Dual Nature of "Radiation" (eg. Light) & "Matter" (Chap. 11)

"Electron" emission from "Metals"

discovered by J.J. Thomson in 1897

→ Concept of work function "ϕ_0" (normally measured in eV)

→ $1 eV = 1.602 \times 10^{-19} J$ [one eV is the energy acquired by an electron when it is accelerated through a p.d. of 1V. ∴ $1eV = 1.6 \times 10^{-19} C \times 1V = 1.6 \times 10^{-19} J$]

→ "work function" → Minimum energy required by an electron to get liberated from the metal surface without imparting any kinetic energy (K) to the electron.

Electron emission can be due to

Thermionic Emission (by heating)	~~Field~~ photoelectric emission (photoelectric Effect)	Field emission (applying strong electric field)

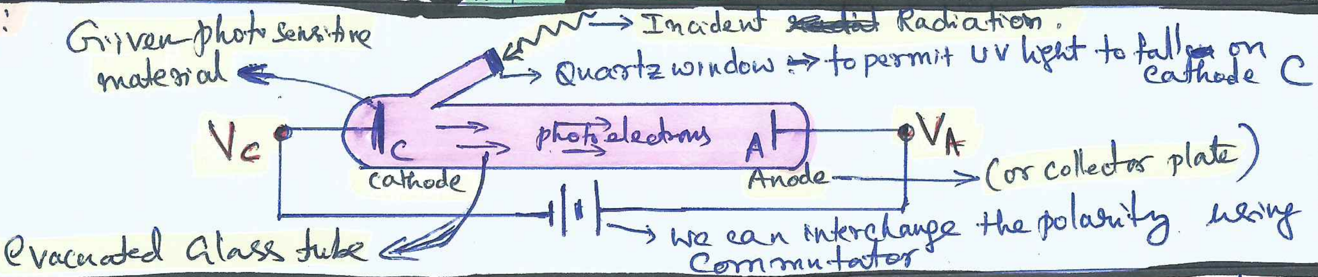
Def^n^: photoelectric effect is the phenomenon of emission of electrons from the surface of metals when radiation of suitable frequency falls on them.

→ The emitted electrons are called "photoelectrons" and the current so produced is called "photo current".

→ In terms of behaviour and their properties, photoelectrons are no different from other electrons. The prefix "photo" simply tells us that the electrons so ejected are due to LIGHT radiation.

Experimental study of photoelectric effect and 4 important observations from experiment

Set-up:



4 important observations from Experiment.

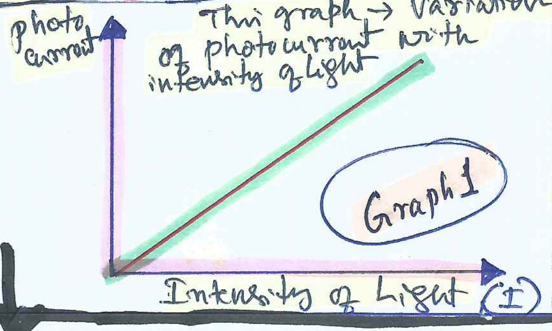
I observation

Variation of photocurrent with Intensity of Light.

Condition: (IMP)

1. For a given photosensitive Material (metal)
2. For a given Freq. of incident radiation
3. Freq. f of incident radiation > threshold freq. f_0 of given metal.

Result: photo current (number of photo electrons emitted per second) is directly ~~prop~~ proportional to the Intensity of incident light radiations, provided condition ③ is satisfied.

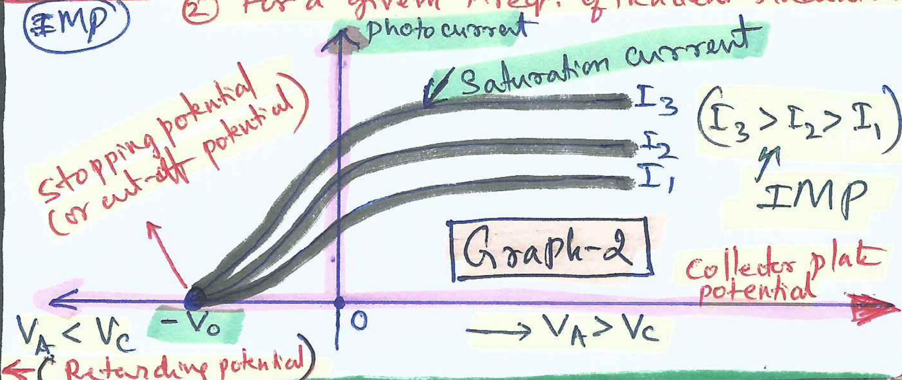


II observation

(Variation of photocurrent with collector plate potential for different Intensities of Incident radiation)

Condition: (IMP)

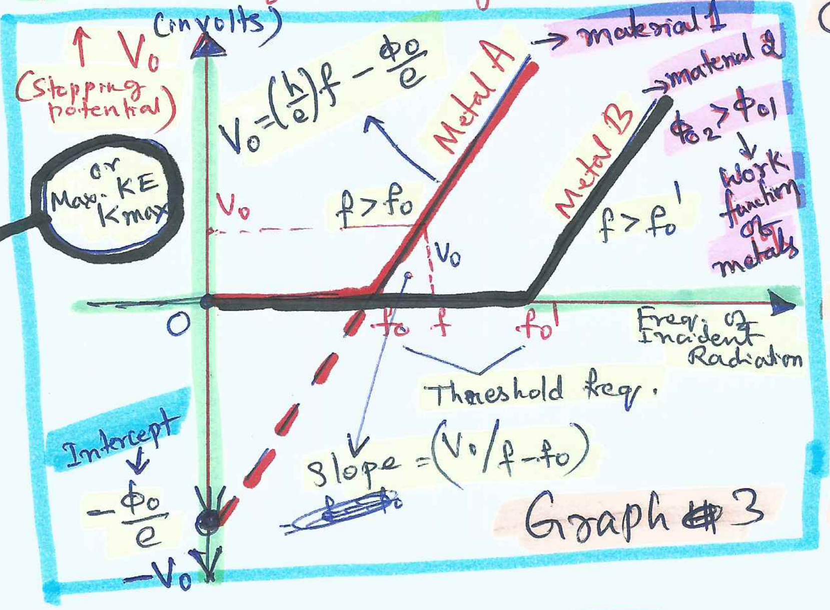
1. For a given photosensitive material
2. For a given Freq. of incident radiation



Result:
1. Saturation Current ∝ Intensity of incident radiation
2. Stopping potential is independent of intensity of incident radiation.

III observation from Experiment

Variation of "Stopping potential" V_0 with freq. f of Incident Radiation



⊙ From graph 3, for eg. for metal A, below threshold freq f_0 → stopping potential $V_0 = 0 \Rightarrow$ no photoemission (No photoelectric effect) is possible for $f \leq f_0$ (even if intensity of f is high) → See IV observation

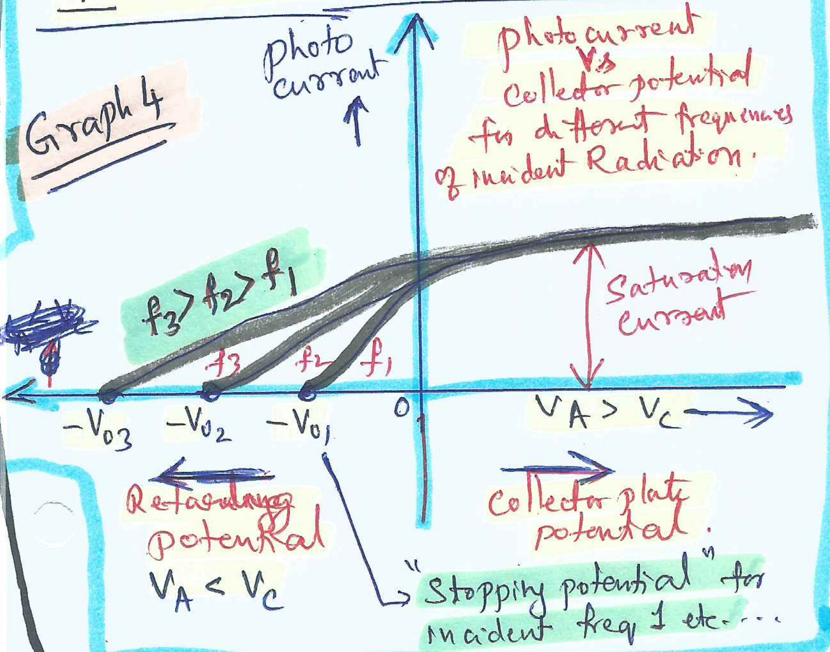
⊙ Above f_0 $(f > f_0)$,
→ V_0 linearly increases with f.
(Recall V_0 is independent of Intensity of f in II observation)

⊙ V_0 (stopping potential) increases with f (also from IV observation)

$$\Rightarrow \boxed{V_0 \propto f \quad \text{for } f > f_0}$$

⊙ $V_0 = 0$ at $f = f_0$ ⇒ electrons emerge with zero KE.
→ At $f = f_0$, incident radiation can only liberate electron without imparting any KE to the electron.
→ At $f > f_0$, ~~electrons~~ liberated and more electrons gain KE and move towards anode. So, energy $E = hf_0$ is used to just liberate an electron and when energy $E > hf_0$, the excess incident energy of the radiation is used to accelerate electrons.

IV observation from Expt.



⊙ Therefore, in graph 3, y-axis V_0 can also be treated as "Max KE" K_{max}. $K_{max} = eV_0$ (Since $K_{max} = hf - hf_0$)

$$\boxed{eV_0 = hf - hf_0} = h(f - f_0) \quad \therefore \boxed{V_0 = \frac{h}{e}(f - f_0)}$$

→ ∴ Slope of graph 3 (linear portion) $= \frac{V_0}{f - f_0} = \frac{h}{e}$ ∴ $\boxed{\text{Slope} = \frac{h}{e}}$

→ Intercept: $eV_0 = \phi - \phi_0$
For Intercept on y-axis, $f = 0$ ∴ $\phi = 0$ ∴ $eV_0 = -\phi_0$

$$\therefore \boxed{V_0 = -\frac{\phi_0}{e}} \qquad \therefore \boxed{V_0 = \left(\frac{h}{e}\right)f - \frac{\phi_0}{e}} \quad \text{III}^{r} \text{ to } y = mx + c$$

∴ For different metals in the above equation slope is same but having different intercepts.

- K_{max} (or eV_0) ∝ incident f and is independent of Intensity of Radiation (Graph-2)
- photoelectric emission is an instantaneous process without any apparent time lag, even when the incident radiation is made exceedingly dim.

Summary of experimental Observations (for photoelectric effect)

(a) For a given photosensitive material and given freq. of incident radiation and $f > f_0$ (threshold frequency),
→ photocurrent (photoelectrons emitted / sec) $\propto$ Intensity of incident light.

(b) For a given photosensitive material AND given f of incident radiation,
→ Saturation photocurrent $\propto$ Intensity of incident radiation
→ Stopping potential (V_0) is independent of Intensity of incident radiation.

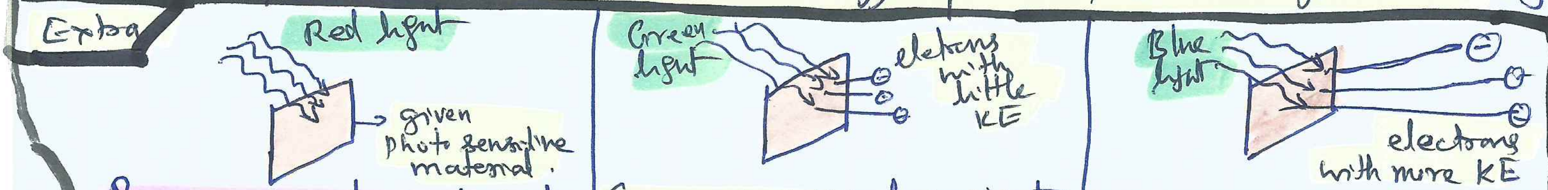
(c) For a given photosensitive material (eg. metal A in graph3, page 112) there exists a certain minimum cut-off frequency of the incident radiation, called the threshold frequency, below which no emission of photoelectrons takes place no matter how intense the incident light is.

→ Above threshold freq, the stopping potential or equivalently the max. KE gained by electrons increases linearly with f of incident radiation, but is independent of its intensity $[K_{max} = h(f - f_0)]$

(d) The photoelectric emission is an instantaneous process without any apparent time lag ($\simeq 10^{-9}$ s or less), even when the incident radiation is made exceedingly dim.

Higher freq: Greater energy	More photons → greater Intensity

Exp:



RED LIGHT does not eject photo electrons if its intensity is very HIGH	GREEN LIGHT does eject electrons (with little KE), even Intensity of green light is very dim	BLUE LIGHT ejects electrons with more KE than green light, even Intensity is very dim.

photoelectric effect and wave theory of Light

(1) According to wave theory of light, Intensity of incident light increases KE_{max}.
→ Explanation: Free electrons on metal surface absorb incident radiation continuously. We know that Intensity $\propto$ (Amplitude)^2 $\therefore$ greater the Intensity of incident radiation, greater are the amplitudes of electric and mag. fields. Consequently, greater the intensity, the greater should be energy absorbed by each electron. $\Rightarrow$ KE_{max} of photoelectrons should increase with increase in Intensity.
→ No matter what freq f of ~~incident~~ incident radiation, a sufficient intense beam of light should impart enough energy to electrons to ~~get~~ get liberated and accelerated. There is no concept of threshold freq. as per wave model.

- The above expectations of wave model contradict experimental observations (a), (b) and (c) of photoelectric effect. So wave model is unable to explain photoelectric emission.

(2) As per wave model, absorption of energy by electron takes place continuously over the entire wave-front of the radiation. Since a large no of electrons absorb energy, the energy absorbed per electron per unit time turns out to be small. Explicit calculations estimate that it can take hours or more for a single electron to absorb sufficient energy to overcome work function and liberate from metal. This contradicts exptl. observation (d). So, wave model is unable to explain basic features of photoelectric emission.

 Contd from 112a

From page 112a, it is confirmed that wave model cannot explain the most basic features of photoelectric emission.

Particle nature of Light

To explain photoelectric emission, Einstein proposed

- Einstein proposed that light behaved like a stream of particles called "photons" with an energy $E = hf$.
- As per Einstein's theory, radiation energy is built up of discrete units called "photons". Each photon has a same energy for a given frequency $\Rightarrow E = h.f.$ where $h = 6.626 \times 10^{-34}$ Js

Particle nature of light

Einstein proposed following equation (particle Nature of light for Radiation)

$\boxed{hf = hf_0 + \frac{1}{2}mv^2}$ (or $\phi = \phi_0 + KE$); where ϕ_0 = work function of metal.

This equation explains all experimental observations of photoelectric emission.

so, back to particle nature of light (particle = photon)
If light interacts with matter, the light behaves as if it is made of particles called "photons".

- Light in interaction with matter behaved as if it were made of quanta (photon energy) or packets of energy; each photon energy $= hf$. The particle was named as "photon".
- Einstein's light quantum can also be associated with Momentum (p)

$\boxed{p = \frac{hf}{c}} \rightarrow (1) \rightarrow$ how?

we know that photon energy $E = h.f \rightarrow (2)$
we also know that mass-energy relation if photon is considered as a particle of mass $m \rightarrow E = mc^2 \rightarrow (3)$

From (2) and (3); $hf = mc^2$ $\therefore m = hf/c^2$

Momentum of photon $p = mc = \left(\frac{hf}{c^2}\right)\cancel{c} = \frac{hf}{c}$

unit tallies

$p = \frac{Js \cdot \cancel{s^{-1}}}{m\,\cancel{s^{-1}}}$

$= (kg \cdot m s^{-2} \cdot m)\, s / m = kg \cdot m s^{-1} = mv$ (or mc)

Wave Nature of Matter

wave Nature of Matter (aka Matter waves)
↳ electron, proton, table, metal, ball etc

de Broglie reasoned that ...

(i) Nature is strikingly symmetrical in many ways.
(ii) Our observable universe is composed of "Light" and "Matter".
(iii) If Light has a dual wave-particle nature, perhaps "Matter" also has.
(iv) de Broglie predicted (proposed) that the wavelength λ associated with a particle of momentum p is given by $\boxed{\lambda = \frac{h}{p} = \frac{h}{mv}} \rightarrow (4)$ — de Broglie Wavelength

where h = planck's constant $= 6.626 \times 10^{-34}$ Js
p = momentum of the particle (matter)
m = mass of the particle
v = speed of the particle.

(v) The dual aspect of "Matter" is evident in de Broglie relation $\lambda = \frac{h}{mv}$
- LHS has λ, which is an attribute of a wave
- RHS has momentum p, which is typical attribute of a particle
→ Planck's constant h relates λ and p in eqn (4) $\lambda = h/p$

P.T.O.

- deBroglie relation $\lambda = h/p$ is basically a hypothesis whose validity can be tested only by experiment.

- It is interesting to know that photon satisfies de Broglie relation.

↓ how ?

→ We know that photon energy (proposed by Einstein) $E = hf$

→ We also know that mass-energy relation (by Einstein) if photon is considered as a particle of mass m } $E = mc^2$

$$\therefore hf = mc^2$$

$$\therefore \boxed{m = hf/c^2}$$

→ Momentum of photon $p = mc$ (Substituting m from above)

$$p = \frac{hf}{c^{\cancel{2}}} \times \cancel{c} = \frac{hf}{c} \quad \therefore \boxed{p = \frac{hf}{c}}$$

→ We need to prove that $h/p = \lambda$

→ From $p = \frac{hf}{c} \Rightarrow \boxed{\frac{h}{p} = \frac{c}{f}}$ Since $c = f\lambda$ for light in Vacuum or in air

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

$$\therefore \frac{h}{p} = \lambda \quad \text{or} \quad \boxed{\lambda = \frac{h}{p} \text{ for photon}}$$

This is the deBroglie' wavelength of a photon (given by de Broglie prediction) equals the wavelength of electromagnetic radiation of which the photon is a quantum of energy and momentum.

↓ Expt. by Davisson and Germer

de Broglie concept is proved by D & G expt. for Electrons.

$$\lambda = \frac{h}{\sqrt{2meV}} \Rightarrow \text{for electron} \quad \boxed{\lambda_{electron} = \frac{1.227}{\sqrt{V}} \text{ nm}}$$

where V is the accelerating voltage in D-G expt.

D-G performed expt. for accelerating voltage ranging from 44V to 68V. They observed a strong peak at V=54V. Strong peak is due to "Constructive Interference of Electrons." (which shows wave nature of electron)

$\therefore$ From expt. @54V ; $\lambda = \frac{1.227}{\sqrt{54}} = 0.167$ nm → which is in excellent agreement with theoretical value of deBroglie λ for electrons (0.165 nm)

[de-Broglie hypothesis is the basic foundation of Quantum Mechanics]

P.T.O.

113b ~~113a~~ -113b-

After excellent agreement between theory of de Broglie and expt. by Davisson-Germer for λ of electron → Confirms Wave-nature of Electrons.

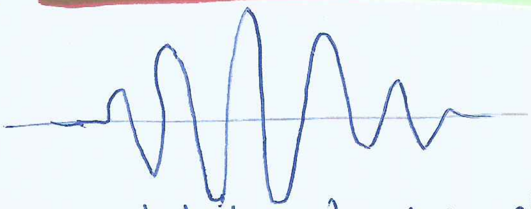
Heisenberg's Uncertainty principle

- The matter-wave (eg. wave nature of electron which is a "matter") picture ~~has~~ elegantly incorporated the Heisenberg Uncertainty principle (HUP)
- As per HUP, it is not possible to measure both position and Momentum of an electron (or any other particle) at the same time EXACTLY. IMP
- There is always some uncertainty
  → position uncertainty → Δx
  → Momentum uncertainty → Δp

$$\boxed{\Delta x \times \Delta p = \frac{h}{2\pi} = \hbar} \quad \left(\hbar = \frac{h}{2\pi}\right)$$

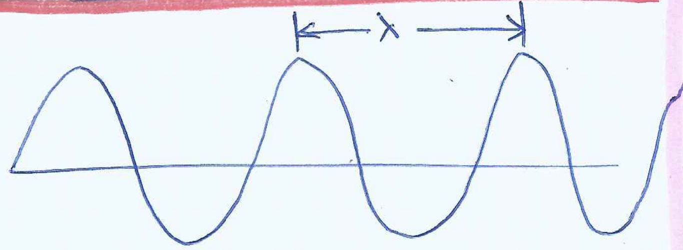
- If $\Delta x = 0$, then Δp must be infinite so that product $\Delta x \cdot \Delta p$ is non-zero.
  If $\Delta p = 0$, then Δx must be do
  ⇒ if ~~the~~ position is exactly ~~measured~~ located, then its momentum has ~~infinity~~ infinite value ⇒ momentum cannot be exactly measured.
- In nature Δx and Δp are non-zero such that their product $= \hbar = h/2\pi$
- If $\Delta p = 0$ (if an electron has definite momentum), as per deBroglie, it has definite wavelength λ → so it extends all over space. By Born's probability interpretation, this means that the electron is not localised in any finite region of space. ⇒ its position uncertainty is infinite ($\Delta x \to \infty$), which is consistent with the uncertainty principle.

- A Localized wave packet



The wave packet description of an electron. The wave packet corresponds to a spread of λ around some central wavelength (and hence by de Broglie relation, a spread in momentum). Consequently, it is associated with an uncertainty in position (Δx) and an uncertainty in Momentum (ΔP)

an extended wave with fixed λ



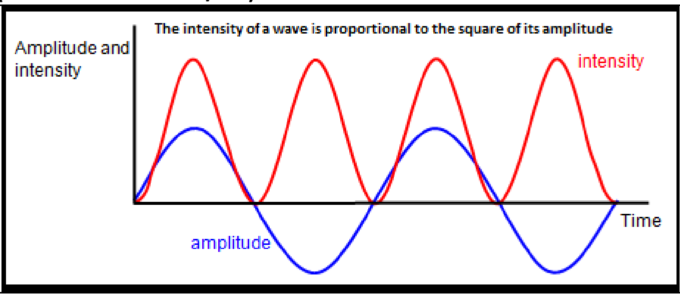
The matter-wave corresponding to a definite Momentum of an electron extends all over space. In this case, $\Delta P = 0$ and $\Delta x \to \infty$

—END—

113bb

Important tips:

- **In photo emission, <u>one photon</u> ejects <u>only one electron</u>**
- **n photons eject ≤ n electrons. Why see the explanation given below…**
  - According to Einstein's explanation, one photon of the incident light would emit one photoelectron from the metal. This, however, does not mean that if 'n' photons fall on the metal, 'n' photoelectrons will be emitted.
  - In fact, the photons falling on the metal are involved in many other processes besides emission of photoelectrons. Hence the ratio of the number of photoelectrons emitted to the number of photons incident on the surface is quite < 1. This ratio can increased by special treatment of the surface.
- How many photons are effective in the emission of one photoelectron? Does every photon eject a photoelectron?
  - **One photon; every photon does not necessarily eject a photoelectron.**
- When a photon falls on a metal, it transfers 'whole' of its energy hf to any 'one' of the elections present in the metal and its own existence is vanished. A part of this energy is used in ejecting the electron from the metal and the rest is given to the ejected electrons as KE. All the electrons are not ejected from the 'surface' of the metal. The electrons which are ejected from <u>within the metal</u>, they expend (lose) some of their acquired energy in collisions with the atoms on their way to the surface. Thus, electrons with different energies are emitted from the metal. The electrons emitted from the surface of the metal have maximum KE because their energy is not lost by collisions.
- If the intensity of light of a given frequency f is increased, then the number of photons striking the surface per second will increase <u>in the same ratio</u>, but the energy hf of each photon will remain the same. Hence the number of photoelectrons will correspondingly increase, but their maximum KE will remain the same.
- **If the amplitude of the e-m source (*<u>basically amplitude of sinewave of a given e-m frequency</u>*) is increased and since intensity of the radiation is proportional to (amplitude)^2 { $I \propto A^2$}, the intensity of source light also increases → this means that the number of photons emitted per second increases. So, more photons incident on the target means more electrons are getting ejected (note that 1 photon ejects 1 electron only). If n photons are incident, then n number of electrons may get ejected (ideal case) and hence photocurrent (number of electrons/sec) increases.**



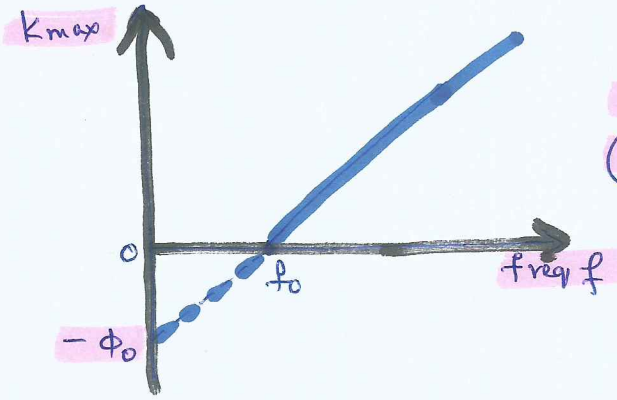
- The emission of photoelectrons 'immediately' after the light is incident may also be explained by Einstein's photon theory. As soon as the first photon falls on the metal, one of the electrons in the metal absorbs it as such and is ejected. Thus, there is no time-lag between incidence e of light (photon) on the metal and emission of electron. This is 5th law photoelectric emission.
- Number of photons emitted per second by a source n = $\frac{Power\ of\ the\ source}{Energy\ of\ one\ photon} = \frac{P}{hf}$; $since\ f = \frac{c}{\lambda}$ $\therefore n = \frac{P\lambda}{hf}$
- Einstein's photoelectric equation $hf = hf_0 + \frac{1}{2}mv^2$; $\frac{1}{2}mv^2$ is the KE of emitted electrons ; hf_0 is the work function of given metal and hf is the energy of the incident e-m radiation.
- De Broglie wavelength of a photon $\lambda = \frac{h}{p}$; De Broglie wavelength of a material particle $\lambda = \frac{h}{mv}$
- De Broglie λ of a particle with a speed comparable to speed of light $\lambda = \frac{h\sqrt{1-\frac{v^2}{c^2}}}{m_0 v}$ $where\ m_0\ is\ the\ rest\ mass\ of\ the\ particle$
- De Broglie wavelength of an electron accelerated through a potential V volt: $\lambda = \frac{12.27}{\sqrt{V}}\ \mathring{A} = \frac{1.227}{\sqrt{V}}\ nm$
- De Broglie wavelength of a particle in terms of temperature T: $\lambda = \frac{h}{\sqrt{3mKT}} = \frac{10.3\ x\ 10^{-23}}{\sqrt{mT}}\ m$
- De Broglie wavelength in terms of energy of a particle (E): $\lambda = \frac{h}{\sqrt{2mE}}$
- Wave nature of matter or material particle is apparent at atomic or microscopic level but it may not be relevant at macroscopic level.
- <u>Pressure exerted by the photons or radiations incident on the metallic surface:</u>
  - Energy of each photon = E = hf = hc/λ
  - Number of photons striking the surface per second = $\frac{Power\ of\ the\ source}{Energy\ of\ one\ photon} = \frac{P\lambda}{hc}$
  - Momentum imparted to the surface when one photon is reflected by the surface = change in momentum = dp = h/λ – (-h/λ) = 2h/λ
  - ∴ Rate of change of momentum, dp/dt = 2h/λ x Pλ/hc = 2P/c = Force
  - ∴ Pressure exerted by the photons incident on the metallic surface = Force/Area = 2P/cA
- The work function of aluminium is 4.2eV. If two photons, each of energy 2.5eV are incident on the aluminium surface, will photoelectric emission occur?
  - **Only 'one' photon is <u>effective</u> in the emission of one photoelectron, provided its energy is not less than the work function of metal. Since energy of each photon is < 4.2 eV, the photoelectric emission will NOT occur.**

Einstein's photoelectric equation

$$\boxed{K_{max} = hf - \phi_0}$$ hf_0

where h = planck's const $= 6.626 \times 10^{-34}$ Js
f = freq. of incident radiation
ϕ_0 = work function of the metal (matter) → material

$\boxed{hf \rightarrow \text{photon Energy}}$ · depends on the property of the metal ~~nature~~ nature of surface etc.



(a) photon's energy = $E = hf$

(b) —"— Momentum $= p = \frac{E}{c} = \frac{hf}{c}$ $= \boxed{p = \frac{h}{\lambda}}$ $\because c = f\lambda$

$p = \frac{E}{c}$ how?
$\frac{E}{c} = \frac{\text{work}}{\text{velocity}} = \frac{F \times d}{v} = \frac{mad}{v}$
$= m\frac{d}{v}.a = m\frac{d}{\cancel{v}}.\frac{\cancel{v}}{t}$
$= m\frac{d}{t} = \underline{mv}$ momentum

(c) Equivalent Mass of a photon

- we know that energy eq^n of photon $E = hf$ → (1)
- we also know that mass-energy relation if photon is considered as a particle of mass m } $E = mc^2$ → (2)

From (1) & (2) : $hf = mc^2$

$$\boxed{m = \frac{E}{c^2}} \leftarrow \boxed{m = \frac{hf}{c^2}} \longrightarrow (3)$$

→ Since $c = \lambda f$ ∴ $f = c/\lambda$
$m = \frac{h}{c^{\cancel{2}}}\cdot\frac{\cancel{c}}{\lambda} = h/c\lambda$ $\therefore \boxed{m = \frac{h}{c\lambda}}$

(d) Momentum of photon

Momentum $= p = mc$ Using (3)

$p = \left(\frac{hf}{c^{\cancel{2}}}\right)\cancel{c} = \frac{hf}{c} = \frac{h}{\lambda}$

→ $mc = \frac{E}{c}$
$p = \frac{E}{c}$
$\boxed{E = pc}$

$\therefore \boxed{p = \frac{h}{\lambda}}$ which de Broglie wavelength.

$$\boxed{\lambda = \frac{h}{\sqrt{2mE}} \quad \text{if KE 'E' is Constant then } \lambda \propto \frac{1}{\sqrt{m}}} \rightarrow (4)$$

how?

(e) • Velocity of photon in free space (vacuum) = Speed of light = c
• velocity of photon in different media is different due to change in λ.

(f) Rest mass of a photon (m_0)

$$\boxed{m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}} \longrightarrow (5)$$

$\therefore m_0 = m\sqrt{1 - v^2/c^2}$.

Since in vacuum, $v = c$, $m_0 = 0$

$\boxed{\text{Rest mass of a photon} = 0} \longrightarrow (6)$

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{m^2v^2}} = \frac{h}{\sqrt{\frac{2}{2}m^2v^2}} = \frac{h}{\sqrt{2m\cdot\frac{1}{2}mv^2}} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}}$$

Nature of Light: Various Theories (Overview)

Theory	Can explain the following phenomenon of light	Failed to explain the following phenomenon of light
Descartes / Newton 's Corpuscular theory ➢ Light is considered as stream of weightless particles called corpuscles (particles) travelling with very high speed ➢ Predicted wrongly that speed of light increases when light travels from rarer medium to denser medium	➢ Rectilinear propagation of light ➢ Reflection ➢ Refraction	➢ Interference ➢ Diffraction ➢ Polarization ➢ Photoelectric effect ➢ Compton effect
Huygens / Fresnel's Wave theory ➢ Huygens assumed light is longitudinal wave (corrected by Fresnel later that it is transverse in nature) ➢ Assumed a material medium <u>Ether</u>, which was never detected **Maxwell's Electromagnetic (e-m) Wave theory** ➢ Light is a e-m wave ➢ Hence light requires no material medium. ➢ It can travel in vacuum as well	➢ Reflection ➢ Refraction ➢ Interference ➢ Diffraction ➢ Polarization	➢ Rectilinear propagation of light ➢ Photoelectric effect ➢ Compton effect
Einstein's Quantum theory ➢ Used Planck's concept of quantum hypothesis of black body radiation. ➢ As per his theory, light consists of packets of energy known as **<u>Photons</u>**. ➢ Photon is a massless particle which travels with speed of light	➢ Photoelectric effect ➢ Compton effect	➢ Interference ➢ Diffraction ➢ Polarization ➢ Reflection (not satisfactorily explained) ➢ Refraction (not satisfactorily explained) ➢ Rectilinear propagation of light (not satisfactorily explained)

De-Broglie's theory of Dual nature of Light

- Till now, it was established that some physical phenomenon like reflection, refraction, interference, diffraction and polarization of light were explained by considering that light is a WAVE. While the phenomenon like **<u>Photoelectric Effect and Compton Effect</u>** were explained by considering that light is a PARTICLE (**stream of photons**).
- Thus, finally de-Broglie concluded that like "matter", the "light" has dual nature.
- He argued that the nature loves symmetry.
- Our universe is made up of **matter** (material particles like electrons, protons, neutrons, table, ball etc..) and **radiation**. If radiation can behave like a particle (photon), then material particles can also behave like radiation (waves).
- According to de-Broglie, a moving material particle is associated with some wave known as matter wave or de-Broglie wave. Thus, LIGHT has dual nature.
- De-Broglie wavelength of a photon: $\lambda = h/p$
- De-Broglie wavelength of a material particle: $\lambda = h/mv$; this implies if velocity is zero (particle is not moving, it is stationary, then $\lambda = \infty$ meaning no wave)
  - When "matter" is stationary, no waves are associated with it
  - Waves are associated with "moving" matter only.

In summary :

- A complete understanding of dual nature of light was not achieved before the 20's in the 20th century. Experiments conducted by scientists of the time (Davisson, Germer, Thompson and others) proved that electrons (and other "particles") also had a dual nature and presented interference and diffraction properties besides their well-known particle properties.
- The modern theory of quantum mechanics of luminous radiation accepts the fact that light seems to have a dual nature. On one hand, light propagation phenomena find a better explanation within Maxwell's electromagnetic theory. On the other hand, mutual action between light and matter, in the processes of absorption and emission, is a photoelectric phenomenon (corpuscular nature).

Work Function ϕ_o of few metals

The work function (ϕ_o) of a metal is the minimum energy required to pull out (or liberate) an electron from the surface of the metal, without imparting any kinetic energy to the electron.

- In Physics, the electron-volt (eV) is a unit of energy ≈ 1.6×10^{-19} J
- Unit of Volt = joule / coulomb = J/c
- Work function can be measured in electron-volt (eV) ;
  - 1 eV is the amount of energy gained (or lost) by a **single electron** when it is moving across an electric potential difference of **one volt**. Therefore 1 eV = 1.6×10^{-19} C x 1 V = 1.6×10^{-19} J
  - **1 eV = 1.6×10^{-19} J**
  - Eg : If ϕ_o = 5.65 eV (for Platinum) → this means for the emission of photoelectrons from the Platinum metal, the minimum energy of light-photon incident on the metal surface should be 5.65 eV
- Work function of a metal depends upon the properties of the metal, **nature of surface**, impurities etc..
  - *The work function is not a characteristic of a bulk material, but rather a property of the surface of the material*

Approximate values of work functions of some metals

Metal	ϕ_o (in eV)	Metal	ϕ_o (in eV)
Caesium (Cs)	2.14 (least among metals)	Mercury (Hg)	4.50
Potassium (K)	2.30	Tungsten (W)	4.55
Lithium (Li)	2.50	Iron (Fe)	4.60
Sodium (Na)	2.75	Copper (Cu)	4.65
Calcium (Ca)	3.20	Silver (Ag)	4.70
Molybdenum (Mo)	4.17	Gold (Au)	5.10
Lead (Pb)	4.25	Nickel (Ni)	5.15
Aluminium (Al)	4.28	Platinum (Pt)	5.65 (highest among metals)

- **Alkali metals have comparatively lower work functions. Hence lower-energy visible light, which is most easily available, is able to eject photoelectrons from them. See picture below**
- **(Photon energy hf of UV light will be around 12 eV to 120eV).**

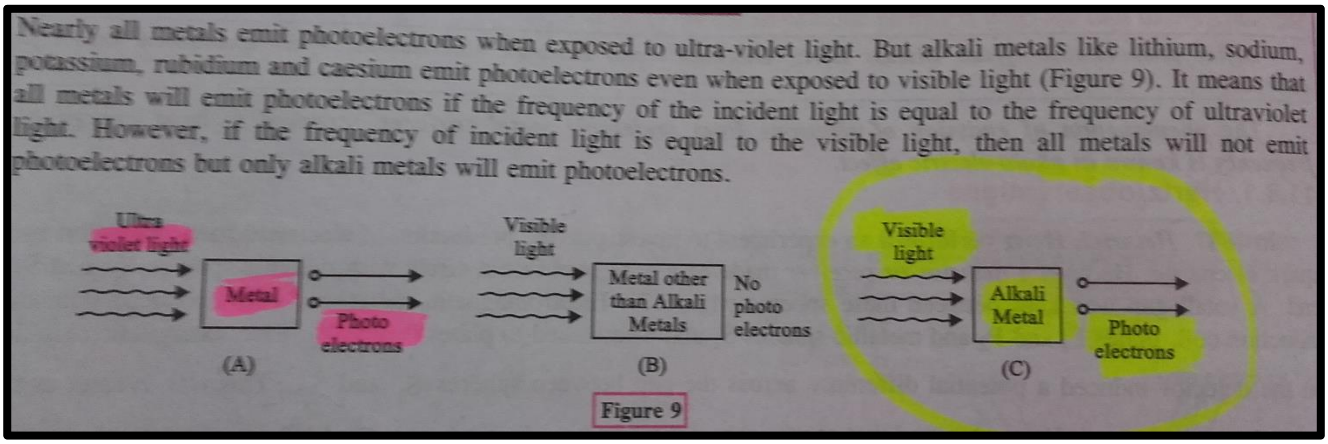

Nearly all metals emit photoelectrons when exposed to ultra-violet light. But alkali metals like lithium, sodium, potassium, rubidium and caesium emit photoelectrons even when exposed to visible light (Figure 9). It means that all metals will emit photoelectrons if the frequency of the incident light is equal to the frequency of ultraviolet light. However, if the frequency of incident light is equal to the visible light, then all metals will not emit photoelectrons but only alkali metals will emit photoelectrons.

Figure 9

- Einstein's photoelectric equation: $\boxed{hf = hf_o + \frac{1}{2}mv^2} = \phi_o + K_{max}$ --------------- (1)
- $\boxed{K_{max} = \frac{1}{2}mv_{max}^2 = hf - \phi_o}$ where
  - K_{max} is the maximum kinetic energy of the electrons
  - m is the mass of electron = 9.1×10^{-31} kg
  - v_{max} is the maximum velocity of the emitted electrons
  - h is Planck's constant = 6.625×10^{-34} Js
  - f is the frequency of the incident radiation ; **hf is the energy of the incident radiation.**
  - **$\phi_o = hf_o$** is the work function of the given metal
  - The photo (light) generated electrons are called **photoelectrons**.
- **From Einstein's photoelectric equation (1), if work function ϕ_o of a given material increases, the kinetic energy of the liberated photoelectrons decreases for a given incident photon energy 'hf'.**

eV is the unit of energy → how ?

How unit eV relates to unit of energy (1 eV = 1.6 x 10^{-19} C x 1 V = 1.6 x 10^{-19} J)

○ SI unit of charge of electron (e) = coulomb ○ SI unit of V = potential energy / coulomb ○ One volt is the potential difference between two points that will impart one joule of energy per coulomb of charge that passes through it. ○ eV = (coulomb)x(potential energy / coulomb) = Energy ; **1 eV = 1.6 x 10^{-19} J**	○ **SI unit of charge of electron = coulomb ; In terms SI base units = As** ○ One volt can be expressed in terms of **SI base units** as ($Kg.m^2.A^{-1}s^{-3}$) since V = Potential energy / Coulomb ○ eV = (As) ($Kg.m^2.A^{-1}s^{-3}$) = Kg m^2 s^{-2} → this is the **base SI unit** symbol for energy ; the SI unit is joule
To convert energy of photon from Joules to eV, the relation is E = (1.2398 x 10^{-6}) / λ eV, where λ should be in meters	

Additional information:

The work is measured by the product of the applied force and the displacement of the body in the direction of the force.

- Work = force * displacement in the direction of force
- If a force F acting on a body produces a displacement S in the body in the direction of force is given by W = FS
- If a force F acting on a body produces a displacement S in the body at an angle θ to the direction of force W = FS Cosθ, where F Cosθ is the component of F in the direction of displacement.
- When θ = 0, W = FS ; when θ = 90°, then W = 0 → when displacement is perpendicular to force, no work is done.
  - When a satellite revolves around the earth, the direction of the force applied by the earth is always perpendicular to the direction of motion of satellite. Hence, no work is done on the satellite by the centripetal force.
- Force and displacement are both vector quantities and hence their scalar (dot) product of $\vec{F}$ and $\vec{S}$ is
  - W = $\vec{F} . \vec{S}$ = FSCos θ ; θ is the angle between $\vec{F}$ and $\vec{S}$
  - Thus, work is the scalar product of force and displacement, and hence is a scalar quantity
  - Dimension : $[MLT^{-2}][L]$
  - Dimensional formula : $[ML^2T^{-2}]$
  - Units :
    - SI unit: joule (J); if a force of 1 newton produces a displacement of 1 meter in the direction of force, the work done is called 1 joule. 1 joule = 1 newton x 1 meter
    - CGS unit: erg. If a force of 1 dyne produces a displacement of 1cm in the direction of force, the work done is called 1 erg. 1 erg = 1 dyne x 1 cm; **1 joule = 10^7 erg**.

- **Energy** of a body is defined as its capacity of doing work. Like work, the energy is also a scalar quantity. **The dimensions, dimensional formula and the units of work and energy are same.**
- Energy is different from power: Energy refers to the total amount of work that a body can do whatever be the time duration in which the work is done. On the other hand, the power of the body is the body's rate of doing work, that is, it depends upon the time in which the work is done.
- Energy has various forms such as **mechanical energy (kinetic energy and potential energy)**, heat energy, light energy, magnetic energy, sound energy, chemical energy etc.…
- Alternative units of work and energy:
  - **Calorie (cal) = 4.186 J**
  - **KWh = 3.6 x 10^6 J**
  - **1 eV = 1.6 x 10^{-19} J ; quantity of electric charge in coulomb © and voltage in volts (V)**
    - **1 eV = 1.6 x 10^{-19} C x 1 V = 1.6 x 10^{-19} J**
    - **By definition, it is the amount of energy gained (or lost) by the charge of a single electron moving across an electric potential difference of one volt**

- **1 erg = 10^{-7} J**
- **1 eV = 1.6 x 10^{-19} J**
- **1 Calorie (cal) = 4.186 J**
- **1 KWh = 3.6 x 10^6 J**

-- 114 aaaa --

(zettaHz = 10^{21}Hz) ; (yottaHz = 10^{24}Hz)

Electromagnetic spectrum

(The electromagnetic spectrum is the range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies. The electromagnetic spectrum covers electromagnetic waves with frequencies ranging from below one hertz to above 10^{25} hertz)

Very Imp

Class			Frequency	λ	1 Photon Energy = hf = hc/λ
Ionizing radiation	γ	Gamma rays	300 EHz (10^{18}) (E=Exa)	1 pm (10^{-12})	1.24 MeV (M= 10^{6})
	HX	Hard X-rays	30 EHz (10^{18})	10 pm (10^{-12})	124 keV
	SX	Soft X-rays	3 EHz (10^{18})	100 pm (10^{-12})	12.4 keV
			300 PHz (10^{15})	1 nm (10^{-9})	1.24 keV
	EUV	Extreme ultraviolet	30 PHz (10^{15})	10 nm (10^{-9})	124 eV
	NUV	Near ultraviolet	3 PHz (10^{15}) (P= peta)	100 nm (10^{-9})	12.4 eV
Visible	NIR	Near infrared	**300 THz (10^{12})**	**1 μm (10^{-6})**	**1.24 eV**
1.6 eV to 3.4 eV: the photon energy of visible light	MIR	Mid infrared	30 THz (10^{12})	10 μm (10^{-6})	124 meV
	FIR	Far infrared	3 THz (10^{12})	100 μm (10^{-6})	12.4 meV
			300 GHz (10^{9})	1 mm (10^{-3})	1.24 meV (m = 10^{-3})
Micro-waves and radio waves	EHF	Extremely high frequency	30 GHz (10^{9})	1 cm (10^{-2})	124 μeV
	SHF	Super high frequency	3 GHz (10^{9})	1 dm (10^{-1})	12.4 μeV
	UHF	Ultra high frequency	300 MHz (10^{6})	1 m	1.24 μeV (μ = 10^{-6})
	VHF	Very high frequency	30 MHz (10^{6})	10 m	124 neV
	HF	High frequency	3 MHz (10^{6})	100 m	12.4 neV
	MF	Medium frequency	300 kHz (10^{3})	1 km (10^{3})	1.24 neV (n = 10^{-9})
	LF	Low frequency	30 kHz (10^{3})	10 km (10^{3})	124 peV
	VLF	Very low frequency	3 kHz (10^{3})	100 km (10^{3})	12.4 peV
	ULF	Ultra low frequency	300 Hz	1 Mm (10^{6})	1.24 peV (pico = 10^{-12})
	SLF	Super low frequency	30 Hz	10 Mm (10^{6})	124 feV
	ELF	Extremely low frequency	3 Hz	100 Mm (10^{6})	12.4 feV (femto = 10^{-15})

Photon energy is the energy carried by a single photon. The amount of energy is directly proportional to the photon's electromagnetic frequency and inversely proportional to the wavelength. The higher the photon's frequency, the higher its energy. Equivalently, the longer the photon's wavelength, the lower its energy.

Photon energy is solely a function of the photon's wavelength. Other factors, such as the intensity of the radiation, do not affect photon energy. In other words, two photons of light with the same colour and therefore, same frequency, will have the same photon energy, even if one was emitted from a wax candle and the other from the Sun.

If photons are in fact massless, photon energy would not be related to mass through equivalence E = mc2. The only two observed kinds of so-called massless energetic particles are photons and gluons. Photons are said to have relativistic mass. Moreover, some hypotheses propose that all mass or "rest mass" might itself actually be composed of stacked relativistic mass, secondary to motion, since no material body is nor can be truly at "rest" relative to all fields. In this hypothesis, as motion becomes zero, mass also becomes zero. On the other hand, photons have motion and varying energy depending on the frequency and wavelength, suggesting that various forms of the photon each have different mass equivalence. Thus, "E = mc2" would show that mass and motion are inextricably linked and fundamentally interchangeable concepts for all matter.

****

Photon energy E= hf = hc/λ ; since c & h are constants ; **c = 3 x 10^{8}ms^{-1} ; h = 6.63 x 10^{-34} Js ; 1eV = 1.6 x 10^{-19} J**

Substituting c, h in the above equation and convert Joule to eV, we get

E = 1.2398 x 10^{-6}/ λ (m) eV , λ in meters ≈ 1.24 x 10^{-6}/ λ (m) eV , λ in meters ; **E = 1.24/ λ (μm) eV, where λ in μm**

Eg : Therefore, <u>ONE PHOTON</u> energy at 1 μm wavelength (*λ of near Infrared radiation*) is ≈ 1.24 eV

Compton Effect

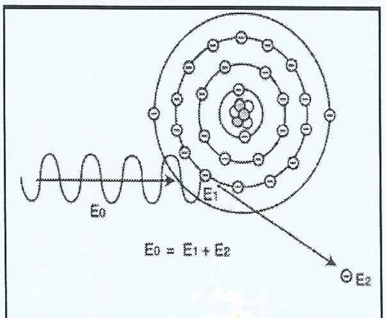
- **Photoelectric Effect :**
  - The first type of ionization is known as the **Photoelectric Effect.**
- **Compton Effect :**
  - The second type of **ionization** is known as the **Compton Effect** (sometimes referred to as Compton Scatter). In this form of **interaction**, the **initial photon energy will be higher than that of the Photoelectric effect**.
  - **The primary difference is that not all of the photon energy will be utilized in "liberating" and "accelerating" an electron. There is also energy left over to cause further ionization.**
  - The "Compton Effect" may occur when photon energies range from approximately **50 KeV to 3 MeV** (**X-rays, gamma rays and above**). Notice that Compton Effect overlaps that of the Photoelectric effect.
  - **At relatively low energies, the Photoelectric effect is the dominant form of interaction, and it becomes less predominant as energy levels increase. It has been determined that the Compton Effect starts slowly and becomes more dominant at energies above 100-150 Kev.**
  - **In the Compton Effect process of ionization, not all of the photon energy is absorbed during the liberation of the electron. This excess energy takes on the form of a new photon having longer wavelength (less energy) than that of the original photon. In addition, the new photon moves through the material in a new path. This is where the term scatter derives from. So what happens with this new photon?**
    - The new photon will continue to interact with the material and its energy may be absorbed in the same manner as the original photon. **The photon may continue to go through several Compton Effect actions depending on its original energy, and eventually it will go through the Photoelectric effect as the energy diminishes.**
    - It should be noted, that the change in the direction of the new photon due to Compton Effect is dependent on the energy of the photon. The higher the energy of the photon, the smaller the change in direction resulting from ionization. Keep in mind that after Compton Effect, the path of the resulting photon is never the same as the original. Relatively low energy photons may result in a direction that is completely opposite the original direction.

Not a very good answer for difference between Photoelectric effect, Compton effect and Pair Production

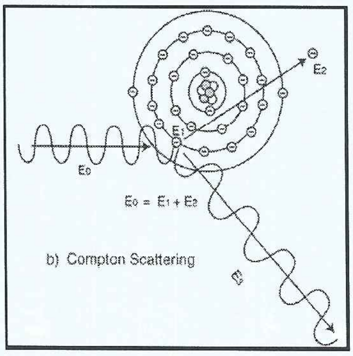
What is the basic difference between a Photoelectric Effect, Compton's effect and Pair Production?

All these 3 methods can be classified in-terms of how an electron interacts with an atom.

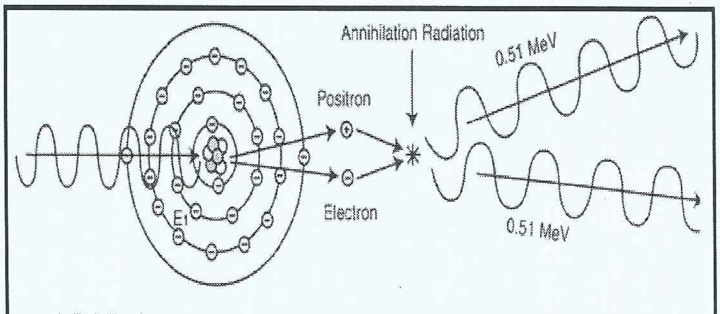
- Suppose we have a **photon**, if it's **energy is above the threshold energy** ϕ_o (called the **work function** of that metal) and then if this photon strikes that metal surface, then it knocks out an **electron from inner shell** of that atom. This process of knocking inner shell electrons is called Photoelectric Effect. Note that this **photon is totally absorbed** in the process.
- Now if that photon strikes the **outer shell electrons,** it may not be **totally absorbed** but part of its energy is transferred to that outer shell electron. In doing so we have a photon whose **energy is reduced** and a **free electron**. Since energy of photon is reduced we have a **change in the wavelength** of that photon. This process is called Compton Scattering or Compton Effect.
- Finally, if the energy of this photon is higher than 1.022MeV, that is the minimum energy required for the pair production of electron-positron pair, then there might be **greater chance** that this photon is **converted in mass** giving two particles an electron and positron. This is called pair production.
- Below is the basis illustration of these processes.



a) Photoelectric Effect



b) Compton Scattering



c) Pair Production

114 aaaaaa

Dual Nature of Radiation and Matter

Radiation

Wave nature of Radiation

This is normal behaviour of any e-m ~~wave~~ radiation

particle nature of light

photoelectric effect

↓

4 expts. & graphs and Conclusion

↓

Wave theory of light cannot explain photoelectric/compton effects

↓

explained by Einstein using photons → packets of energy

- 1 photon energy = hf
- n —— = nhf

↓

Einstein's famous equation to explain photoelectric effect

$$hf = hf_0 + \frac{1}{2}mv^2$$

$$hf = \phi_0 + KE$$

$$hf = \phi_0 + eV_0$$

$$eV_0 = hf - \phi_0$$

$$\boxed{V_0 = \left(\frac{h}{e}\right)f - \frac{\phi_0}{e}}$$

Extra:

$\cos(-x) = \cos x$

$\sin(-x) = -\sin x$

$\tan(-x) = -\tan x$

$\sin(x+2\pi) = \sin x$

~~$\cos(x+2\pi)$~~

$\sin(x+\pi) = -\sin x$

$\sin(x+\pi/2) = \cos x$

Matter

~~Radiation~~ wave nature of Matter (aka Matter waves)

de Broglie' hypothesis

$\lambda = \frac{h}{p} = \frac{h}{mc}$ (for photon)

$\lambda = \frac{h}{p} = \frac{h}{mv}$ (for any other material particle like electron ...)

↓

proved by Davisson & Germer ~~expt~~ expts. on Electrons.

↓

$\lambda_{theory} = 0.165\ nm$ (using Diffraction phenomenon)

$\lambda_{expt(D-G)} = 0.167\ nm$

excellent agreement

↓

proves electrons can behave like wave and also can ~~have~~ undergo diffraction phenomenon.

particle nature of matter

↓

Normal behaviour

$E = mc^2$ also $E = hf$

$\therefore mc^2 = hf$

$$\boxed{m = hf/c^2}$$

$$mc = \boxed{p = \frac{hf}{c}}$$

$c = f\lambda \therefore \frac{c}{f} = \lambda$

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

Force $= \frac{dp}{dt} \approx \frac{p}{t}$

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{m^2v^2}} = \frac{h}{\sqrt{\frac{2}{2}m^2v^2}}$$

$$= \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV_0}}$$

$$\therefore \lambda = h/\sqrt{2meV_0} \text{ or } \lambda = \frac{h}{\sqrt{2mE}}$$

---- 114 b ----

(CET 2018 Question)

The number of photons falling per second on a completely darkened plate to produce a force of 6.62 x 10^{-5} N is 'n'. If the wavelength of the light falling is 5 x 10^{-7}m , then n = __ x 10^{22}

A	1
B	0.2
C	5
D	3.3

Answer : C

We know that $c = f\lambda$ $\therefore$ $\boldsymbol{f = \frac{c}{\lambda}}$ --- **(1)**

*"**Energy**" of a body is defined as its capacity of doing work. Energy refers to the total amount of work that a body can do whatever be the time duration in which the work is done.*

*Whereas, "**power**" of a body is the body's rate of doing work ⇒ it depends upon the time in which the work is done.*

****

- Energy of 1 photon emitted by the source = $\boldsymbol{E = hf}$
- Energy of "n" photons emitted by the source (or work done by the source in emitting n photons $\boldsymbol{E = nhf}$ -- **(2)**
- Power is the rate doing work = $P = \frac{Work}{time} = \frac{work\ done\ or\ total\ energy\ used\ (in\ J)}{Time\ taken\ to\ do\ the\ above\ work\ (in\ s)}$
- $\therefore P = \frac{E}{t}$; $from\ (2), we\ get$ $\boldsymbol{P = \frac{nhf}{t}}$ ---(3)
- LHS of (3) → $P = \frac{Force\ x\ Displacement}{time} = \frac{F.S}{t} = F\left[\frac{s}{t}\right] = Fv$; Since photon travels with the velocity of light, then $v = c$ $\therefore$ $\boldsymbol{P = Fc}$ --------------------- **(4)**
- From (2) & (3), $\boldsymbol{Fc = \frac{nhf}{t} = \frac{nh}{t}f\ ; using\ (1), Fc = \frac{nhc}{t\lambda}}$ $\therefore$ $\boldsymbol{F = \left[\frac{n}{t}\right]\left[\frac{h}{\lambda}\right]}$----**(5)**
- $\boldsymbol{\left[\frac{n}{t}\right]}$ *is the number of photons emitted per "t" second. Given that the source takes 1 s to emit "n" photons, then t = 1 s*
- ***From (5),*** $\boldsymbol{\left[\frac{n}{t}\right] = \left[\frac{F\lambda}{h}\right] \Rightarrow \frac{n}{1s} = \frac{F\lambda}{h} = \frac{(6.62\ x\ 10^{-5}N)\ x\ (5\ x\ 10^{-7}m)}{(6.62\ x\ 10^{-34}Js)} = 5\ x\ 10^{22}}$
- $\therefore \boldsymbol{\frac{n}{1\,s} = 5\ x\ 10^{22}\ means\ "number\ of\ photons\ emitted\ per\ second = 5\ x\ 10^{22}}$

Verifying units for the equation $\left\{\boldsymbol{\frac{n}{t} = \frac{F\lambda}{h}}\right\}$

- $\left[LHS = \frac{1}{s}\right]$
- $\left[RHS = \frac{(\boldsymbol{kg\,.m\,s^{-2}})\ (\boldsymbol{m})}{(\boldsymbol{kg.ms^{-2}m})\ (\boldsymbol{s})} = \frac{\boldsymbol{1}}{\boldsymbol{s}}\right]$ $\therefore$ ***units match***

The cut-off wavelength for a photon able to create electron-hole pair in a semiconductor having energy band gap of 1.6 eV is
A)8050A B)7275A C)7758A D)7000 A

First problem

Formula : $E\ (in\ eV) = \frac{1.24}{\lambda\ (in\ \mu m)}$; Given $E = 1.6\ eV$

$\therefore \lambda = \frac{1.24}{1.6}\ \mu m$ $(1\ \mathring{A} = 10^{-10}\ m)$

$= \frac{12400}{1.6}\ \mathring{A}$

$\boxed{\lambda = 7750\ \mathring{A}}$

Nearest Answer = (c)

1 ~~114bb~~ — ~~114a~~ — ~~114a~~ — 114 bb —

Example 1 : What ~~is the~~ wavelength is predicted for a beam of electrons whose KE is 100 eV ?

we know that $\lambda = \frac{h}{p} = \frac{h}{mv}$

$h = 6.6 \times 10^{-34}$ Joule-sec
$m = 9.1 \times 10^{-31}$ kg
$v = ?$
$1 eV = 1.6 \times 10^{-19}$ J

114bb

Given $KE = K = \frac{1}{2} m v^2$ $\quad K = 100 eV = 100 \times 1.6 \times 10^{-19}$ J

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2 \times 100 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}}$$

$$v = 5.9 \times 10^6 \ ms^{-1}$$

$$p = mv = 5.4 \times 10^{-24} \ kg \ ms^{-1}$$

$$\lambda = \frac{h}{p} = \frac{6.6 \times 10^{-34} \ JS}{5.4 \times 10^{-24} \ kg.ms^{-1}} = 1.2 \ \mathring{A}$$

Ex 2 The wavelength of incident light is 6000 Å. If the work function of the material is 1 eV, calculate the velocity of emitted electron (Take $h = 6.64 \times 10^{-34}$ JS, mass of electron $= 9.1 \times 10^{-31}$ kg)

→ Einstein's photoelectric eqn

$$K_{max} = hf - \phi_0$$

Given
$\phi_0 = 1 eV = 1.6 \times 10^{-19}$ J
λ of incident light $= 6000$ Å $= 6000 \times 10^{-10}$ m $= 6 \times 10^{-7}$ m

$$\therefore f = \frac{c}{\lambda} = \frac{3 \times 10^8 \ ms^{-1}}{6 \times 10^{-7} \ m}$$

$$= 0.5 \times 10^{15}$$

~~$f = 5 \times 10^{14}$ Hz s^{-1}~~

$$f = 5 \times 10^{14} \ s^{-1}$$

$$\frac{1}{2} m v^2_{max} = 6.64 \times 10^{-34} \times 5 \times 10^{14} - 1.6 \times 10^{-19}$$

$$\frac{1}{2} m u^2_{max} = 33.2 \times 10^{-20} - 1.6 \times 10^{-19}$$

$$= (3.32 - 1.6) \ 10^{-19}$$

$$= 1.72 \times 10^{-19} \ J$$

$$v^2_{max} = \frac{2 \times 1.72 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$$v_{max} = \sqrt{\frac{3.44}{9.1} \times 10^{12}} = \sqrt{\frac{3.44}{9.1}} \times 10^6 \ ms^{-1}$$

$$\approx \frac{1.8}{3} \times 10^6 = 0.6 \times 10^6$$

$$= 6 \times 10^5 \ ms^{-1}$$

Matter waves : (from Nootan book)

I In 1924, French physicist de-Broglie reasoned that

(i) Nature loves symmetry

(ii) Our observable universe is composed entirely of matter and (e-m) radiation (light)

(iii) if light (e-m radiation) has dual, wave-particle nature, perhaps "matter" has also.

Thus, according to de-Broglie, all matter in motion (particle) ~~have~~ has wave nature also. (IMP) The waves associated with moving particles of matter are ~~calle~~ called 'de-Broglie waves" or "matter waves"

II de-Broglie wavelength of photon:

- From planck's energy eqn., the energy of photon is given by

$$\boxed{E = hf} \quad (1)$$

$f \rightarrow$ freq. of radiation
$h \rightarrow$ planck's const.

- From Einstein's mass-energy eqn

$$\boxed{E = mc^2} \quad (2) \quad \therefore \quad m = \frac{E}{c^2}$$

where $c \rightarrow$ velocity of light
m = mass of photon.

$$\therefore m = \frac{E}{c^2} = \frac{hf}{c^2}$$

- Momentum of photon $p = mv = \frac{hf}{c^2} \cdot v$

Since photon travels with the velocity of light $v = c$

$$\therefore p = \frac{hf}{c^2} \cdot c = \frac{hf}{c}$$

$$\therefore \boxed{p = \frac{hf}{c}} \quad (3)$$

- Since λ is the dist. travelled by photon in its own time period T, velocity of photon $c = \frac{\lambda}{T} = \lambda f$

$$\therefore \lambda = \frac{c}{f}$$

From (3) $p = \frac{h}{\lambda}$ $\quad \therefore \boxed{\lambda = \frac{h}{p}} \quad (4)$ is the wavelength associated with a photon.

III de-Broglie λ of "matter" waves

He reasoned that nature loves symmetry and "matter" wave also should have a similar eq^n for λ

∴ wavelength associated with "matter"

$$\lambda = \frac{h}{p}$$ p → momentum of "matter" (particle)

— If matter ~~is moving~~ of mass 'm' moving with velocity 'v'

$$\boxed{\lambda = \frac{h}{mv}}$$ IMP

— If $v = 0$ (particle is not moving, it is stationary), then $\lambda = \infty \Rightarrow$ no wave

- When 'matter' is stationary, no waves are associated with it.
- waves are associated with "moving" matter only.

- de-Broglie λ does not depend on whether the moving matter particle is charged or uncharged. ⟹ matter waves are not e-m in nature because e-m waves are generated by motion of charged particles only.

IV de-Broglie λ of "Electron"

We know that $\lambda = \frac{h}{mv}$

If K is the KE of electron $K = \frac{1}{2}mv^2 \quad \therefore v = \sqrt{\frac{2K}{m}}$

$$\therefore \lambda = \frac{h}{m} \cdot \frac{1}{\sqrt{\frac{2K}{m}}} = \frac{h\sqrt{m}}{m \cdot \sqrt{2K}} = \frac{h}{\sqrt{2mK}}$$

$$\therefore \boxed{\lambda = \frac{h}{\sqrt{2mK}}}$$ IMP

is the general formula for moving particle in terms of KE of particle

→ For electron: If the electron acquires KE on being accelerated from rest through a potential difference of V volt, then $K = eV$ where e → charge of electron

$$\therefore \lambda_{electron} = \frac{h}{\sqrt{2meV}} = \frac{6.63 \times 10^{-34}\, Js}{\sqrt{2 \times (9.1 \times 10^{-31}\, kg)(1.6 \times 10^{-19}\, C)(V\ volt)}} = \frac{12.27}{\sqrt{V}}\ \mathring{A}$$

$$\therefore \boxed{\lambda_{electron} = \frac{12.27}{\sqrt{V}} \text{ Å}} = \boxed{\frac{1.227}{\sqrt{V}} \text{ nm}} \quad \left(\begin{array}{l} 1 \text{ Å} = 10^{-10} \text{ m} \\ 1 \text{ Å} = 0.1 \text{ nm} \end{array}\right)$$

V Experimental Demonstration of de-Broglie (matter) ~~waves~~ waves

- Davission and Germer expt on electron diffraction.
- If 'matter' has wave-like property, they are expected to show phenomena like interference and diffraction.

Expt. — D & G did ~~one~~ an electron diffraction experiment and ~~calculated~~ observed $\boxed{\lambda_{electron} = 0.165 \text{ nm}}$ (1.65 Å) [@ V = 54 V]

Theory — From de-Broglie eqn $\lambda = \frac{1.227}{\sqrt{V}} \text{nm} = \frac{1.227}{\sqrt{54}} \text{nm} = 0.167 \text{ nm}$ (1.67 Å)

Thus there ~~which~~ is ~~the~~ excellent agreement betn theory & expt.

IMP: DPS (118) Assignment 10 wave optics (118)

IMP

Q1: In young's double slit expt, the intensity of light at a point on the screen where the path difference is λ is K units. Find the intensity at a point where the path difference is $\lambda/4$

Ans: If the phase difference betw two waves = ϕ, then intensity $I = 4 I_0 \cos^2(\phi/2)$

$$I = K \cos^2\left(\frac{\phi}{2}\right)$$

if path diff = λ, phase diff = 2π $\therefore I = K\cos^2\pi = K$

if ~~phase diff~~ path diff = $\lambda/4$, Phase diff = $\frac{2\pi}{4}$ = $\frac{\pi}{2}$ $\therefore I = K\cos^2\frac{\pi}{4} = \frac{K}{2}$

Q2: In young's double slit expt light of green, yellow and orange colors are successively used. Write the fringe width for the 3 colors in increasing order.

Ans: Fringe width $\beta = \lambda\frac{D}{d}$ when D, d are kept constant, $\beta \propto \lambda$

Since $\lambda_{orange} > \lambda_{yellow} > \lambda_{green}$

$\therefore \beta_{orange} > \beta_{yellow} > \beta_{green}$

$\therefore$ Ans: $\rightarrow$ fringe width in increasing order $\rightarrow \beta_{green}, \beta_{yellow}, \beta_{orange}$

(3) Two coherent sources have intensities in the ratio 25 : 16. Find the ratio of the intensities of maxima to minima, after interference of light occurs?

Given $\frac{I_1}{I_2} = \frac{25}{16}$ $\therefore$ Amplitude ratio $= \frac{\sqrt{I_1}}{\sqrt{I_2}} = \frac{5}{4}$

~~After interference~~

$\therefore \frac{I_{max}}{I_{min}} = \frac{(\sqrt{I_1}+\sqrt{I_2})^2}{(\sqrt{I_1}-\sqrt{I_2})^2} =$

$$= \frac{(\sqrt{I_1}+\sqrt{I_2})^2}{(\sqrt{I_1}-\sqrt{I_2})^2} = \frac{\left(\sqrt{\frac{I_1}{I_2}}+\sqrt{\frac{I_2}{I_2}}\right)^2}{\left(\sqrt{\frac{I_1}{I_2}}-\sqrt{\frac{I_2}{I_2}}\right)^2}$$

$$= \frac{\frac{5}{4}+1}{\frac{5}{4}-1} = \frac{\frac{9}{\cancel{4}}}{\frac{1}{\cancel{4}}}$$

$$= 9$$

Q84) For a given medium, the polarizing ∠ is 60°, what will be the refractive index and critical angle of this medium.

→ Brewster's law is

$n = \tan i_B$ — i_B → polarizing angle or Brewster's angle

$n = \tan 60° = \sqrt{3} = \boxed{1.7}$

If i_c is the critical ∠ of the medium, according to Snell's law for critical ∠

$n = \frac{1}{\sin i_c}$ ∴ $\sin i_c = \frac{1}{n} = \frac{1}{1.7}$

$\sin i_c = 0.5882$

$$\boxed{i_c = 36°}$$

85): Two slits in Young's double slit expt have width in the ratio of 81 : 1. What is the ratio of amplitudes of light waves from them.

→ The intensity of light is directly ∝ to width of the slits

∴ $\frac{81}{1} = \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$

∴ $\boxed{\frac{a_1}{a_2} = 9}$ Ratio of amplitudes of light waves.

Q6) What is the ratio of the slit width when amplitudes of light waves from them have a ratio $\sqrt{2} : 1$

Ratio of intensities $\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{(\sqrt{2})^2}{(1)} = 2$

Since Slit widths $\propto$ intensity.

$$\frac{W_1}{W_2} = \frac{I_1}{I_2} = 2$$

$\therefore$ Ratio of widths $= 2 : 1$

(2) Two plane monochromatic waves propagating in the same direction with amplitudes A and 2A and differing in phase by $\pi/3$ superpose. Calculate the amplitude of the resultant wave.

Resultant amplitude of two superposed waves is given by

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos\phi$$

here $a_1 = A$, $a_2 = 2A$, $\phi = \pi/3$

$$R^2 = A^2 + 4A^2 + 2 \cdot A \cdot 2A \cos 60^\circ$$

$$= 5A^2 + 4A^2 \cdot \frac{1}{2}$$

$$= 7A^2$$

$$\therefore R = \sqrt{7}A \simeq \underline{2.6A}$$

Extra:

if $\phi = 0$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2 \cdot 1$$

$$= (a_1 + a_2)^2$$

$$\boxed{R = a_1 + a_2}$$

if $a_1 = a_2 = a$

$$R = 2a$$

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Q.8) Define the resolving power of a compound ~~microscope~~ microscope. How does the resolving power change when
i) refractive index of medium betⁿ object and objective lens increases.
ii) wavelength of radiation used is increased?
(iii) Diameter of the objective lens is decreased.

→ Resolving power of a compound microscope is the power of the microscope to produce distinctly separate images of the two close objects.

Note Resolving power $= \dfrac{1}{\text{Limit of resolution}}$

Limit of resolution of microscope $= \dfrac{1.22\lambda}{2n \sin\alpha}$

λ = wavelength of Incident light
α = angle of incidence at the objective lens
n = Refractive index betⁿ object and objective lens of Microscope

$\therefore$ $\boxed{\text{Resolving power} = \dfrac{2n \sin\alpha}{1.22\lambda}}$

(i) If μ increases, Resolving power increases
(ii) If λ increases, ——"—— decreases
(iii) If dia. of objective lens is decreased, α decreases hence resolving power decreases.

Q9) State 2 conditions for sustained interference of light. Also write the expression for the fringe width!

→ In order to obtain a well-defined, observable interference pattern, the following conditions must be fulfilled.
(i) The two sources of light should be coherent (same freq, wavelength and ~~const~~ const. phase difference or zero phase difference)
(ii) The separation betⁿ light sources should be as small as possible.

Fringe width $\beta = \dfrac{\lambda D}{d}$

where λ → wavelength of light source
d → dist betⁿ sources
D → dist betⁿ source and screen.

Q10 Two slits in Young's double slit expt are illuminated by 2 different lamps emitting light of same wavelength. What will you observe on the screen?

→ No interference pattern is observed, because light waves emitted from 2 different lamps do not have a constant phase difference. The intensity of bright and dark fringes changes rapidly and continuously with time due to a changing phase difference. Our eyes are unable to see this change because the time of persistence of fringes is much smaller than the time of persistence of vision.

Q11 A slit of width 'd' is illuminated by red light of $\lambda = 6500 \text{ Å}$. For what value of d will
i) the first minimum fall at an ∠e of diffraction of 30°
ii) the first maximum ———————————— of 30°.

→ First Minima formula $a \sin\theta = n\lambda = \lambda \quad (n=1)$

$$a = \frac{\lambda}{\sin\theta} = \frac{6500 \times 10^{-10} \text{ m}}{\sin 30^\circ} = 13000 \text{ Å} = 1.3 \times 10^{-6} \text{ m}$$

→ First Maxima formula $a \sin\theta = (n + \frac{1}{2})\lambda \quad (n=1)$

$$= \frac{3}{2}\lambda$$

$$a = \frac{3}{2} \cdot \frac{6500}{\sin 30^\circ} = 19500 \text{ Å} = 1.95 \times 10^{-6} \text{ m}$$

Q12 Give reason for the following. The value of the Brewster angle for a transparent medium is different for lights of different color?

→ Brewster's formula is given by

$$n = \tan i_B \qquad i_B \rightarrow \text{Brewster's } \angle e$$
$$n \rightarrow \text{refractive index of medium}$$

However, the refractive index of a material depends on the wavelength of light. It is the property of a given material (medium). So Brewster's angle is different for different wavelengths.

Q13 Define resolving power of an astronomical telescope. How does the resolving power get affected on

(i) increasing the aperture of the objective lens
(ii) increasing the λ of light used ?
(iii) — " — the focal length of the objective lens,
iv) If the aperture of the objective lens is doubled, how does it affect the intensity of the image.

→ The resolving power of a telescope is its ability to show two ~~distan~~ distant closely-lying objects as ~~just~~ just separate.

$$\text{Resolving power} = \frac{1}{\text{limit of resolution}}$$

$$\left.\begin{array}{l}\text{Resolving power of}\\ \text{a telescope}\end{array}\right\} = \boxed{\frac{1}{1.22}\frac{d}{\lambda}}$$

where $d \rightarrow$ Aperture of objective, ~~lens~~ lens or diameter
$\lambda \rightarrow$ wavelength of incident ~~light~~ light.

i) if aperture increases, the resolving power ~~increases~~ increases.
ii) if λ increases, the resolving power ~~decreases~~ decreases
iii) if focal length of objective lens increase, the resolving ~~power~~ ~~increases~~ power of the telescope will not change.

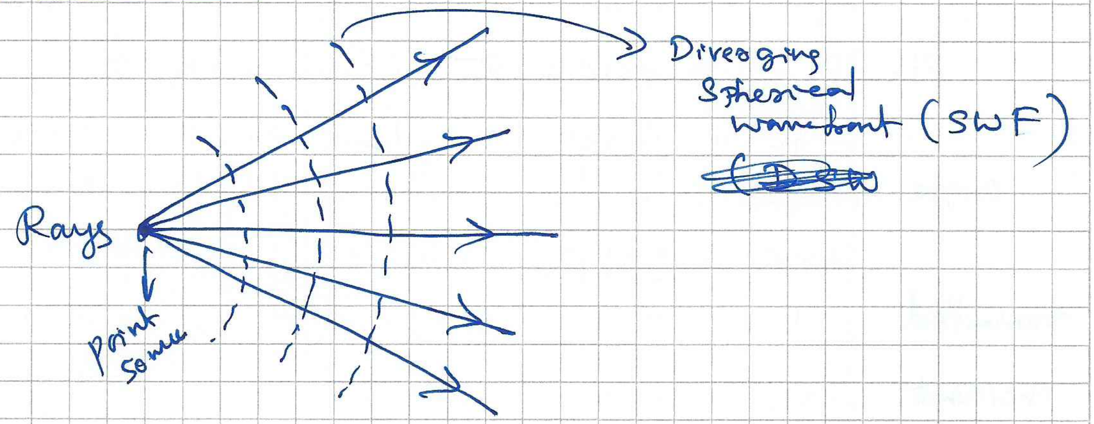
iv) if aperture is doubled, the intensity of ~~images~~ image increases by 4 times ~~as area of the objective lens becomes~~ as the intensity of the image depends ~~on the~~ on the area of the aperture (diameter).

Q14 Draw the shape of the wavefront in each of ~~the~~ the following cases

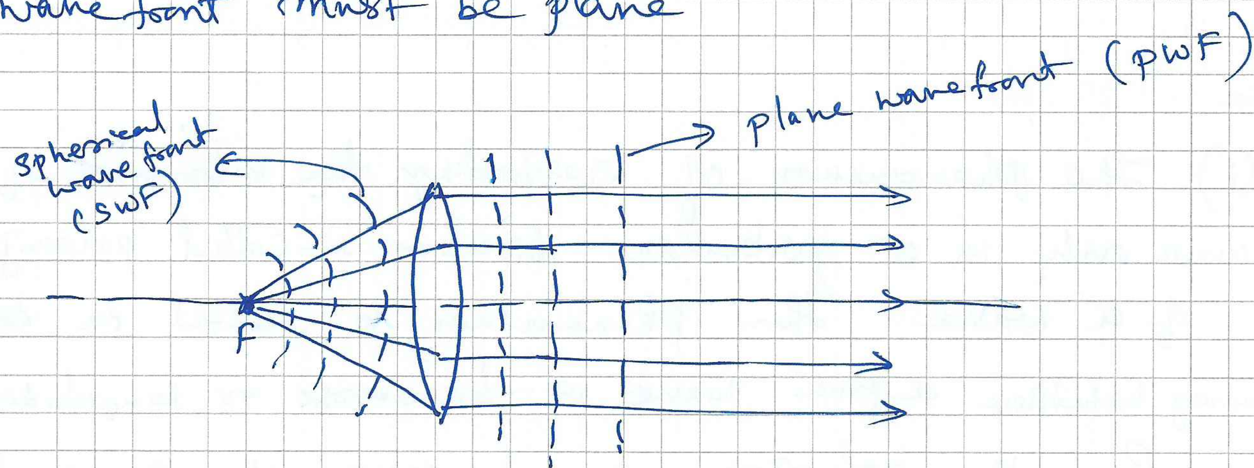
a) light diverging from a point source
b) light emerging out of a convex lens when a point source is placed at its focus
c) the portion of the wavefront of light from a distant star intercepted by the earth.

Ans: (also in pradeep's page 6/190)

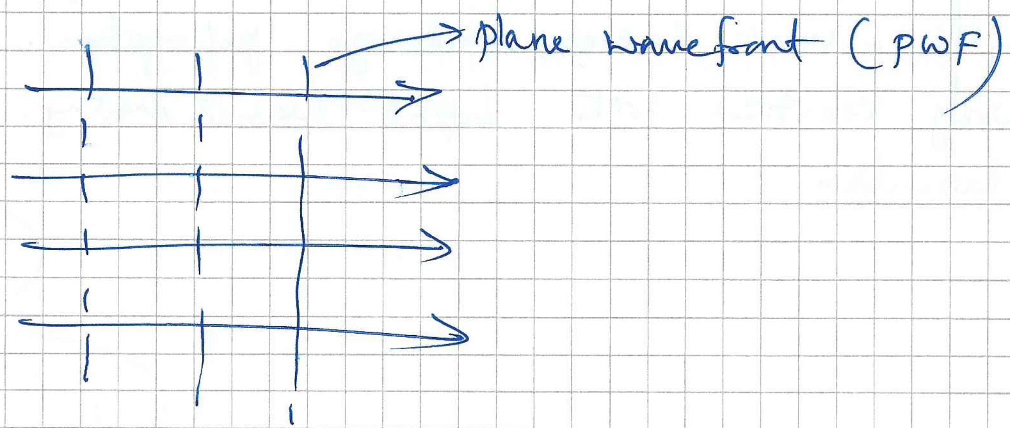
(a) The geometrical shape of the wavefront would be diverging spherical wavefront as shown below



(b) When point source is kept at focus of the convex lens, the refracted rays will be parallel, so the wavefront must be plane



(c) As the star is very far off, the rays are parallel and hence the wavefront intercepted by earth must be a plane wavefront (PWF) as shown below



PTO

Q19) i) What do you understand by polarization of a wave? How does this phenomenon help us to decide whether a given wave is transverse or longitudinal in nature?

(ii) Light from a sodium lamp is passed through a polaroid sheet P1. The transmitted light is then made to pass through a second polaroid sheet P_2 which can be rotated so that the angle θ betw the two polaroids sheets varies from $0°$ to $90°$. Show graphically the variation of the intensity of light, transmitted by P_1 and P_2 as a function of the angle θ. Take the incident beam intensity as I_0.

(iii) Let P_1 and P_2 are placed $90°$ to each other and the transmitted intensity is zero. What happens when one more polaroid is placed betw these two bisecting the angle betw them.

(iv) How will be the intensity vary on further rotating the third polaroid.

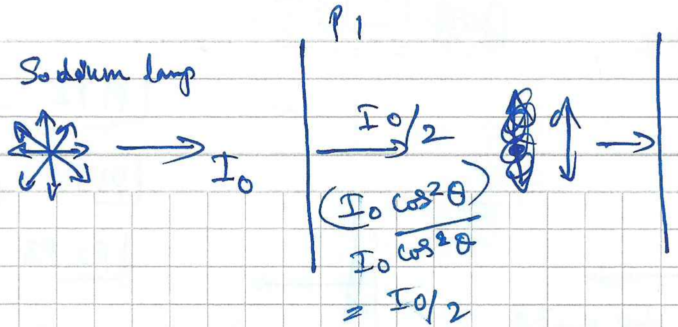
Ans: (i) The phenomenon of restricting the vibrations of a wave only in a particular direction is called polarization of a wave. This phenomenon is useful in determining whether a given wave is transverse or longitudinal.

Since the polarization can occur when the particles of the wave vibrate ⊥ to the direction of motion of wave, and since there can not be any polarization effect when particles vibrate along the direction of wave motion only transverse waves undergo polarization. This can be easily verified with light waves using polaroids.

P.T.O

P.T.O

(ii)

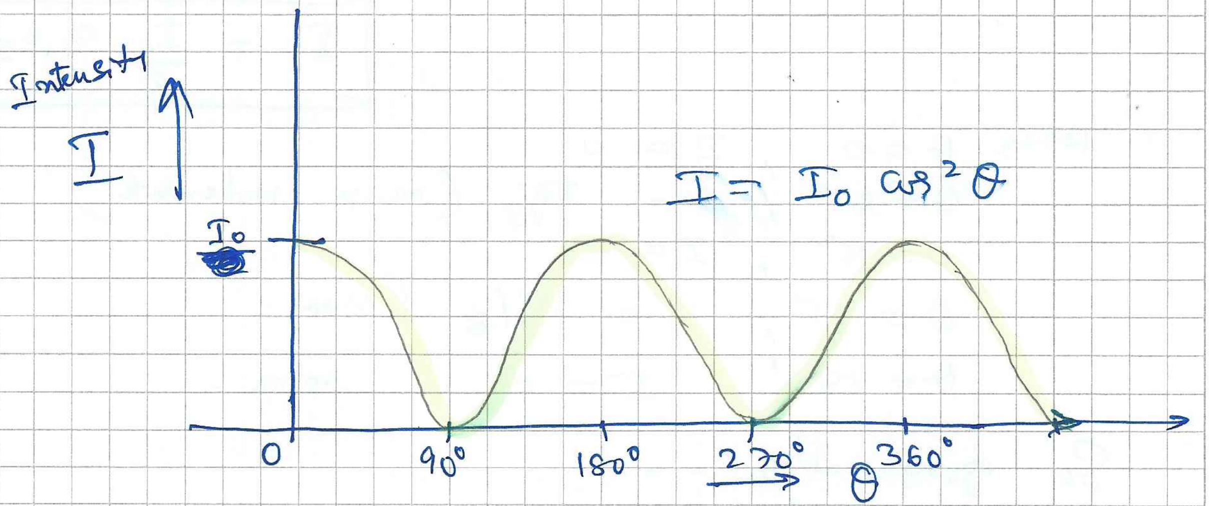


$I = [I_0\cos^2\theta]\cos^2\theta$
$= \frac{I_0}{2}\cos^2\theta$

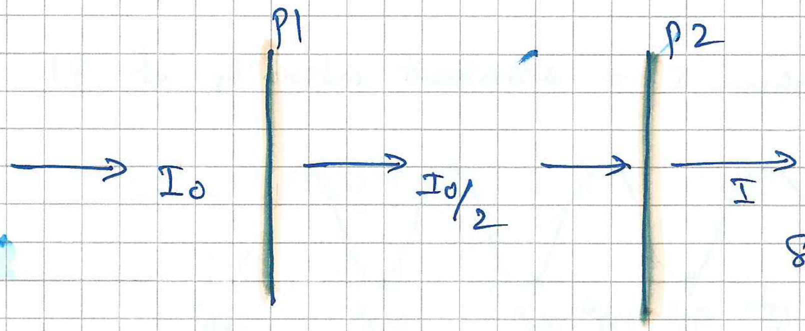
$I = \frac{I_0}{2}\cos^2\theta$

where θ is the angle between pass-axis p1 and pass-axis p2

Since $I \propto \cos^2\theta$, the graph would be a cosine function shifted up from origin (due to $\cos^2\theta$)



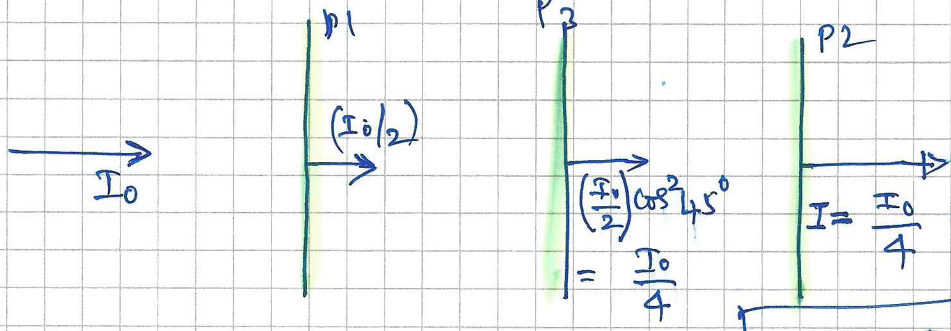
(iii)



$\frac{I_0}{2}\cos^2\theta$

Since ~~cos~~ $\theta = 90°$

$I = 0$



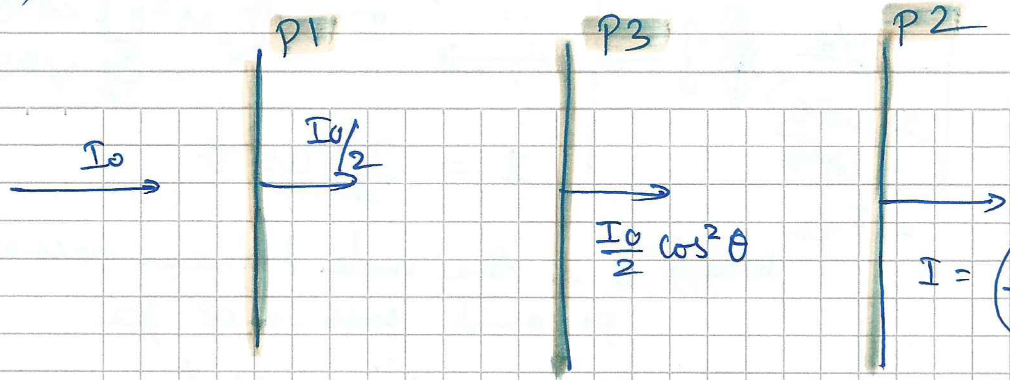
$I = \frac{I_0}{4}\cos^2 45 = \frac{I_0}{4}\cdot\frac{1}{2}$

$$\boxed{I = \frac{I_0}{8}}$$

(iv)

P.T.O

(iv) When rotating P3,



$\angle P1\,P2 = 90^0$

$\angle P1\,P3 = \theta$

$\angle P2\,P3 = 90-\theta$

$$I = \left(\frac{I_0}{2}\cos^2\theta\right)\left(\cos^2(90-\theta)\right)$$

$$= \frac{I_0}{2}\cos^2\theta\,\sin^2\theta$$

$$= \frac{I_0}{2}\cdot\frac{1}{4}(2\sin\theta\cos\theta)^2$$

$$\boxed{I = \frac{I_0}{8}\sin^2 2\theta}$$

$\therefore$ when $\theta = 0$, $I = 0$

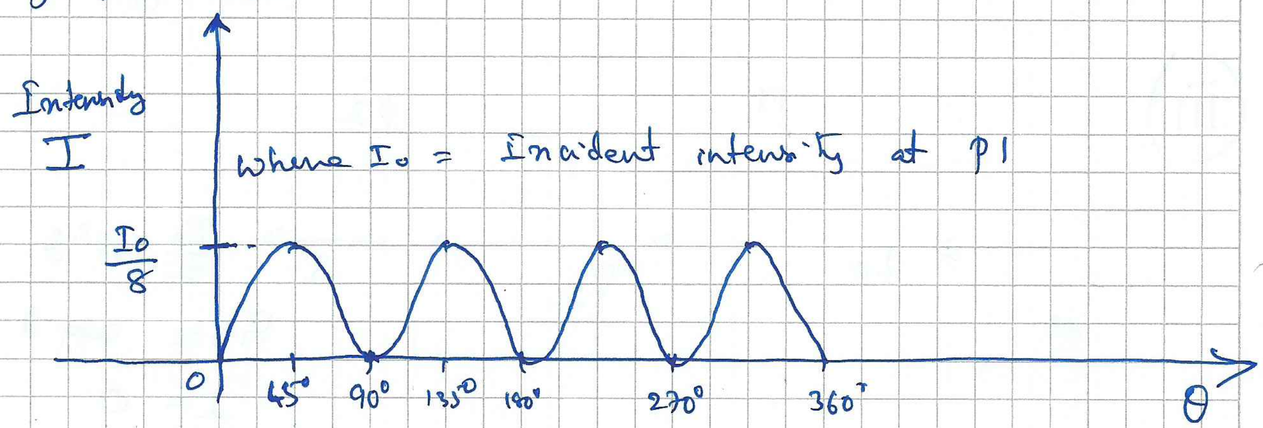
$\theta = 45^0$, $I = I_0/8$ (max intensity)

$\theta = 90^0$, $I = 0$

$\theta = 135^0$, $I = I_0/8$ (max

$\theta = 180^0$, $I = 0$ so on . .

So graphically . . .



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XII : I pre-board Question paper :

Q1: A magnetic needle free to rotate in vertical plane, orients itself with its axis vertical at a certain place on the earth. What are the values of

a) horizontal components of earth's magnetic field?

b) Angle of dip at this place.

Ans:→ (page 186 NCERT book) (a) Since the needle is $\perp^r$ to earth's surface at the "magnetic poles" of the earth, the angle of dip $= 90°$

and since $H = B \cos I$

$= B \cos 90° = 0$

$\therefore$ Horizontal components $H = 0$

(b) Angle of dip $= I = 90°$

(2) What is the power dissipated in an ac circuit in which voltage and current are given by

$V = 230 \sin(\omega t + \pi/2)$ and $I = 10 \sin \omega t$

Ans: power $P = VI \cos\phi$; As the phase difference betw voltage and current is $\pi/2$

since $\phi = \pi/2$

(Modern page 585) $P = VI \cos 90° = 0$

(3) Ultra-violet radiations of different frequencies ν_1 and ν_2 are incident on 2 photosensitive materials having work functions W_1 and W_2, $(W_1 > W_2)$ respectively. The KE of the emitted electrons is same in both the cases. Which one of the two radiations will be of higher frequency?

Ans:- $K_1 = h\nu_1 - W_1$

$K_2 = h\nu_2 - W_2$

Since $K_1 = K_2$; $h\nu_1 - W_1 = h\nu_2 - W_2$

$h\nu_1 = h\nu_2 + (W_1 - W_2)$

Since $W_1 > W_2$, $(W_1 - W_2) > 0$

$\therefore \nu_1 > \nu_2$

(4) How will the drift velocity of the electrons change, if the length of a conductor is doubled, keeping the p.d. across it unchanged?

Ans: Since $v_d = \frac{eE}{m}\tau$ and $E = V/l$

$$v_d = \left(\frac{eV}{ml}\right)\tau \quad \therefore v_d \propto \frac{1}{l}$$

$\therefore$ if length is doubled, v_d is halved.

(5) Identify the part of em spectrum to which the following ~~following~~ wavelengths belong i) 1 mm and 10^{-12} m

Ans: i) 1 mm $\longrightarrow$ Microwaves

ii) 10^{-12} m $\longrightarrow$ X-rays / Gamma rays.

(6) A i) series ii) parallel combination of two given ~~resistors~~ resistors is connected, one by one, across a cell. In which case ~~will the~~ will the terminal p.d. across the cell have a higher value?

Ans: parallel ~~Series~~ Combination

Since in parallel ~~series~~ combination, the ~~effective~~ total Resistance in the ~~is the~~ ~~$R = R_1 + R_2$ is greater and~~ ~~p.d. across it is also higher~~ current is lower, current ~~is more~~ is more and hence drop across the cell is higher.

~~whereas in parallel combination $R = \frac{R_1R_2}{R_1+R_2}$~~, ~~$R < R_1$ and R_2~~

p.d. across it is ~~is~~ smaller.

(8) the wavelengths of some of the spectral lines obtained in hydrogen ~~hydrogen~~ spectrum are 9546 Å, 6463 Å and 1216 Å, which of these wavelengths belong to Lyman series.

Ans: $\frac{1}{\lambda} = R\left[1 - \frac{1}{n^2}\right]$ $n = 2, 3, 4$

for $n = 2$; $= 10^7\left[\frac{3}{4}\right]$ $\therefore \lambda = \frac{4}{3} \times 10^{-7} = \frac{4000}{3}$ Å

$\simeq 1216$ Å

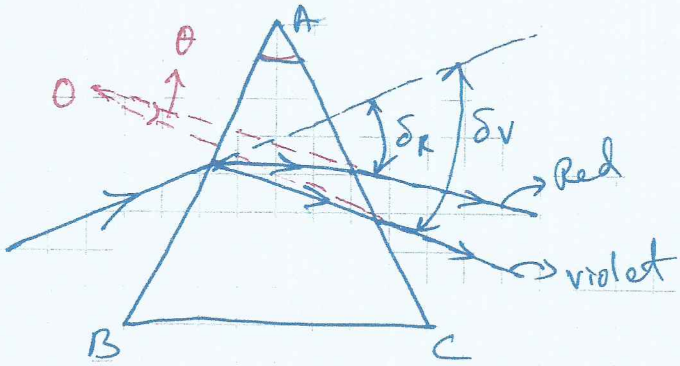
for $n = 3$; $\frac{1}{\lambda} = R\left[1 - \frac{1}{9}\right]$ $\lambda = \frac{9000}{8 \times 1.09}$ Å $\simeq 1032$ Å

$= R\frac{8}{9}$

$\therefore$ Ans 1216 Å belongs to Lyman series. ~~series~~

Q17) Define the term angular dispersion. Draw the path of ray of white light passing through a prism and mark angular dispersion on it. How can you produce deviation without ~~disp~~ dispersion

> The angle between the emergent rays of any two colors is called 'angular dispersion' between those colors.



$\theta = \delta_V - \delta_R$

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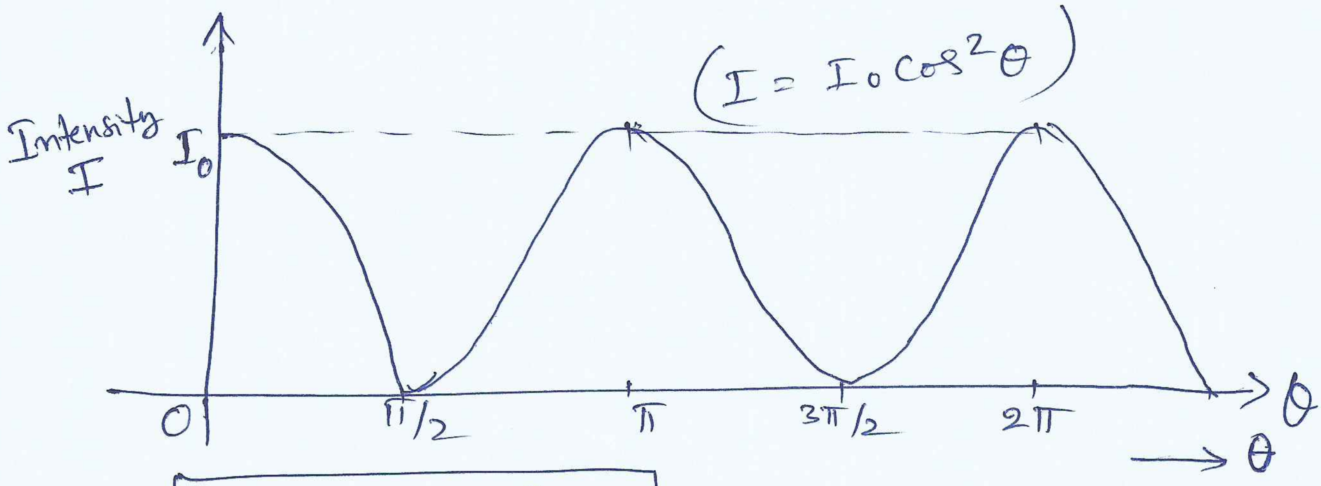
Deviation without dispersion can be produced by passing light through a rectangular glass slab (lateral deviation). It can also be found by using 2 prisms (one of ~~the~~ them inverted).

Q: A partially polarized beam of light is passed through a polaroid. Show graphically the variation of the transmitted light intensity with the ~~angle~~ angle of rotation of the polaroid.

Ans:



$$\boxed{I = I_0 \cos^2\theta}$$

$\therefore$ ~~p.d. across 15 Ω~~ = ~~I × 15~~ ~~128~~

 $= \cancel{\frac{24}{47} \times 15} = \cancel{\frac{360}{47}} = \cancel{7.66\,V}$

Q23) Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW.

NCERT page 407

i) find the energy and momentum of each electron in the light beam.

ii) how many photons per second, on the average, arrive at a target irradiated by this beam? (assume the beam to have the uniform cross section which is less than the target area)

(i) $E = h\nu = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}) \times (3 \times 10^{8})}{632.8 \times 10^{-9}} = 3.14 \times 10^{-19}\ J$

$\lambda = \frac{h}{p} \quad \therefore \quad p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{632.8 \times 10^{-9}} = 1.05 \times 10^{-27}\ kg\,m\,s^{-1}$

ii) $N = \frac{\text{Power}}{E} = \frac{9.42 \times 10^{-3}\ W}{3.14 \times 10^{-19}\ J} = 3 \times 10^{16}$ photons/sec

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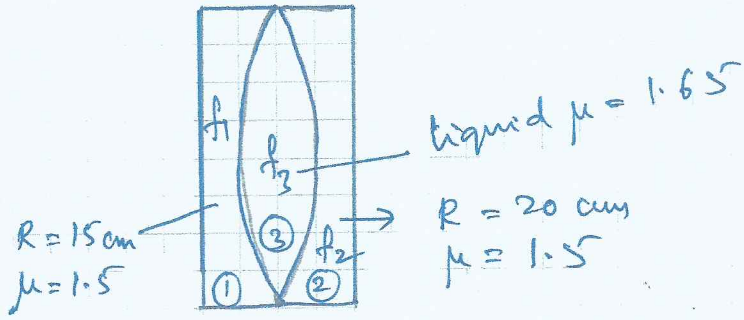
(Q27) Two plano-concave lenses of glass of μ 1.5 each, radii of curvature 15 cm and 20 cm respectively are placed in contact with the curved faces towards each other. The space betw curved faces is filled with a liquid of μ 1.65. Find the focal length of the combination.



$$\frac{1}{f_1} = (\mu-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left(\frac{1}{\infty} - \frac{1}{15}\right)$$

$$= -\frac{0.5}{15} = -\frac{5}{150} = -\frac{1}{30}$$

$$\boxed{f_1 = -30 \text{ cm}}$$

$$\frac{1}{f_2} = (\mu-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0.5\left(-\frac{1}{20}\right) = -\frac{1}{40}$$

$$\boxed{f_2 = -40 \text{ cm}}$$

$$\frac{1}{f_3} = (0.65)\left(\frac{1}{15} - \frac{1}{-20}\right) = 0.65\left(\frac{1}{15} + \frac{1}{20}\right) = 0.65\left(\frac{4+3}{60}\right)$$

$$\frac{1}{f_3} = \frac{0.65 \times 7}{60}$$

$$\boxed{f_3 = \frac{60}{0.65 \times 7} = \frac{60}{4.55} \simeq 13 \text{ cm}}$$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} = -\frac{1}{30} - \frac{1}{40} + \frac{1}{13}$$

$$= \frac{-4-3}{120} + \frac{1}{13}$$

$$\frac{1}{f} = -\frac{7}{120} + \frac{1}{13} = \frac{-91+120}{120 \times 13} = \frac{29}{120 \times 13}$$

$$\boxed{f = \frac{120 \times 13}{29} \simeq 53 \text{ CM}}$$

(Q30) i) Draw a ray diagram to show the formation of image of a distant object by an astronomical telescope in normal adjustment position.
ii) Define the terms magnifying power and resolving power of a telescope. Write the expression for both.
iii) Explain with reason, how the resolving power of an astronomical telescope will change when
a) the frequency of incident light on the objective lens is increased
b) aperture of the objective lens is halved.

(i) See this book for ray diagram page -136-

(ii) Magnifying Power of a telescope is the extent to which the object is captured and enlarged

$$m = -\frac{f_o}{f_e}$$ (-ve sign indicates that the final image is inverted)

Resolving power of a telescope is the ability of the instrument to produce distinctly separated images of two closely spaced objects.

$$RP = \frac{d}{1.22\lambda}$$ where d = aperture of objective lens
λ = wavelength of incident light.

(Limit of resolution $= \frac{1}{RP}$)

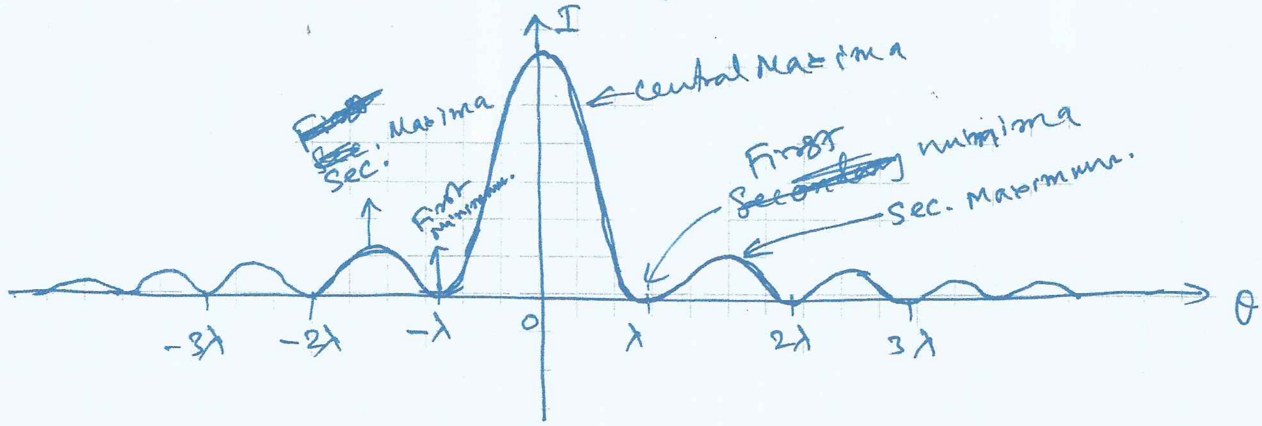
(iii) Since $RP = \frac{d}{1.22\lambda}$

a) As f increases, λ decreases, RP increases.
b) When aperture of objective lens is halved, RP is also halved.

(130(b)) i) What is meant by diffraction of light? State the essential condition for diffraction of light to take place.
ii) Draw a graph showing the variation of intensity with angle in a single slit diffraction experiment.
iii) How would the linear width and intensity of ~~centr~~ central maximum change if monochromatic yellow light is replaced with red light
iv) A slit of width 'd' is illuminated by red light of $\lambda = 6500\,\text{Å}$. For what value of 'd' will
a) the first minimum fall at an angle of diffraction of $30°$
b) the first maximum fall at an angle of diffraction of $30°$

1) (i) Diffraction is the bending of light around an obstacle when the obstacle size is comparable to the wavelength of the incident light.
The essential condition for diffraction is size of the obstacle or aperture should be comparable to the wavelength of the incident light; then there is a departure from straight line propagation and the light bends around the corners of the obstacle or aperture and enters the geometrical shadow.
Diffraction is a characteristic of wave-motion.

(ii)



~~(iii) Since red is having longer wavelength, the linear width will increase (as compared to yellow light) and the intensity of central maxima reduces. diffraction fringes become broader and farther apart. And the intensity of central maxima reduces.~~

(iii) Since red is having longer wavelength, the central maximum is broadened and hence its intensity decreases.

(iv) (a) The angular position θ of the first minimum fall is

$\sin\theta = \frac{\lambda}{d}$ $\qquad \sin\theta = \sin 30^\circ = 0.5$

$d\sin\theta = n\lambda$
$n = 1$

$d = \frac{\lambda}{0.5} = 2\lambda = 2\times 6500 = 13000\ \text{Å}$
$= 1.3\times10^{-6}\ m$

(b) The angular position θ of the first maximum wrt the central maximum is given by

$\sin\theta = \frac{3\lambda}{2d} = 0.5 \qquad 3\lambda = d$

$d\sin\theta = (n+\frac{1}{2})\lambda$
$n = 1$

$d = 3\lambda = 3\times6500 = 19500\ \text{Å}$
$= 1.95\times10^{-6}\ m$

problem: The work function of a certain metal is 4.2 eV. Will this metal give photoelectric effect for an incident radiation of $\lambda = 330$ nm?

Given → Work function of metal $\phi_0 = 4.2$ eV → ①
→ Incident Radiation $\lambda = 330$ nm → ②

using ②, we need to calculate E_{photon} in eV.

There is a very simple formula to calculate E_{photon} in eV.

$$\boxed{E = \frac{1.24 \times 10^{-6}}{\lambda(m)}} \to ③ \quad \text{OR} \quad \boxed{E = \frac{1.24}{\lambda(\mu m)}} \to ④ \quad \text{OR} \quad \boxed{E = \frac{1240}{\lambda(nm)}} \to ⑤$$

λ should be in meters

where λ should be in μm

where λ should be in nm.

using eqn ⑤, $E = \frac{1240}{\lambda(nm)} = \frac{1240}{330} \simeq 3.8$ eV

Since $E_{incident\ photon}$ (3.8 eV) < work function ($\phi_0 = 4.2$) of metal ~~no electr~~ no photoelectric effect takes place.

how? we know that $\boxed{E = hf = \frac{hc}{\lambda}} \to ⑥$

In eqn ⑥, h & c are constants, simplify as below

$h = 6.63 \times 10^{-34}$ Js
$c = 3 \times 10^{8}$ ms^{-1}
$1\,eV = 1.6 \times 10^{-19}$ J
$1\,J = \frac{1}{1.6 \times 10^{-19}}$ eV

$\therefore hc = (6.63 \times 10^{-34} \cancel{Js})(3 \times 10^{8} m\cancel{s^{-1}})$

$hc = 19.89 \times 10^{-26}$ J . m

$\therefore hc = (19.89 \times 10^{-26})\left(\frac{1}{1.6 \times 10^{-19}} eV\right) . m$

$= \left(\frac{19.89}{1.6}\right)\left(\frac{10^{-26}}{10^{-19}}\right)$ eV . m

$hc \simeq 12.4 \times 10^{-7}$ eV . m

~~hc = 12~~ $hc = 1.24 \times 10^{-6}$ eV . m

$\therefore E = \frac{hc}{\lambda} = \frac{1.24 \times 10^{-6} eV . \cancel{m}}{\lambda\ \cancel{m}}$

$$\boxed{E = \frac{1.24 \times 10^{-6} eV}{\lambda(m)}} \quad \text{or} \quad \boxed{\frac{1.24\ eV}{\lambda(\mu m)}} \quad \text{or} \quad \boxed{\frac{1240\ eV}{\lambda(nm)}}$$

Given λ should be entered in meters

Given λ should be entered in μm

Given λ should be entered in nm

In the above problem λ is given as 330 (nm), so use this $\frac{1240}{\lambda(nm)} = \frac{1240}{330} \simeq 3.8$ eV

These two are very useful since generally λ is given in nm or μm.