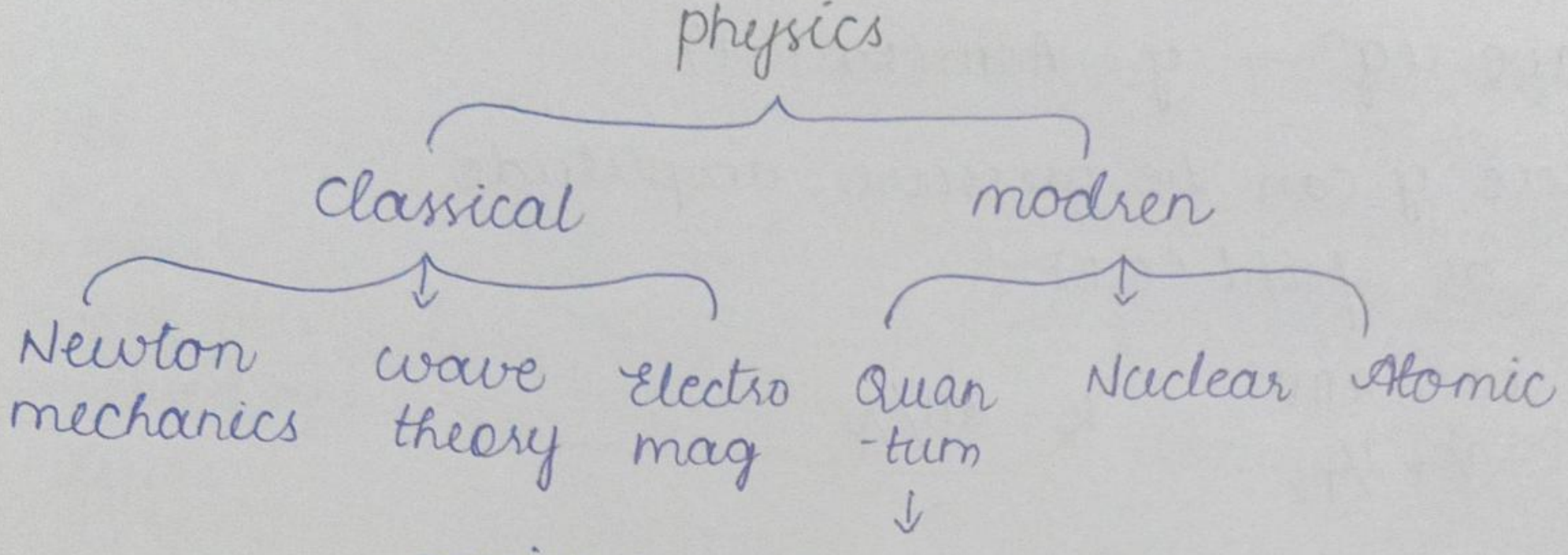
IC 151

Quantum physics - 2 credits

- Dr. Dhruv Pratap Singh Sir
- One tierce
- Concepts of modren physics & Quantum physics
  Arthur beiser HC verma

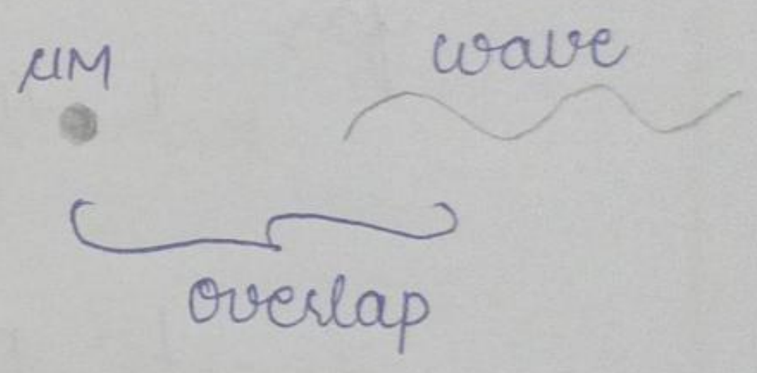
Lecture 1 & 2 :



majorly belongs to modren
but classical is involved

Topics :~

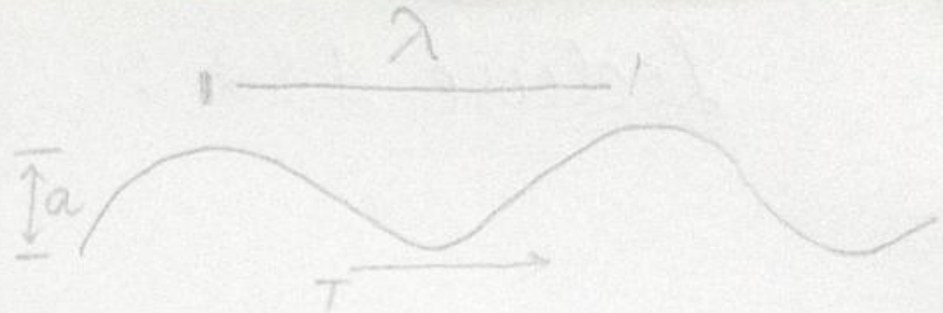
photoelectric effect
Compton effect / scattering
Black body radiat^{n}
Pair production
X- ray production
electron diffract^{n}



Duality :
- A particle may have waveline nature
- A wave may have particle like nature

Light :
- Straight lines (rectilinear propagat^{n})
- Splits into colors
- reflect^{n} law by euclid (300 BC)
- refract^{n} (bending of light) by snell (1621)
- converges & diverges by galileo (1610)
- Its a wave/particle by hooke's & huygen's (17^{th} century) in wave theory research.

Wave theory of light :



wave eq^n - $y = A\sin(kx - \omega t)$

here y can be pressure, amplitude
or feild (E, B)

$\omega = 2\pi\nu$ $\quad k = 2\pi/\lambda$

$\nu = 1/T$

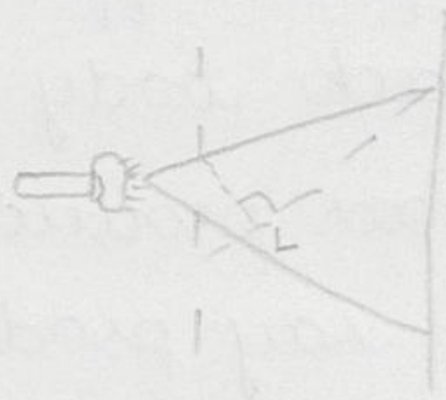
A - max amplitude

Light when tested with young's double slit experiment, it was proven that light is wave (1801)

for

$L = (n + 1/2)\lambda$

destructive

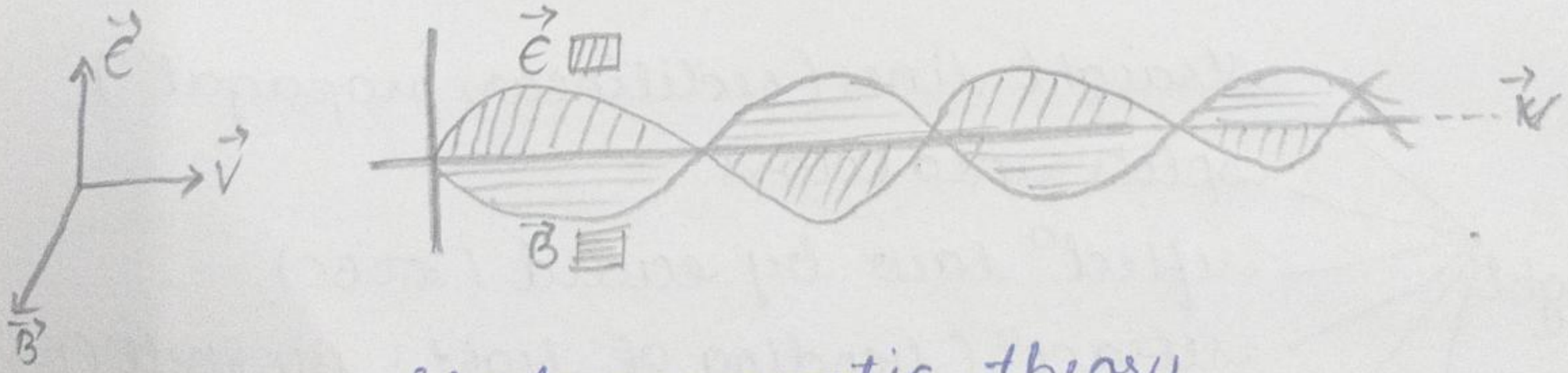


$L = n\lambda$

constructive

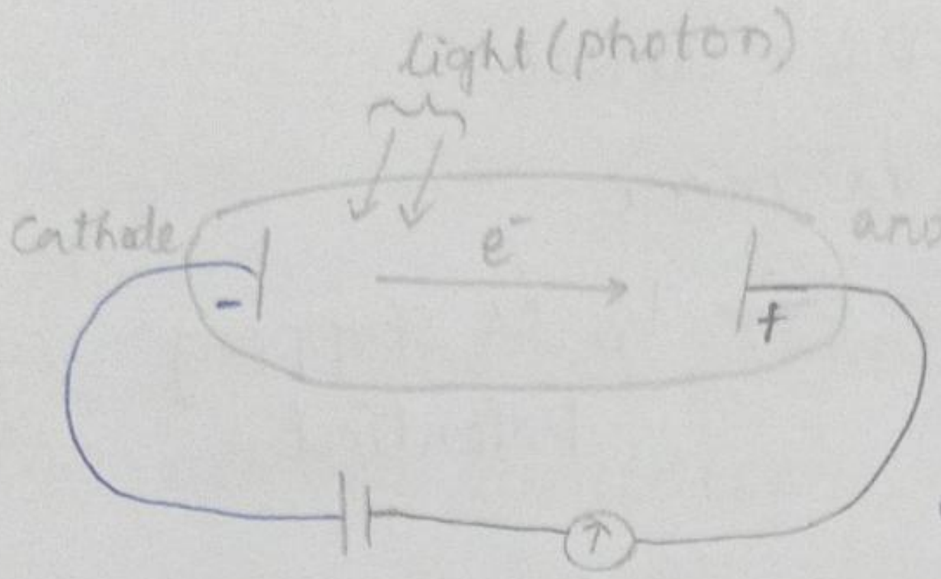
here $n \in W$ i.e $0, 1, \ldots$

Maxwell proposed an eq^n on electromagnetic nature of waves / light in late 19th century



Electromagnatic theory of light

photoelectric effect was first performed in the laboratory of hertz



→ e^- emitted are Photo electron
→ current generated is photo current

Ionizat° tube

1926
↓
photon word was proposed by Lewis

paramters in this experiment
- V - potential diff
- ν - frequency of e^- emitted
- i - photo current
- I - Intensity of light incident

hertz used em theory and formed

$$\text{Energy} = \tfrac{1}{2}\epsilon_0 E^2 + \tfrac{1}{2}\mu_0 B^2$$

here $B = E/c$, $c = 1/\sqrt{\mu_0 \epsilon_0}$, $I = \tfrac{1}{2} c \epsilon_0 E^2$

with increase of I, energy E increase

Energy is transformed to wave fronts in case of wave which makes delay but hertz observed that its an instantaneous process

How? from lec 2

For the transfer of wave it need some energy as it travel from a region, it takes time but by the value of photoelectric effect i.e 10^{-8} s which is very less, so this a clue by which we can say it as a particle instead of wave, so its instant (by dual nature of light)

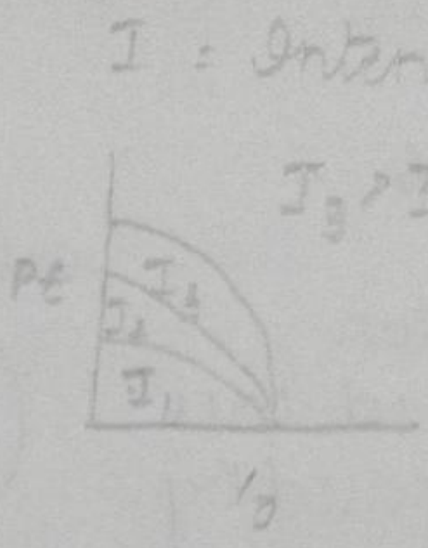
from ionizat^{n} tube diagram

v = const, V & i varies

when $V = 0$, i is max

when $V = V_0$, $i = 0 \rightarrow V_0$ is stopping potential

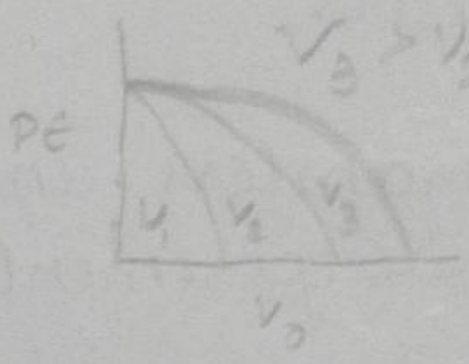
As $I \uparrow$, $i \uparrow$



when I is const, v & i varies

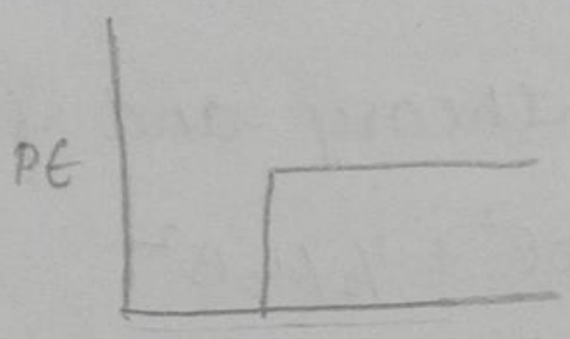
In this stopping potential is changed

As $v \uparrow$, $V \uparrow$

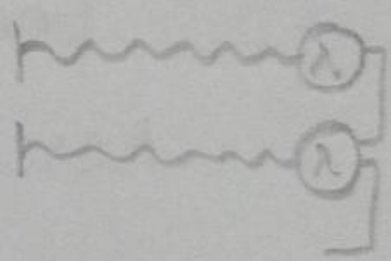


For i & v

Till some region there's no current



Instant emission of photo electrons



(2)

Limitations of EM theory explanat^{n} for photo-electric current

It didn't explain instant emission which indicates that the light is a particle of e^-

Acc to EM theory (wave energy transfers to region) there is a time lapse which is not correct.

EM theory doesn't explain relation btw energy & v. So we can't explain "why we get diff stopping potential" for same initial photo current
It canot explain the concept of threshold frequency

So later in 1905, Einstein proposed new concepts to overcome the above limitations (got nobel prize - 1922)

He assumed that light is madeup of photons
each photon has $h\nu$ energy $E = h\nu$

In this case intensity means no. of photons falling on surface per unit area per unit time

He introduced concept of work funct^n

$$E = W + KE$$

$$h\nu = h\nu_0 + KE$$

W = min energy req to make e^- to come out of surface

$$\nu = \nu_0 \Rightarrow KE = 0$$

$$E \propto \nu \;,\; KE \propto \nu \;,\; KE \uparrow \Rightarrow KE \uparrow \nu \uparrow \nu \uparrow$$

h = plank's const = 6.62×10^{-34} J·sec

Applicat^n of PEE => PMT (photo multiplier tubes used for detecting radiat^{ns})
(MVCS, CCD, image sensors)

Compton effect / Compton scattering (1923) & got nobel in 1927.
when we consider elastic collision of photon with any other body then we should also consider rest mass of photon along with KE while applying energy conserv^n.

$E' = m_0c^2$

↓ rest mass energy

↳ rest mass

$\therefore E = m_0c^2 + KE$

$= \gamma m_0c^2$

$\gamma = 1/\sqrt{1 - v^2/c^2}$ here γ = lorenz const

v = speed of particle

c = speed of light

m_0 = rest mass

m = relativistic mass

momentum $p = mv = \gamma m_0 v$

$E^2 = (m_0c^2)^2 + p^2c^2$

when $m_0 = 0$

$E = pc \Rightarrow p = E/c$

This is the case of photon

$p = E/c = h\nu/c = h/\lambda$

$h/2\pi = \hbar$, $2\pi/\lambda = k$

$p = h/\lambda$ $\quad p = \hbar k$

$E = h\nu$

$= h\nu/2\pi \times 2\pi$

$= \hbar\omega$

From Slides

$$E = \frac{1}{2} G_0 B^2 + \frac{1}{2\mu_0} B^2$$

$$B = G/C$$

$$C = 1/\sqrt{\mu_0 \epsilon}$$

} Now dont ask what is this

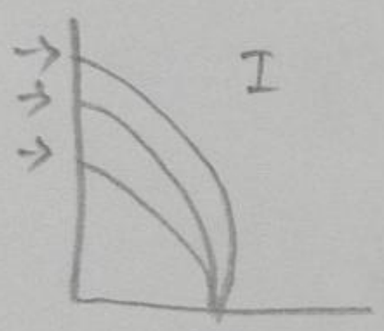
Intensity of light = no. of photon

energy = $h\nu$ = of each photon

Each photon can interact with each e^-

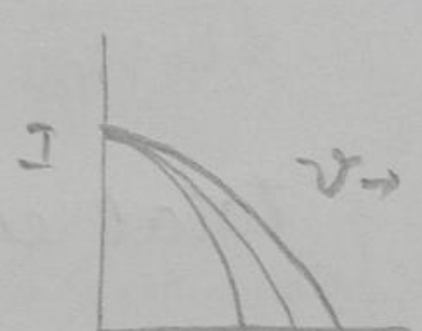
= energy transfer one-one process

= emission will be instantaneous



$\nu \propto F$

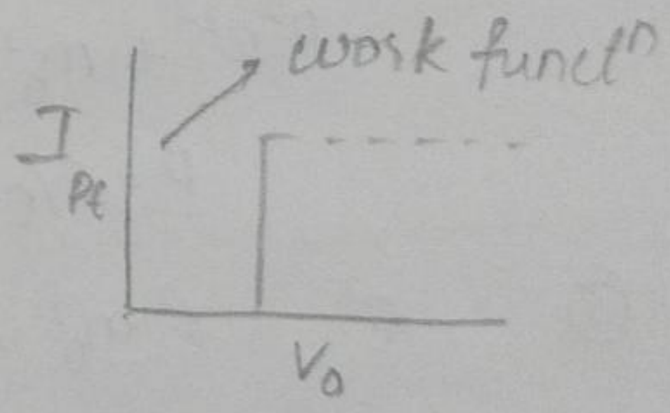
$E = h\nu$



Intensity & energy are not linked

$$E = KE + \phi$$

↓ light ↓ kinetic energy PE ↓ work funct^n

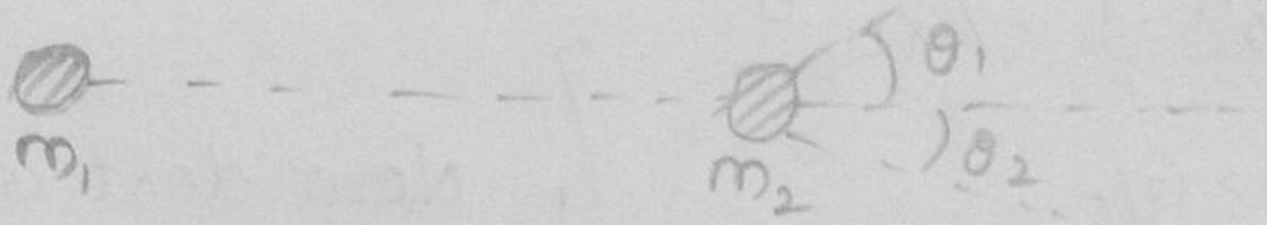


$$h\nu = KE + \phi \quad (\because \phi = h\nu_0)$$

$h\nu = KE + h\nu_0 \rightarrow$ PE eq^n

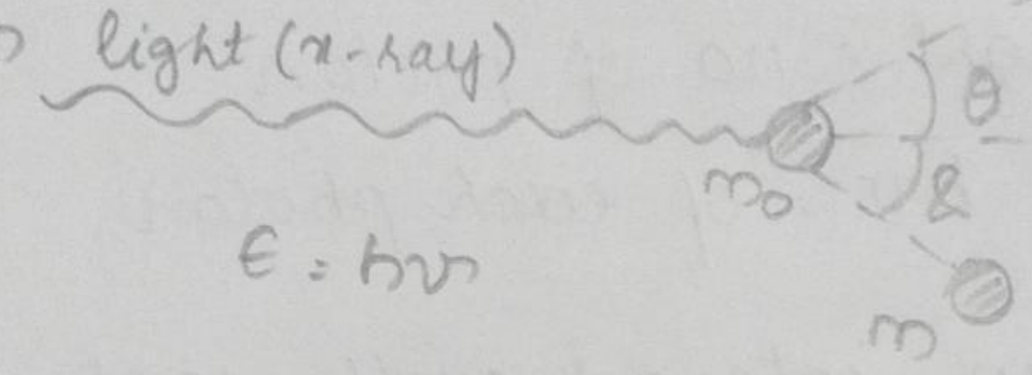
Light is not just a wave but also a particle.

Compton effect (scattering)



P, KE conserved
elastic collision

momentum $P = mv$



$$\epsilon = h\nu$$

$$\epsilon = m_0 c^2$$

$$= \gamma m_0 c^2 = \frac{1}{\sqrt{1 - v^2/c^2}} m_0 c^2$$

① $\epsilon = m_0 c^2 + K\epsilon$ = total energy

② $p = \gamma m_0 v \rightarrow mv = v m_0$

$$p^2 c^2 + m_0^2 c^4 = \epsilon^2$$

$$p = \epsilon / c$$

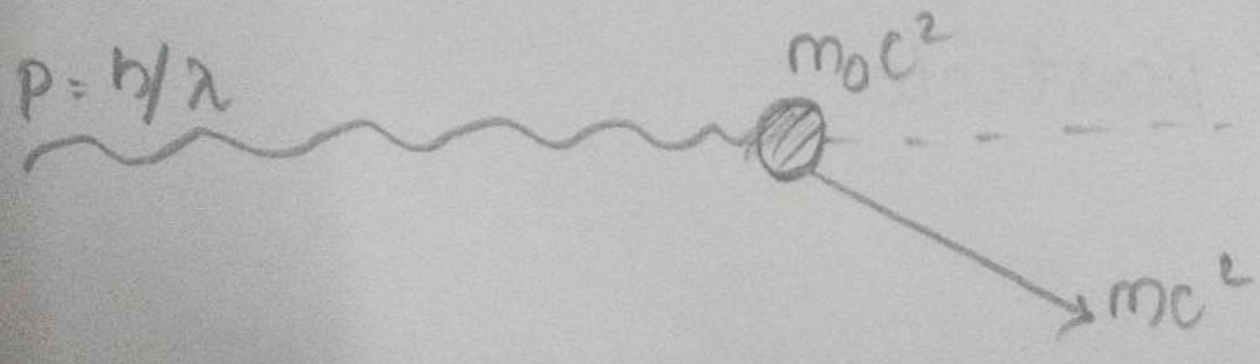
③ $p^2 = \gamma^2 m_0^2 v^2$ | $\gamma^2 = 1 / 1 - \frac{v^2}{c^2}$

$$\gamma^2 v^2 = v^2 c^2 - c^2$$

$$\epsilon^2 = m_0^2 c^4 + p^2 c^2$$

of $m_0 = 0$, $\epsilon^2 = p^2 c^2$

$$\epsilon = pc$$



Lecture 3

Compton effect (Continous) :~

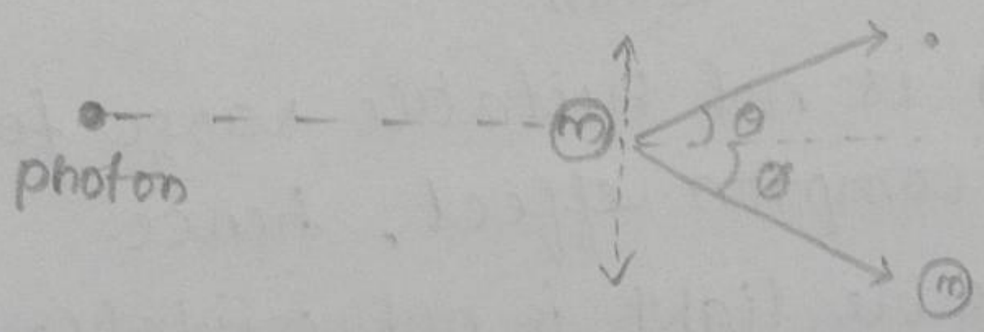
It explains that there is an elastic collision between photon & other massive products particles at rest, since the collision is elastic both P & E are conserved

$$P_{1_i} = P_{1_f} + P_{2_f} \quad , E_{1_i} = E_{1_f} + E_{2_f}$$

(assume massive particle is at rest

along x-axis $\Rightarrow h/\lambda = h/\lambda' \cos\theta + P\cos\phi \rightarrow ①$

" y-axis $\Rightarrow 0 = h/\lambda' \sin\theta - P\sin\phi \rightarrow ②$



Similarly for energy

$$\frac{hc}{\lambda} + m_0c^2 = hc/\lambda' + \sqrt{(m_0c^2)^2 + (Pc)^2} \rightarrow ③$$

from ①, ② & ③

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

↓

Compton wave length

$\theta = 180^\circ$

(max shift)

This is independent of λ

λ is a wave property but the change in wave length is independent of λ which indicate that wave theory couldn't explain this.

hence it was finally concluded that it has both particle & wave nature (duality)

→ It is observed for x-ray or other waves of the higher frequency

for $\Delta\lambda$ to be max, $\theta = 90^\circ$

$$\Delta\lambda = \frac{h}{m_0 c^2} = 0.01 \text{ nm for x-rays range}$$

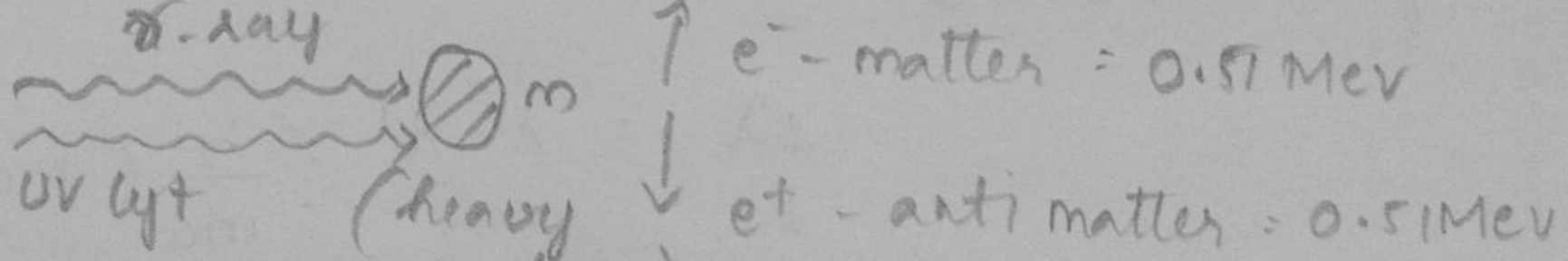
but for visible light

$$\Delta\lambda = 10^2 \text{ nm}$$

This is not suitable range for compton effect, hence visible light is not suitable.

Pair Product? :-

Light can be converted into matter



$h\nu = 1.02$ MeV

$\nu = \frac{1.02 \text{ MeV}}{h}$ => frequency of γ ray

It's matter can be converted into light which indicates that there exist relat° btn energy & matter

Energy of e^- & e^+ together is 1.02 MeV

hence any radiat° with energy greater than or equal to 1.02 MeV can produce e^+/e^-

To produce such energy, γ rays r suitable.

$$\epsilon = 1.02 \text{ MeV } (\gamma \text{ ray})$$

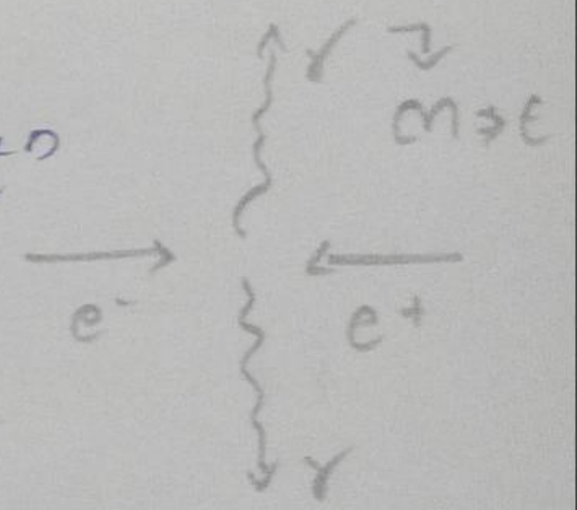
0.51 e^- 0.51 e^+

$$\epsilon = 2m_0c^2$$

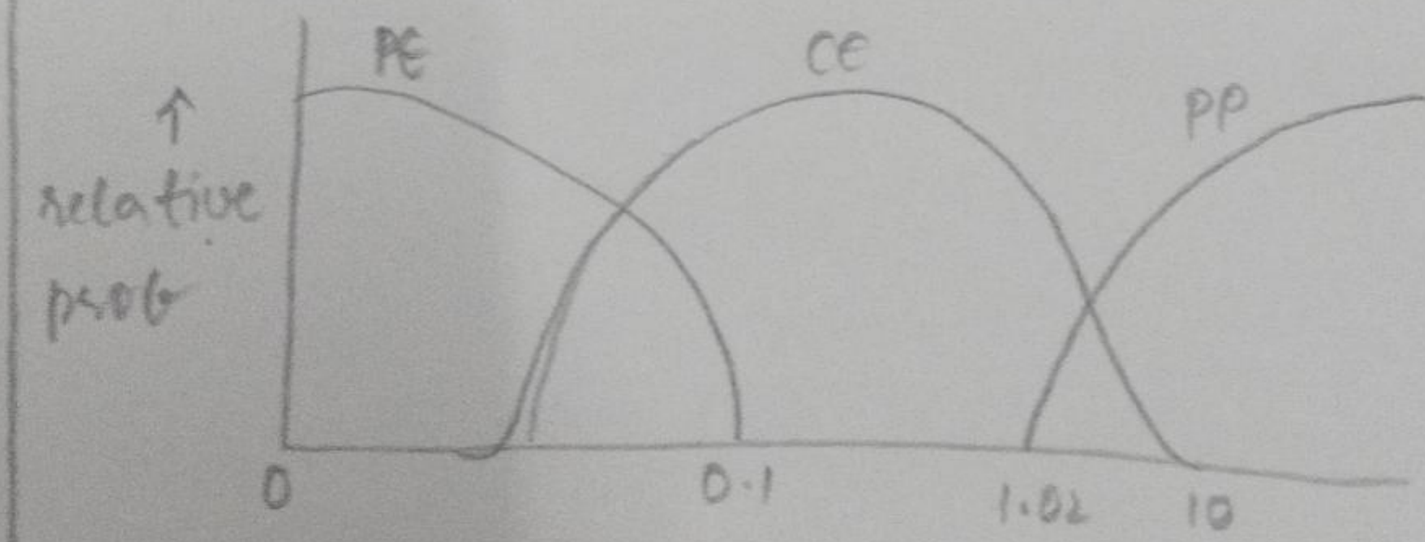
Pair Annihilation :-

when one e^- & one e^+ collide then 2 γ rays are produced

This is known as pair annihilat°



here 0.51 MeV of each 2 particle converts into γ radiat°



$\epsilon = KE + 2m_0c^2$

$\epsilon = \omega t + KE$

The increase in energy cause more chace of occurance of PP. of its less than PE (happens mostly)