{1}{244.85}\right]$

$= 8.25\times10^{-5}\times1.24\times10^{6}$

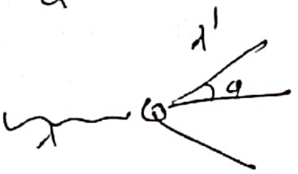
$= 102.34\ eV$

$\Delta E = \frac{hc\times\Delta\lambda}{1.6\times10^{-19}}$

9 $\lambda = 0.24\,nm$

$\lambda' = 0.2412\,nm$

$Q = ?$



2 $\lambda' - \lambda = \lambda_e(1 - \cos Q)$

$1 - \cos Q = \frac{\lambda' - \lambda}{\lambda_e}$

$= \frac{241.2 - 240}{\cancel{4.85}\ 2.43}$

$= \cancel{0.247}$

1 $\cancel{\cos Q = 0.75}$

$\frac{1}{244.85 \times 10^{-12}}$ $\quad Q = \cancel{41}^{\circ}$

$1 - \cos Q = 0.49$

$\cos Q = 0.506$

$Q \approx 59^{\circ} \to 60^{\circ}$

$\frac{h\nu' \sin\phi}{c} = p \sin Q = \frac{E}{c} \sin Q$

$E \sin\phi = h\nu' \sin\phi Q$

$\sin\phi = \frac{h\nu \sin Q\phi}{h\nu'}$

$Q = \sin^{-1}\left(\frac{\nu \sin\phi}{\nu'}\right)$

$= \sin^{-1}\left(\frac{\lambda'}{\lambda}\sin\phi\right)$

$= \sin^{-1}(0.87) \approx 60.49^{\circ}$

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