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DAWN of the MODERN PHYSICS

→ **Introduction:** Plank's quantum theory in 1900 and Einstein's theory of relativity inspired new theories and developments in the fields of atomic, nuclear and condensed-matter physics.

→ **Reference frames:** "A coordinate system in which an experimenter makes position and time measurements of physical events is called as a reference frame."

To record an event experimenter uses a reference frame that consists of ~~to~~ a set of x, y, z axes (called a coordinate system).

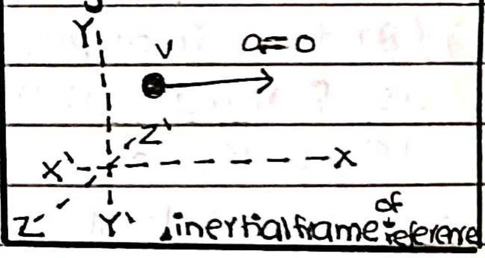
A. Inertial Reference Frame:

"An inertial frame is one in which an object subjected to no forces moves in a straight line at constant speed."

→ **Newton's First Law of motion** holds true in an inertial reference frame

→ **Example:** a stationary or uniformly moving car with no acceleration. A stationary room; A space craft in deep space without encountering significant gravitational forces or external disturbances

Diagram:



B. Non-Inertial Reference Frame:

"An accelerating frame of reference is called a non inertial frame of reference"

→ Newton's First law isn't hold true, forces act on objects.

→ **Example:** Accelerating elevator, car making a turn

→ **Is Earth's surface an inertial or non-inertial frame?**

In small scale observations, Earth's surface can be approximated as an inertial frame. But for large scale observations, earth's rotation is taken in account and Earth is considered as non inertial reference frame for example to analyze a meteor falling towards Earth, Earth's rotation is considered.

→ **Special Theory of Relativity:** In Physics, the special theory of relativity, or special relativity for short, is a scientific theory of relationship between space and time. The theory presented in 1905 is based on just two postulates.

1. The Principle of Relativity: "The laws of physics are same in all reference frames which are inertial."

→ **Elaboration:** Physical laws help us understand how and why our envirorment reacts the way it does. As per this postulate pouring of tea in aeroplane moving with constant speed is same as that on Earth.

2. The Principle of Constancy of speed of light:

" The speed of light in a vacuum has the same value $c = 2.99792458 \times 10^8 ms^{-1}$, in all inertial reference frames regardless of the velocity of observer or the velocity of source emitting the light."

→ **Elaboration:** Suppose you are present in a car with velocity $40 ms^{-1}$. If a car having velocity $80 ms^{-1}$ passes by your car, crossing it, the velocity of that car will appear $40 ms^{-1}$ to you. Now if another car with $80 ms^{-1}$ passe by your car but in opposite direction, the speed will appear to you as $80 + 40 = 120 ms^{-1}$. **but** speed of light remains constant regardless of wether the source emitting light is moving with respect to observer or not.

→ **Consequences of Special Theory of Relativity:**

A. Simultaneity: "Two events that are simultaneous in one frame are in general not simultaneous in a second frame moving with respect to the first."

→ **Thought experiment of Einstein:** Consider a boxcar having ends A' and B. Suppose an observer O' in the boxcar and O on the ground. Box car moves with uniform velocity and two lightening bolts strike the ends of the box

According to observer O: Light strikes A and B simultaneously.

According to observer O`: light strikes front of box first and rear end of box afterwards

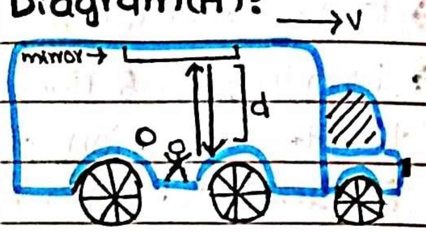
→Conclusion: Due to different reference frames, observers can never agree on simultaneity of event. Both are correct with respect to their reference frames.

B. Time Dilation:

"The time taken for an event to occur within its rest frame is called proper time Δt_p. Observers in different frames in relative motion will always judge the time to be longer called time dilation Δt."

→Mathematical Proof: Consider a vehicle moving with speed v having a mirror fixed at ceiling. A laser at distance 'd' emits a pulse of light towards mirror and its reflected back covering total distance of 2d.

Diagram(A):



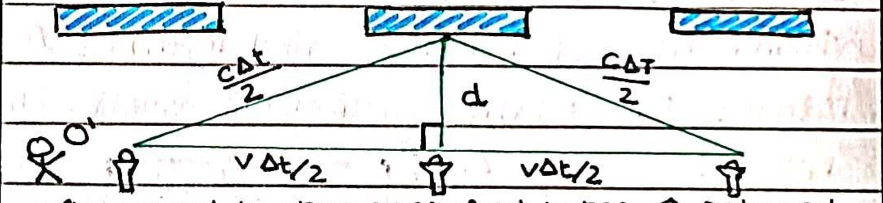
▲ with respect to observer O

According to observer O: Sitting inside the vehicle, time taken by light to travel 2d is ΔT_p or proper time

According to observer O`: Distance is traveled in a time larger than proper time

→Mathematical Calculations:

Diagram (B):



▲ with respect to observer O', light takes ^ path and hence travels a greater distance.

Consider diagram (A)

(O's frame of reference)

$S = vt$

$S = v\Delta t_p$ (proper time)

$S = c\Delta t_p$ where c = speed of light.

But total distance travelled by light is d+d or 2d thus

$\boxed{2d/c = \Delta t_p}$ (i)

Consider Diagram (B) (O`'s frame of reference) Right angle triangle is obtained

Applying Pythagora's theorem; $\left(\frac{c\Delta t}{2}\right)^2 = (d)^2 + \left(\frac{v\Delta t}{2}\right)^2 \rightarrow \frac{c^2\Delta t^2}{2^2} = \frac{v^2\Delta t^2}{2^2} + d^2$

$\frac{c^2\Delta t^2}{2^2} - \frac{v^2\Delta t^2}{2^2} = d^2$, $\frac{\Delta t^2}{2^2}(c^2 - v^2) = d^2$ taking $\sqrt{}$ b.s $\sqrt{\Delta t^2} = \sqrt{\frac{2^2 d^2}{c^2 - v^2}}$

$\Delta t = 2d/\sqrt{c^2 - v^2}$ taking $\sqrt{c^2}$ common $\Delta t = \frac{2d}{\sqrt{c^2}} \cdot \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $\Delta t = \frac{2d}{c} \times \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

From eq(i) $\boxed{\Delta t = \frac{\Delta t_p}{\sqrt{1 - \frac{v^2}{c^2}}}}$

- where Δt = time observed in other frame of reference
- Δt_p = time in observer's own frame of reference
- v = velocity of moving object. • c = speed of light.

→ **What does the equation for time dilation tell us?** Time intervals Δt in a moving frame of reference appear dilated or stretched compared to the time intervals Δt_p in a stationary frame. In practical terms this means that time appears to pass more slowly for an observer in motion at high speeds. The faster you move through space, the slower you move through time.

C. Length Contraction:

"The length of an object measured within its rest frame is called proper length ΔL_p. Observers in different frames in relative motion will always measure the length to be shorter called length contraction."

→ **Mathematically:** $\boxed{\Delta L = \Delta L_p \sqrt{1-\frac{v^2}{c^2}}}$ $\boxed{\Delta L < \Delta L_p}$ as $\boxed{\sqrt{1-\frac{v^2}{c^2}} < 1}$

→ length contraction only happens along the direction of motion.

→ length contraction can not be observed when length is perpendicular to the direction of motion.

Example: Distance from Earth to a star measured by an observer in a moving space ship would seem smaller than the distance measured by an observer on Earth frame.

D. RELATIVISTIC MASS:

"The mass of an object measured within its rest frame is called restmass Δm_o. Observers in different frames in relative motion will always measure mass to be greater called relativistic mass Δm."

→ **Mathematically:** $\boxed{\Delta m = \frac{\Delta m_o}{\sqrt{1-v^2/c^2}}}$ $\boxed{\Delta m > \Delta m_o}$

Therefore relativistic mass during motion is greater than rest mass.

E. Mass Energy Equivalence:

"Mass of an object is equivalent to certain quantity of energy"

→ **Mathematically:** $\boxed{E=mc^2}$

F. Speed Limit:

"An object's speed must be less than the speed of light. This speed limit applies only to material objects."

→ **Mathematically:** calculations of expanded times and contracted lengths involve the expression $\sqrt{1-\frac{v^2}{c^2}}$. For calculations to be true, $\boxed{v^2/c^2 < 1}$ This implies $\boxed{v<c}$

→ **What happens if v=c?** let us put values in formula $\Delta t = \frac{\Delta t_p}{\sqrt{1-\frac{v^2}{c^2}}}$ or $\Delta t = \Delta t_p \div \sqrt{1-c^2/c^2}$, $\Delta t_p = \Delta t_p/\sqrt{1-1}$ $\boxed{\Delta t=\infty}$

This is undefined thus object's speed must be less than speed of light.

→ **Photon's rest mass is considered zero, why?**

Photon moves with the speed of light. If rest mass or actual mass of proton isn't considered zero, apparent mass becomes equal to infinity. To escape this mathematical controversy, we must consider $m_o = 0$.

Mathematically: $m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$ as for photon $v=c$ thus $m = \frac{m_o}{\sqrt{1-\frac{c^2}{c^2}}}$, $m = \frac{m_o}{\sqrt{1-1}}$ or $m = \frac{m_o}{0}$, $\boxed{m=\infty}$ (x)

→ to escape this situation (equation x) let us put $m_o = 0$ this way $m=0$ and not infinity.

→ **Black Body Radiation**: "The electromagnetic radiation emitted by objects because of their temprature, are called thermal radiations."

→ **Explanation:** Every body regardless of being cold or hot absorbs a certain portion of electromagnetic spectrum and emits it. It is not the same as reflection as in phenomena of reflection, there is no absorbance occuring first.

→ **Example:** When a knife is heated, it glows in red colour

→ **Strongly and weakly emitting waves:** At lower tempratures, cooler objects emit visible light waves onlly weakly and do not appear to glow like human body at 310K. On the other hand, hot objects emit waves strongly in the visible spectrum thus appear to glow.

Perfect black body: A perfect black body at a constant temp.

absorbs and re-emits all the electromagnetic radiation that fall on it. Radiations emitted by black body are called black body radiations."

→ Ideal black body doesn't exist.

→ **Absorption power:** of an ideal black body is equal to 1

★ Some important relations:

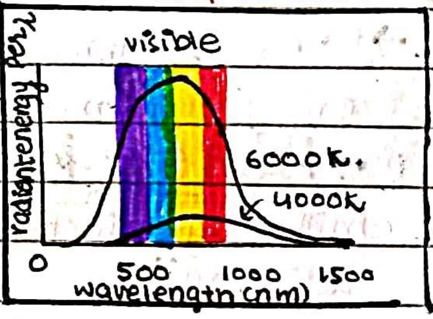
→ Temprature ∝ 1/wavelength	$T \propto 1/\lambda$
→ Temprature ∝ energy	$T \propto E$
→ Energy ∝ 1/wavelength	$E \propto 1/\lambda$
→ Energy ∝ frequency	$E \propto f$
→ Frequency ∝ 1/wavelength	$f \propto 1/\lambda$

↖ Grab The Concept ☺

When platinum wire is heated it appears dull red about 500°C, cherry red at 900°C, orange red at 1100°C, yellow at 1300°C and white at 1600°C. Because $T \propto 1/wavelength$

A. Wein's Displacement Law:

"With increase in temprature T the peak of radiation curve shifts toward shorter wavelength (i.e T and λ_{max} are inversely proportional and the product of the peak wavelength λ_{max} and Temprature is constant."



→ **Mathematically:** $\lambda \propto 1/T$, $\lambda \propto 1/Energy$

$\boxed{\lambda_{max}T = constant}$ where constant equal 0.2898×10^{-2} mK

B. Stephen-Boltsmann Law:

"Total energy radiated per unit area is directly proportional to fourth power of absolute temprature of black body."

→ **Mathematically:** $E \propto T^4$ or $\boxed{E = \sigma T^4}$ where σ is called stephen's constant.

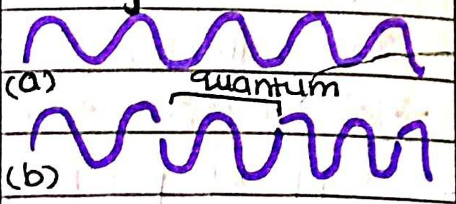
→ **What are the drawbacks of these laws?** Weinn's law is true for shorter wavelengths but not longer wavelengths. Overall both these laws are formulated in the light of perspective that absorbance and emittance is a continuos process which isn't true. Max Plank removed these flaws.

→ Planck's Quantum Theory:

1. "The vibrating molecules of the black body cavity which emitted radiations where only having discrete amount of energy En."

→ **Mathematically:** $\boxed{E_n = nhf}$ where n is an integral integer. $h = 6.626 \times 10^{-34}$ J s

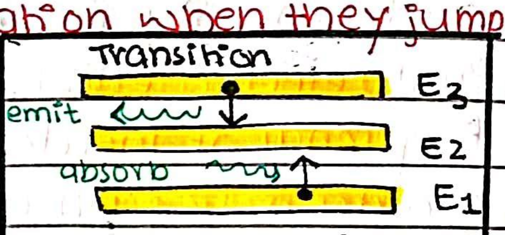
Diagram:



(b) is the correct procedure of absorbance or emittance of radiation. (a) is continuous form which is incorrect

→ **Concept of quanta:** PKMZ Quanta is just like a packet of biscuit biscuits are sold in discrete packets, similarly light or radiation is emitted or absorbed in discrete bundles called quanta or photon.

2. "Atoms or molecules emit or absorb radiation when they jump from one quantum state to another. If it remain in one quantum state, no energy is emitted or absorbed."



▲ Jumping to lower (E_1) and Jumping to higher (E_3).

→ Photoelectric Effect:

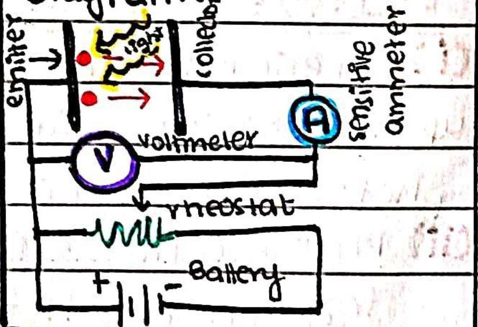
"When light hits the metal surface, electrons are emitted, the phenomena is called photoelectric effect and electrons emitted are called photo-electrons."

→ Beam of light having short wave length is used as shorter the wave length, greater the energy.

First Photoelectric Experiment:

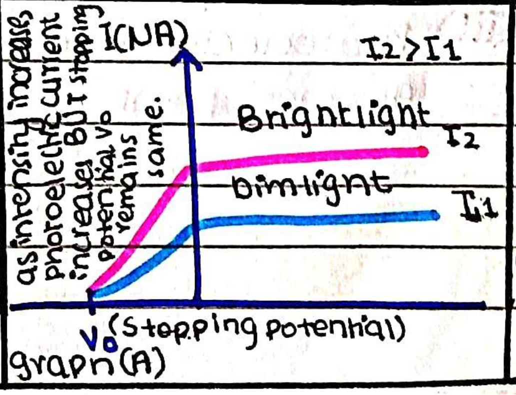
Rheostat is used to adjust potential difference 'V'. If collector is made negative with respect to the emitter, only high energy electrons will be able to reach collector.

Diagram:



→ **luminous intensity increased:** If luminous intensity is increased, the current also increases.

→ **stopping potential:** Also called as retarding potential is the potential



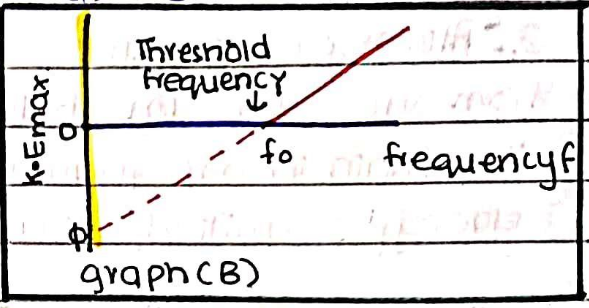
as intensity increases, photoelectric current increases BUT stopping potential V_0 remains same.

graph (A)

when electrons having maximum K.E are stopped from reaching the collector it is donated as V_0

→What does the graph tell us? Graph (a) tells us that stopping potential of metal and maximum kinetic energy of photoelectrons do not depend on intensity of light. (Even when intensity of light was doubled, stopping potential remained same)

Second Photo Electric Experiment: If we vary the frequency 'f' of incident light and measure maximum K.E and stopping potential of electrons Photoelectric effect doesn't occur if frequency of incident light is below a certain frequency called **threshold frequency, f_0**. $\boxed{\lambda_0 = \frac{c}{f_0}}$ where λ_0 is cut-off wavelength.



graph (B)

→What does the graph tell us? Graph (b) tells us that K.Emax increases with increase in frequency of incident light if frequency $f > f_0$. When frequency of light is increased, stopping potential also increases.

Failure of Classical Physics Theory:

(i) Experiments show maximum K.E of photoelectron doesnot depend upon intensity of light. Although increased luminous intensity increases photoelectric current but K.Emax is not dependent on luminous intensity.

(ii) Photoelectric effect requires a frequency above threshold frequency ∴ $f \geq f_0$.

(iii) Photoelectric effect has instantaneous nature.

All these points deviate from classical physics concepts.

Einstein Explanation of Photoelectric Effect :

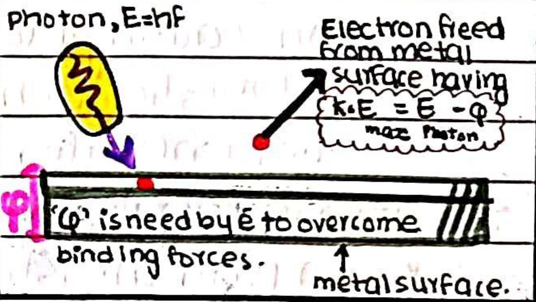
→ **Background:** using planck's quantum theory, einstein explained how kinetic energy of emitted electrons depends on frequency and not the intensity of light how classical physics suggested.

→ **Stopping Potential and Photon energy:** As frequency of photon increases, kinetic energy of emitted electron increases and the stopping potential also increases. (This means that although collector is at negative potential which will stop the electrons with K.Emax coming towards it say at −20V but if K.Emax is increased through increasing photon frequency electron wont be stopped at −20V but at −60V [values are arbitrarily taken for an example])

→ **Work function:** "Minimum energy needed to pull an electron from metal surface."

→ Einstein used plancks quantum theory, if a single quantum having energy 'hf' is used to take out an electron, then work function will be the energy absorbed by electron and the remaining energy will be the kinetic energy of emitted electron.

Diagram:



→ **Mathematically:** $\boxed{K.E_{max} = hf - \varphi}$

K.E of electron · Energy of photon · work function or energy required by electron to come out.

{φ is measured in eV}

→ 'φ' has different value for different metals.

→ Now if the energy provided by photon is just as much as required by the electron to set free from metal, then all energy provided by photon will be equal to work function! This means K.E of electron will be zero as all energy is absorbed by it and the energy of photon will be corresponding to threshold frequency f^o and cut-off wavelength λ_c

→ **Mathematically:** $\boxed{0 = hf - \varphi}$

$hf = \varphi$ [but in such a case f must be f^o (threshold f)]

$hf_o = \varphi$ or $\boxed{f_o = \frac{\varphi}{h}}$ ① [general wave eq becomes] $c = f_o \lambda_c$ or $\boxed{\lambda_c = \frac{c}{f_o}}$ ② putting ① in ② we get;

$$\boxed{\lambda_c = \frac{hc}{\varphi}}$$

→ Compton Effect:

"The scattering of high frequency photon (x-ray) with less frequency from a stationary electron is called compton effect."

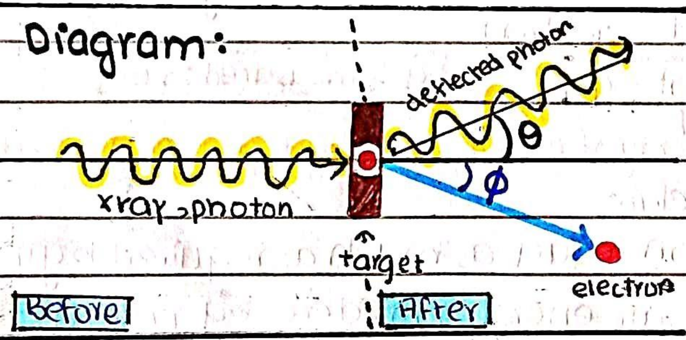
Experimental Arrangement: A beam of x-rays having wavelength 'λ' is directed towards a target of graphite. An electron is knocked out of the target, incident photon or x-ray deflects from its path.

→ **Wavelength of photon after deflection:** wavelenght of photon becomes greater as its frequency and energy decreases. Wavelength becomes λ'.

→ **Why does wavelength become great?** Photon of high frequency and low wavelength strikes the electron in target and imparts some energy electron causing it to expell out of target. Thus energy of photon becomes low, frequency becomes low and wavelength becomes great. Frequency after deflection becomes f'

→ **Scattering angle:** The angle at which photon deflects from its straigh path after striking target is scattering angle θ while angle with which electron is expelled is ϕ phi.

Diagram:



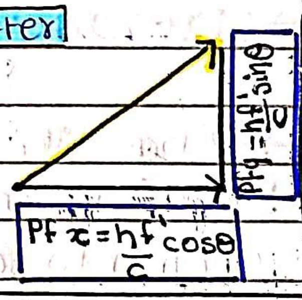
Momentum of Photon

Before

$P_{ix\,(ph)} = \frac{hf}{c}$

$P_{iy} = 0$ (no motion along Y axis)

After



$P_{fx} = \frac{hf'}{c}\cos\theta$

Frequency and wavelength of photon

Before	After
{λ↓, f↑, E↑}	{λ↑, f↓, E↓}

Energy of photon and electron

photon	$E_i = hf$	$E_f = hf'$
electron	$E_i = m_0c^2$	$E_f = mc^2$

Momentum of electron

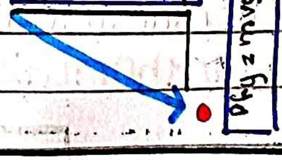
Before

● (rest)

$P_{ix\,(e)} = 0$

After

$P_{fx} = mv\cos\phi$



('m_o' is rest mass of electron)

Compton Shift: "change in wavelength $\Delta\lambda$, between the scattered x-ray photon of wavelength λ' and incident x-ray photon of wavelength λ is called compton shift." $\boxed{\lambda'-\lambda=\Delta\lambda}$

Mathematical Derivation:

(consider main diagram for values)

→ **By law of conservation of Energy**

E_i(photon) + E_i(electron) = E_f(photon) + E_f(electron) [Putting values]

$$\boxed{hf + m_oc^2 = hf' + mc^2} \quad (i)$$

→ **By law of conservation of Momentum** [momentum is a vector, thus resolving in x and y components]

Along x axis

P_{ix}(photon) + P_{ix}(electron) = P_{fx}(photon) + P_{fx}(electron)

$$\boxed{hf/c + 0 \text{ (e's at rest)} = hf'/c \cos\theta + mv\cos\phi} \quad (ii)$$

$E=mc^2$, $E=hf$

compare; $mc^2=hf$

as $P=mv$ & $v=c$ thus $P=mc$

thus; $(mc)c=hf$

$Pc=hf$

or $\boxed{P=hf/c}$

Along y axis

P_{iy}(photon) + P_{iy}(electron) = P_{fy}(photon) + P_{fy}(electron)

$$\boxed{0 + 0 = \frac{hf'}{c}\sin\theta - mv\sin\phi} \quad (iii)$$

[- sign because motion along -y axis]

→ solving eq (i), (ii) and (iii) simultaneously we get:

$$\boxed{\frac{1}{f'} = \frac{1}{f} + \frac{h}{m_oc^2}(1-\cos\theta)}$$

[multiplying whole eq by 'c']

$$\frac{c}{f'} = \frac{c}{f} + \frac{h\cancel{c}}{m_oc^2}(1-\cos\theta) \quad \text{or} \quad \frac{c}{f'} = \frac{c}{f} + \frac{h}{m_oc}(1-\cos\theta)$$

here $c/f' = \lambda'$ and $\frac{c}{f} = \lambda$ thus $\lambda' = \lambda + \frac{h}{m_oc}(1-\cos\theta)$

$\lambda'-\lambda = \frac{h}{m_oc}(1-\cos\theta)$ ($\lambda'-\lambda=\Delta\lambda$ which is compton shift)

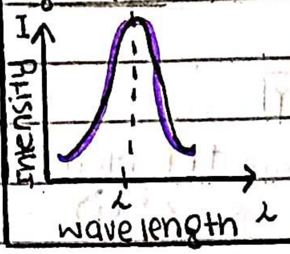
→ $\boxed{\Delta\lambda = \frac{h}{m_oc}(1-\cos\theta)}$ (where $\frac{h}{m_oc}$ is constant called compton wavelength having value 2.43×10^{-12}m)

→ Cases for Scattering Angle :

Case I

→ $\theta = 0°$

→ graph:



→ Mathematically :

$\Delta\lambda = \frac{h}{m_\circ c}(1-\cos\theta)$

(Putting value of θ, cos0 = 1)

$\Delta\lambda = \frac{h}{m_\circ c}(1-1)$

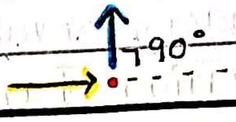
$\Delta\lambda = \frac{h}{m_\circ c} \times 0$ or $\Delta\lambda = 0$.

$\boxed{\Delta\lambda = \frac{h}{m_\circ c}(0)}$

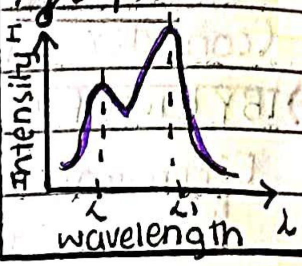
→ No change in wavelength occurs.

Case II

→ $\theta = 90°$



→ graph:



→ Mathematically:

$\Delta\lambda = \frac{h}{m_\circ c}(1-\cos\theta)$

(putting value of θ, cos90 = 0)

$\Delta\lambda = \frac{h}{m_\circ c}(1-0)$

$\Delta\lambda = h/m_\circ c(1)$ or $\Delta\lambda = \frac{h}{m_\circ c}$

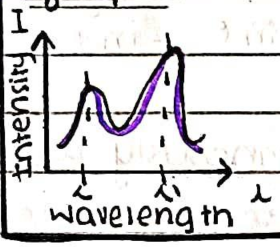
$\boxed{\Delta\lambda = \frac{h}{m_\circ c}(1)}$ where $h/m_\circ c$ = compton wavelength

→ compton shift = compton wavelength

Case III

→ $\theta = 135°$

→ graph:



→ Mathematically:

$\Delta\lambda = \frac{h}{m_\circ c}(1-\cos\theta)$

(putting value of θ, cos 135 = -0.707)

$\Delta\lambda = \frac{h}{m_\circ c}[1-(-0.7)]$

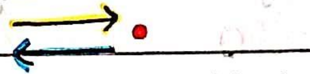
$\Delta\lambda = h/m_\circ c \times 1.7$

$\boxed{\Delta\lambda = \frac{h}{m_\circ c}(1.7)}$

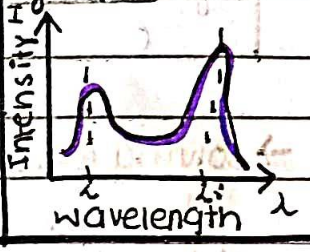
→ compton shift = 1.7 times compton wavelength

Case IV

→ $\theta = 180°$



→ graph:



→ Mathematically:

$\Delta\lambda = \frac{h}{m_\circ c}(1-\cos\theta)$

(putting value of θ, cos 180 = -1)

$\Delta\lambda = \frac{h}{m_\circ c}[1-(-1)]$

$\Delta\lambda = \frac{h}{m_\circ c} \times 2$

$\boxed{\Delta\lambda = \frac{h}{m_\circ c}(2)}$

compton shift = 2 times compton wavelength

→ Important Points:

(i) Greater the change in wavelength, greater the distance between peaks.

(ii) Greater the angle theta, greater the change in wavelength

(iii) Depression between two peaks shows conversion of wave as it strikes electron.

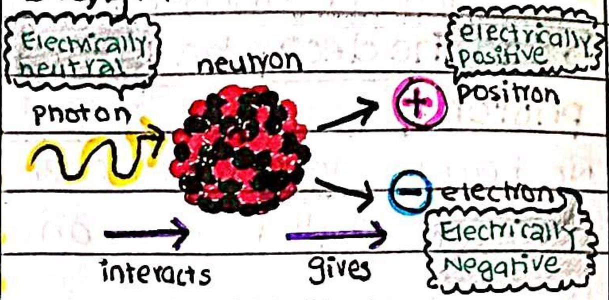
→ Pair Production:

"Conversion of a neutral boson into a subatomic particle and its antiparticle upon interaction with a nucleus is called pair production." $\boxed{\gamma \rightarrow e^{+} + \bar{e}}$

→ neutral boson can be photon and anti particle and particle can be

Paritcle	Antiparticle
• electron	• positron
• muon	• anti-muon
• proton	• anti-proton

Diggram:



▲ Pair Production

→ **Why is positron created?** Law of conservation of charge

Positron is created to conserve the charge. Photon is electrically neutral It produces positron having +ve charge and electron having -ve charge to conseve charge.

→ **Can any Photon create an $\bar{e}$ and +e pair?** Law of conservation of Energy

No, only a photon having energy equal to combined rest mass of particle and antiparticle can create a pair which is equal to $2m_oc^2$ or minimum energy.

If $\boxed{E_{photon} < 2m_oc^2}$ → no pair created
If $\boxed{E_{photon} = 2m_oc^2}$ → particle antiparticle are created at rest
If $\boxed{E_{photon} > 2m_oc^2}$ → particle antiparticle are created with Kinetic Energy

→ Mathematically: $\boxed{hf = 2m_oc^2 + (K.E)_{-e} + (K.E)_{+e}}$

Energy of photon rest mass of $\bar{e}$ and $\bar{e}$ combine

(eq ① shows amount of E required to not only produce particles but cause them to move as well) $\boxed{hf = 2m_oc^2}$ (This eq shows the minimum amount of energy required to just produce particles at rest)

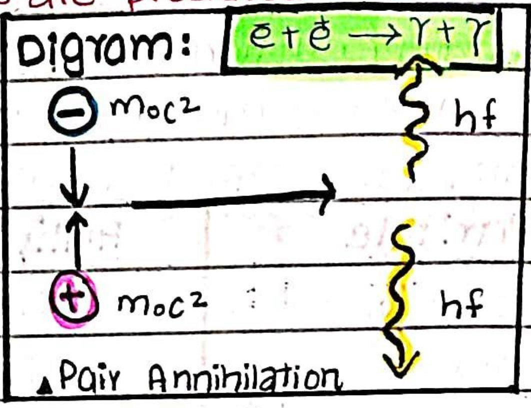
Thus minimum energy is, $hf = 1.023 \times 10^{6}\,eV$ or $1.02\,MeV$ {important mcq ☺}

→ **Can pair production take place without neutron?**

Law of Conservation of momentum No, as nucleus' role is to conserve the momentum, without nucleus this process can't take place.

→ Pair Annihilation:

"When an electron ē and a positron e⁺ combine or collide, two gamma ray photons are produced and the phenomenon is called pair annihilation."



▲Pair Annihilation

→ Can the decay be into a single photon? **law of Conservation of Energy**

No, because total initial energy is $2m_o c^2$, a single photon can't compensate for that

→ Why resulting photons travel in opposite directions?

Law of Conservation of Momentum The resulting photons, in order to conserve momentum travel in opposite directions.

→ Mathematically: $\boxed{\underbrace{m_oc^2 + m_oc^2}_{\text{Before}} = \underbrace{hf + hf}_{\text{after.}}}$

or $m_oc^2 = hf$ (energy of each photon).

$9.11\times10^{-31}kg \times (3\times10^8 ms^{-1})^2 = hf$ → $\boxed{hf = 8.19\times10^{-14} J \text{ or } hf = 0.51 MeV}$

→ Wave Nature of Particle:

"Wave-particle duality is a theory that proposes that all matter exhibits the properties of not only particles but also waves, which transfer energy."

→ Dual Nature of Electromagnetic Radiations: "Light and some electromagnetic radiation act sometimes as waves and sometimes like particles.

→ De-Broglie's proposal: De-Broglie made a proposal that considering duality of light, if nature is symmetric this duality should also hold for matter. Matter shall have wave nature as well.

→ Mathematically: according to Planck $\boxed{E = hf}$ ①

according to Einstein mass-Energy relation, $\boxed{E = mc^2}$ ②

comparing, $\boxed{hf = mc^2}$ (dividing b.s w/ c)

$\boxed{E = \frac{hf}{c} = mc}$ where hf/c = momentum 'p' thus $\frac{hf}{c} = P$ by general wave equation we know $c = f\lambda$ thus

$\frac{h\cancel{f}}{\cancel{f}\lambda} = P$ or $h/\lambda = P$ hence $\boxed{\lambda = h/p}$ ③

→ DeBroglie argued that we can also assign wavelength to particle having mass 'm' moving with velocity 'v' thus eq ③ becomes

$\lambda = h/mv$ Relativistic momentum can be expressed as $\boxed{P = \frac{m_o v}{\sqrt{1 - \frac{v^2}{c^2}}}}$

→ **Relation between wavelength and momentum:**

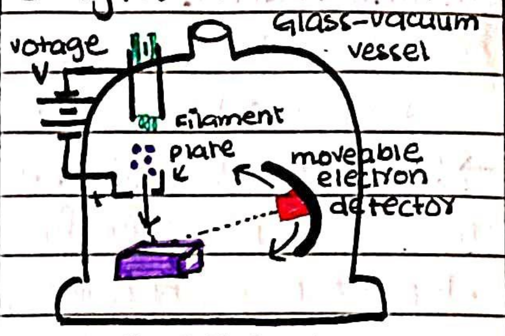
They are inversely related $\boxed{\lambda\downarrow = \frac{h}{p\uparrow}}$

→Davisson And Germer Experiment:

→**Introduction:** American physicists Clinton J. Davisson and Lester H Germer were the first to prove wave nature of particles experimentally.

→**Experiment:** Inside a vacuum chamber (vacuum is nessecary as in air, ēs ionize air). electron gun was used to create a beam of electrons targetted at Nickel. Electrons were scattered after striking the target and detected by a detector.

Diagram:



▲Experimental arrangement

→ **Information:** (i) Electrons scattered at various angles just like waves, this proved the wave nature.

(ii) At certain angles there was a peak in intensity of scattered beam.

(iii) Diffraction pattern of electrons from nickel crystal were found similar to that of Xray diffraction.

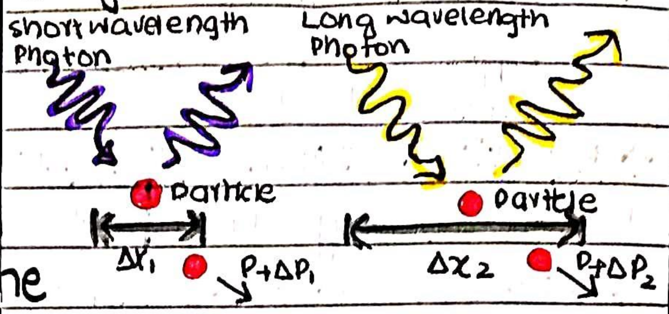
→ *The Uncertainty Principle:*

"The more precisely the position is determined, the less precisely the momentum is known in this instant and vice versa."

→ **Explanation:** Suppose a photon with a certain wavelength strikes an electron. Some momentum is imparted by photon into electron.

- **If we manage to determine 'position':** as the photon strikes the electron, if we manage to locate the position of electron we wont be able to accurately measure the momentum of electron as due to striking electron has moved away with a large speed and unkown momentum imparted to it.

Diagram:



▲ If Δx is v.small, then ΔP_x is large and vice versa.

- **If we are too quick to determine the 'momentum':** If we somehow manage to calculate momentum, the electron will have moved away and we wont be able to tell its position accurately.

→ Mathematically: • If incoming photon has momentum h/λ then uncertainty in e's momentum can be $\boxed{\Delta P_x \approx h/\lambda}$ ①

- If photon has wavelength λ and e also shows wave nature then uncertainty in position can be $\boxed{\Delta x \approx \lambda}$ ② by ① and ② $\Delta x . \Delta P_x \approx \cancel{\lambda} \times h/\cancel{\lambda}$

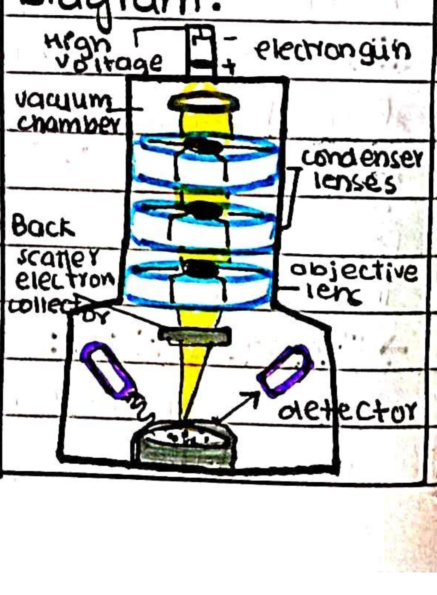
$\Delta x . \Delta P_x \approx h$

- **What is minimum uncertainty?** minimum uncertainty is $\Delta x . \Delta P = h$ it can be greater than 'h' but not less. $\boxed{\Delta x \cdot \Delta P_x \geq h}$
- **Uncertainty in energy:** There will always be uncertainty in a particle about exact momentum aswell $\boxed{\Delta E \Delta t \approx h}$

→ Electron Microscope:

"An electron microscope is a type of microscope that uses an electron beam with its wave like properties to illuminate a specimen and produce a magnified image"

Diagram:



→ Why is EM better than optical microscope?

Electrons have wavelength of about 100,000 times shorter than visible light photons. They can achieve better than 50pm resolution and resolution upto 10,000,000x while light microscopes have resolution 200nm and magnification below 2000x.

→ **Basic construction:** in a vacuum chamber; ① Electron gun used for accelerating electrons. ② Condenser lenses control and define size of beam ③ objective lens to focus $\bar{e}$ beam onto sample ④ Detector.

→ **Working:** Two types of electrons are used for imaging Backscattered Electrons (BE) and Secondary Electrons which are those knocked out by $\bar{e}$ beam from specimen along with generated X-rays are detected by detectors and then a computer produces 3D images.