Chapter = 19

Dawn of Modren Physics

Introduction:

By the end of 19th Century, Scientists throught that the existing physics (Now called classical physics) explained all the phenomena. They throught that there was nothing left to be explained.

Classical physics i.e, Newtons law of motion, laws of thermo dynamics, Kinetic theory and Maxwells theory of electromagnetic radiations was very successful in explaining many problems in the natural word. The nature of light had been explained in terms of Electromagnetic Waves.

In the early part of 20th century, there was a series of new experiment, which could not be explained on the basis of classical physics.

Classical physics was not able to explain the behaviour of matter on the atomic level tiny particls and particles moving at very high speed.

Modren Physics:

To explain the behaviour of very small, tiny particls moving with very high speed, there was Dawn of Modren Physics.

1- Theory of Relativity

The behaviour of the objects moving at very high speed comparable to the speed of light are explained by the special theory of relativity.

Quantum theory:

The behaviour of electromagnetic radiations as discrete patches of energy and the behaviour of tiny particles (atoms, ions, molecules, electrons and protons etc)- is explained on the "Quantum theory" of wave Mechanics.

Classical Physics:

Classical physics is still valid in ordinary process of every day life. But to explain the behaviour of tiny particles or very fast moving objects, Modren physics is used.

19-1 Relative Motion:

When a ball is thrown 'up', the up direction is only for that particular place. It will be down position for a person on the diametrically opposite side of the globe (Earth) So, the concept of direction is not absolute, but direction is a relative term.

Rest and Motion are also relative terms:

Rest and motion are not absolute terms but they are relative terms.

The rest position or the motion of an object is not same for different observers.

Example:

The walls of the cabin of a moving train are stationary with respect to the passangers sitting inside it but are in motion relative to person stationary on the ground. So

we cannot say whether an object is

absolutely at rest or absollutely in motion. All motions are relative to a person or instrument observing it.

Experiment:

Suppose car A is stationary. The person in car B which is moving with constant velocity throws a ball straight up. He will receive the ball straight down. But the person sitting in the stationary car A observe that the path of the ball is a parabola (curved path).

Hence the observations of two different observers are different.

19.2 Intertial Frame of reference

Frame of Referance:

"A coordinate system relative to which measurement are made is known as frame of refrence."

Examples:

i) The position of a table in a room can be Located relative to the walls of the room. The room is then frame of referance.

ii) For measurments taken in a college laboratory, the Labaratoryis the frame of referance.
If the same experiment is performed in the train, the train becomes the frame of referance.

iii) The position of a space ship can be described relative to the position of distant stars.
A coordinate system based on these stars is then the frame of referance.

Intertial frame of referance:

"A frame of reference in which Law of intertia is valid is called intertial frame ofreferance."
It is not accelerated.
"A coordinate system in which a body at rest remains at rest and a body moves with uniform velocity unless an unbalanced force acts on it, is called intertial frame of referance."

Examples:

i) If we place a body on earth, it remains at rest unless an unbalanced force acts on it.
In this case earth may be considered as an intertial frame of referance.

ii) A body placed in a car moving with a uniform velocity with respect to earth also remains at rest, so a moving car is also an intertial frame of reference.

Non-Intertial frame of reference:

"A frame of reference in which the law of interia is not valid is called non-intertial fram of referance."

"An accelerated frame of reference is called non-intertial frame of refenece."

Examples:

i) When the moving car is suddenly stopped, the body placed in it. no Longer remains at rest. This is so because the car is suddenly accelerated. In this situation the car is non-intertial frame of reference.

ii) Earth is rotating and revaling, hence it has some acceleration. Therefore it is not an intertial frame of reference. But often it can be treated as an intertial frame of reference without serious error because of very small acceleratin of earth.

19.3 Special theory of relativity

Theory of relativity is concerned with relations between the observations taken by two observers on two different forms of refarence.

These frames have relative motion between them.

There are two types of theory of relativity.

1- General theory of relativity

2- Special theory of relativity.

General theory of relativity:

General theory of relativity deals with the problems involving non-intertial fram of reference.

Special theory of relativity:

Special theory of relativity deals with the problems involving internal or unaccelerat frames of reference. It was given by Einstein in 1905. It is based upon two postulates.

Postulate 1:

It states that all the laws of physics can be expressed in same set of equations in all intertial Frames. It means that laws of physics are same in all intertial frame of refrence.

Postulate 2:

It states that speed of Light in free space is a universal constant and its value is independent of motion of source or observer $C = 3 \times 10^8 \, ms^{-1}$

Results of Special theory of relativity:

1- Time Dialation:

According to special theory of relativity time is not absolute, its value is different according to different intertial frames.

Suppose an observer is stationary in an intertial frame. He measures the time intertial of an event happening in this frame. This time interval is called proper time t_o.

If the observer is moving with respect to the frame of event, with velocity V, or the frame of event is moving with respect to the observer with a uniform velocity V, the time measured by the observer would not be t_o, but it would be t, such that

$$t = \frac{t_o}{\sqrt{1 - V^2/c^2}}$$

c = Speed of Light

As

$$V < c \; ; \; \sqrt{1 - \frac{V^2}{c^2}} < 1$$

So

$$t > t_o$$

So,

the time interval is dialated or time

is slowed down due to the relative motion of observer and the frame of refrence of events.

This result applies to all timing processes such as physical, Chemical and Biological. Even aging process of human body is slowed by motion at very high speeds.

2- Length Contraction:

The distance from earth to a star measured by an observer in a moving spaceship would seem smaller than the distance measured by an observer on earth.

It means that if you are in motion relative to two points that are a fixed distance apart, the distance between the two points appears shorter than if you were at rest relative to them.

This effect is called length contraction.

The length of an object or distance between two points measured by an observer who is relativity at rest is called proper length L_0. If an object and observer are in relative motion with speed v, then the contracted Length L, is given by

$$L = L_o \sqrt{1 - \frac{v^2}{c^2}}$$

As

$$v < c \;;\quad 1 - \frac{v^2}{c^2} < 1$$

$$\Rightarrow \boxed{L < L_o}$$

3. Mass Variation with velocity:

According to special theory of relativity mass of an object is not a constant quantity. It varries with velocity.

m_o = Rest Mass of an object.

m = Mass of the same object moving with velocity v.

$$\boxed{m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}}$$

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because in daily life

$$v << c$$

So

$$\frac{v^2}{c^2} \cong 0 \; ; \; \sqrt{1-\frac{v^2}{c^2}} \cong 1$$

So

$$m = m_o$$

$$L = L_o$$

$$t = t_o$$

C = speed of light
$C = 3 \times 10^8$ m/s

$C = 3 \times 10^5$ km/s
C = 300000 km/s

C = Three lack km/s

Even the Orbital speed of Earth

$$V = 30 \text{ km/s}$$

It is small as compared to c.

When $v << c$.

No relativistic effects.

This is why Newton's Laws are valid in daily life.

As

$$v < c \; ; \; \sqrt{1-\frac{v^2}{c^2}} < 1$$

$$; \; m > m_o$$

So

mass of an object increases with increasing velocity.

When

$$V \to c \; ; \; \frac{v}{c} \to 1 \; ; \; \sqrt{1-\frac{v^2}{c^2}} \to 0 \; ;$$

$$m \to \infty$$

$$\left[m = \frac{m_o}{0} = \infty \right]$$

When Speed of the object approaches to c (Spee of light) mass approaches to inifinity. It would have infinite inertia.

So an infinite force is required to accelerate an infinite mass.

Because infinite forces are not available, so an object cannot be accelerated to the speed light c in free space.

In our reaily life, we do not observe relativistic effects. This is so

Atomic Particles:

When dealing with atomic particles (such as protons, electrons etc) moving with velocities apporaching to the speed of light, the relativistic effects are prominent.

4- Mass Energy relation:

According to the special theory of relativity, mass and energy are different quantities but are interconvertable.

The total energy E and mass m of an object are related by

$$E = mc^2$$

m= relativistic mass

The rest energy is

$$E_o = m_o c^2$$

m_o = rest mass

As

$$m > m_o \quad ; \quad mc^2 > m_o c^2$$

$$E > E_o$$

So, the difference of energy is due to motion and it is the Kinetic energy.

$$KE = E - E$$

$$KE = mc^2 - m_o c^2$$

$$KE = (m - m_o)c^2$$

As

$$E = mc^2$$

$$\Delta E = \Delta mc^2$$

$$\Delta m = \frac{\Delta E}{c^2}$$

This is the change in mass Δm due to change in energy ΔE

As

c^2 is very large term, so Δm is very small.

Hence very large amount of energy ΔE is required to get a considerable change in mass Δm.

In daily life

The energy changes are of small amount, so no considerable change of mass taken place.

In nuclear reaction

The change of mass with energy is observed in accordance with above equations.

Navstar navigation System.

The result of Special theory of relativity are applied in modren System of navigation satellite called Navstar.

By the help of this, the position and speed of ship / aircrafts can be determined, anywhere in the world up to an accuracy of $2\ cms^{-1}$.

If relativity effects are not taken into account, speed could not be determined any closer than about $20\ cms^{-1}$

The position of an aircraft after one hour of its flight can be predicted upto 50 m - accuray by using special theory of relativity, while without the use of this theory the estimation is off about 760 m.

19.4 Black body radiation

When a body is heated, it emits radiations. The wavelength of emitted radiations depend upon the temperature of the body.

i) Long wavelength radiation (infrared) are emitted when temperature of the body is Low.

ii) Shorter wavelength radiations are emitted when temperature of the body is high.

iii) The amount of emitted radiation is different for different wavelengths. So distributaion of energy is different wavelengths.

Example:

When a platinium wire is heated then at about 500°C its colour is dull red, at about 900°C it changes to cherry red, at 1100°C becomes orange red, at 1300°C becomes yellow and finally becom-

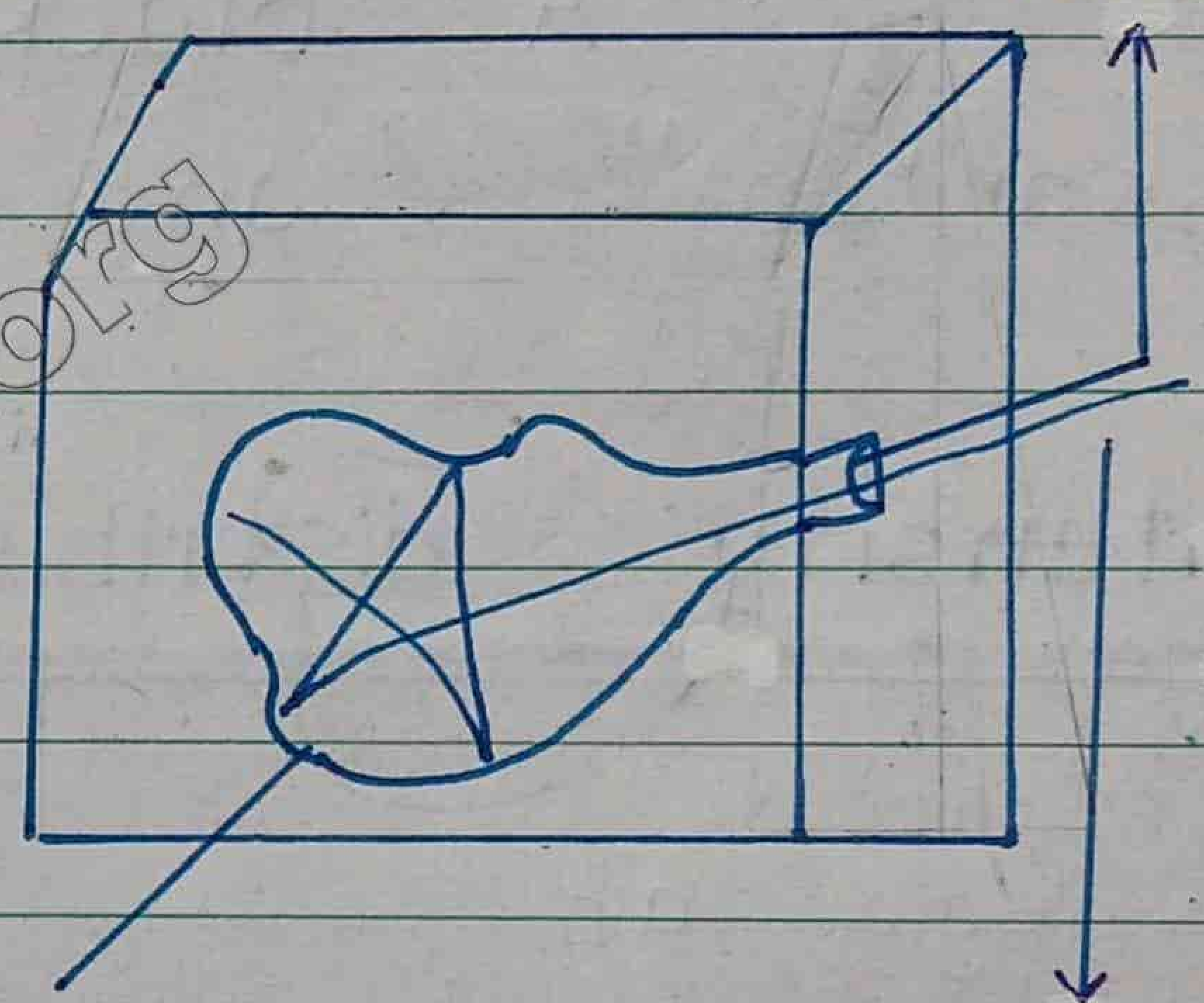
S white at 1600°C

Result:

It means that wavelength of emitted radiations decreases as the temprature of hot body increases.

Black body:

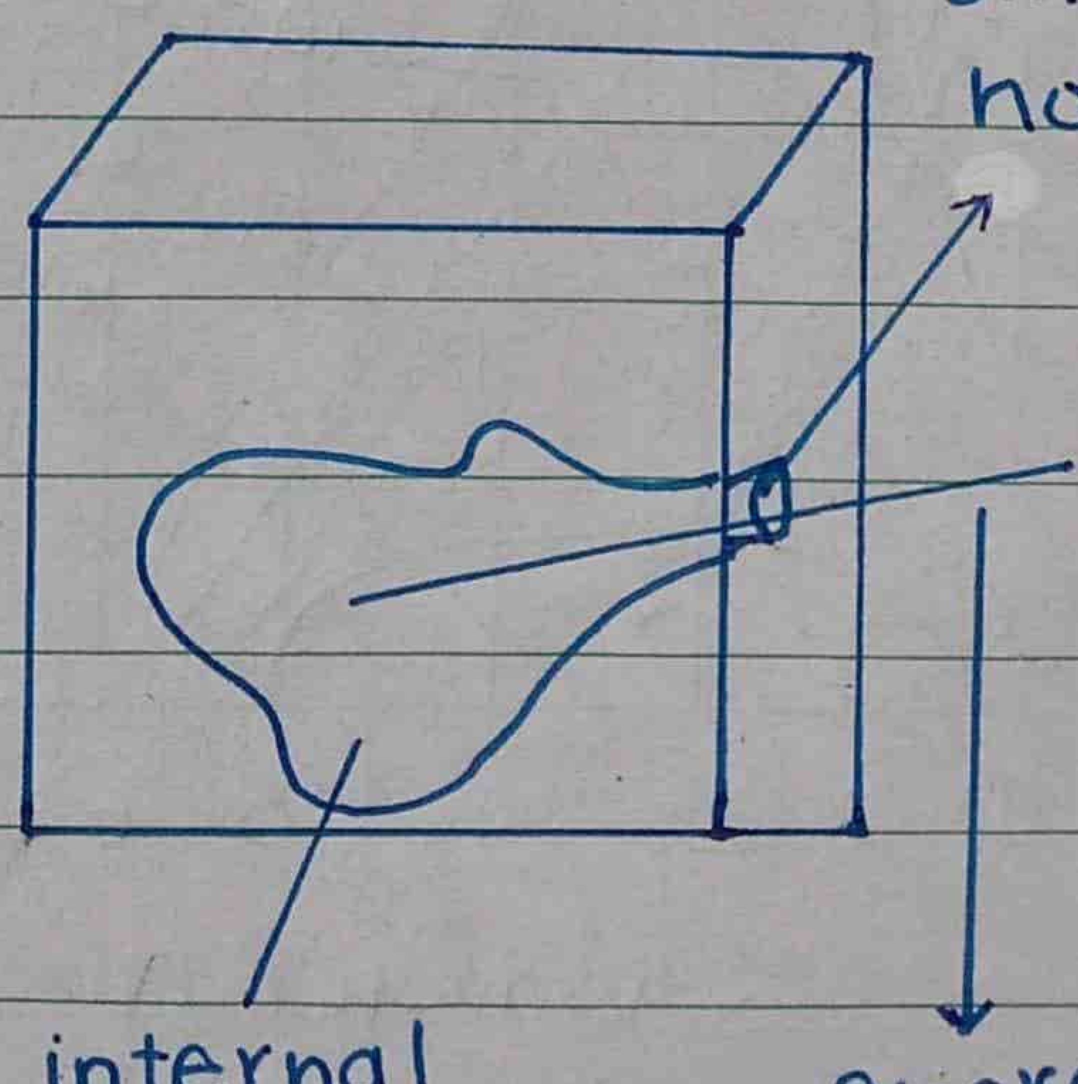
An ideal body which absorbs all the radiations falling on it is called a black body. It reflects no radiations. When heated, it emits radiations called black body radiations.



(a) Absorption of radiation

Construction:

Consider a Solid in which a cavity is made but its opening is small. Its inner walls are blackened with Lamp lulack to make it a very good

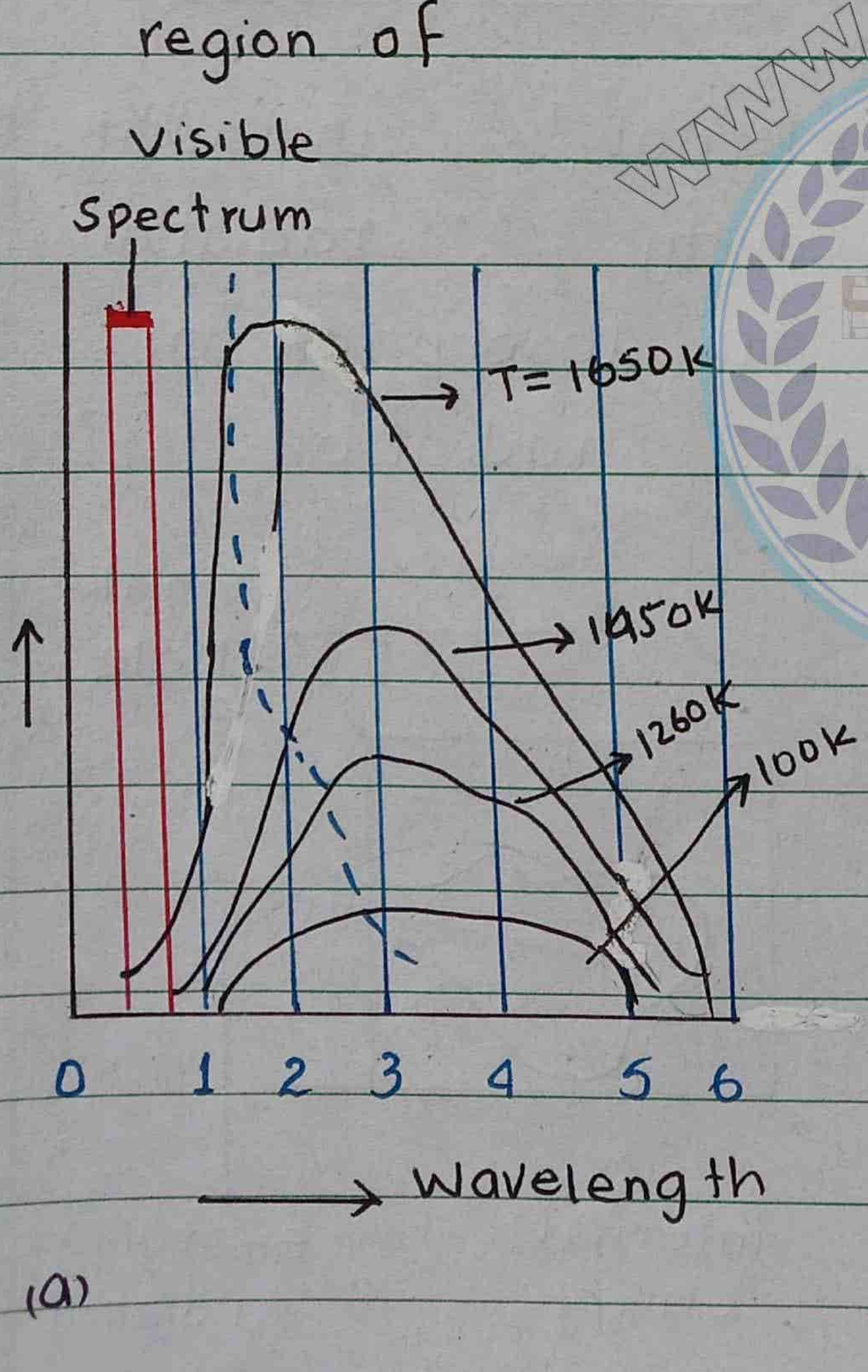


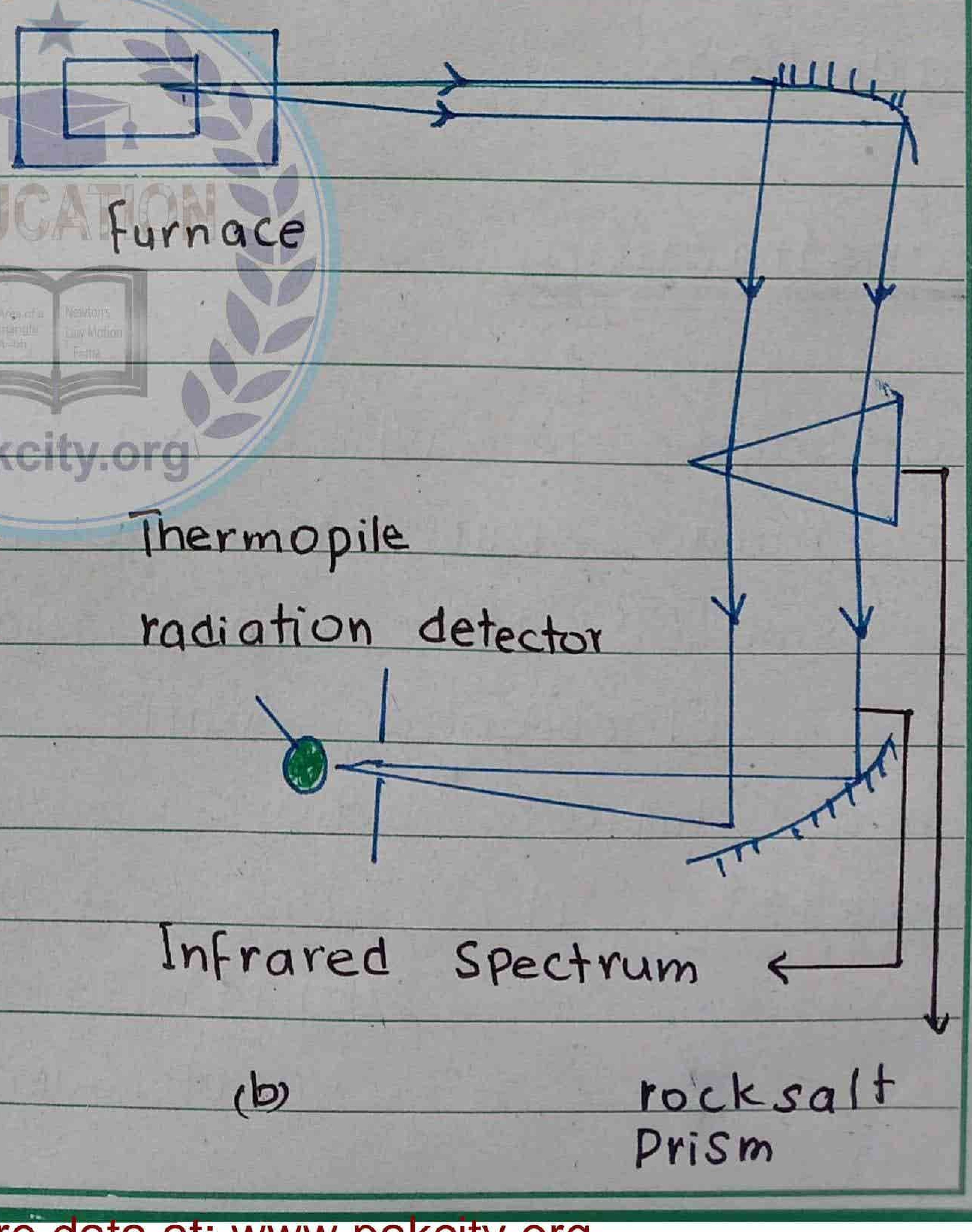
(b) Emission of radiation

absorber and a bad reflector. The radiation can enter and a leave only through the small hole or opening. The hole appears black because the radiations after suffering multiple reflections are absorbed inside the cavity. Such a body is known as black body. radiations entering it.

A black body is an "ideal absorber" and an "ideal radiator."

Intensity distribution diagrams:





Lummer and pringshein measured the intensity of different radiations of different wavelength at different temperature with the help of an appratus shown in Fig.

The amount of radiations (intensity) with different wavelengths is shown in the "Energy distribution curves." for each temperature in Fig.

The curves show the following facts:

i) At a given temperature, the energy is not uniformly distributed in radiation spectrum of black body.

ii) At a given temperature, the emitted energy has maximum value for a certain wavelength λm.

Weins displacement Law:

λm is inversely proportional to the absolute temperature of the black body.

$$\lambda m = \frac{1}{T} \quad \text{or} \quad \lambda m = \frac{\text{constant}}{T}$$

$$\lambda max \times T = \text{constant}$$

Weins constant $= 2.9 \times 10^{-3}$ mk.

The value of the constant as

From the above equation, it is clear that as temperature increases, the wavelength λ_m decreases and it shifts towards shorter wavelength.

iii) For all wavelengths, an increase in temperature there is increase in the energy emission.

iv) The area under each curve repents the total energy E radiated over all wave-lengths at a particular temperature.

It is found that Area (energy) is directly proportional to the fourth power of Kelvin temperature, T

$$E \propto T^4$$

$$E = \sigma T^4$$

This is called Stefen's - Boltzmann's Law.

σ = Stefen's - Boltzmann's Law

σ = stefen's constant $= 5.67 \times 10^{-8}$ Walt m^{-2} K

σ = Stefen's Boltzmann constant

Plancks Assumption:

Electromagnetic wave theory of radiation cannot explain the energy distribution in intensity wave-length curves.

To solve this problem, in 1900 Max Planck presented his Quantum theory which successfully explained the energy distribution in the energy distribution curves.

According to plancks energy is not continuously emitted from a source, rather energy is emitted or absorbed discontinuously in the form of packets of energy known as "Quanta".

Each quantum has a specific energy depending upon its frequency i,e,

$$E \propto f$$

$$E = hf$$

h = Plancks constant $= 6.63 \times 10^{-34}$ J x S

J x S is also the unit of Angular momentum.

Planks constant h in physics is as importent as speed of Light c in vacuum.

Max plancks was awarded Noble Prize in physics in 1918 for his discovery of energy quanta.

The Photon:

Einstein extended the idea of planck and postulated that bundles of energy are integral part of electromagnetic radiations and they could not be subdivided. These tiny bundles of energy were called photons by Einstein.

The energy of a photon is = $E = hf \longrightarrow (1)$

From the theory of relativity, the momentum P of photon is realted to its energy E as $E = pc$.

$E = mc^2$

$E = mc.c$

$E = pc \longrightarrow (2)$

$\therefore mc = p$

$mv = p$

Comparing eq (1) and eq (2)

$$pc = hf$$

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

$$p = h \cdot \frac{f}{c}$$

$$p = \frac{h}{\lambda} \times \frac{1}{\lambda}$$

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

$$v = f\lambda$$

$$c = f\lambda$$

$$\frac{1}{\lambda} = \frac{f}{c}$$

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

This is the formula for the momentum of photon.

$$p \propto f \quad ; \quad p \propto \frac{1}{\lambda}$$

19.5 Interaction of Electromagnetic radiations with matter

Electromagnetic radiations interact with matter in three different ways depending upon their energies.

i) Photo electric Effects:

A low energy photon on interacting with a metal is usually completely absorbed with the emission of electrons.

ii) Compton Effect:

A high energy photon such as x-ray photon is scattered by an atomic electron transferring a part of its energy the electron.

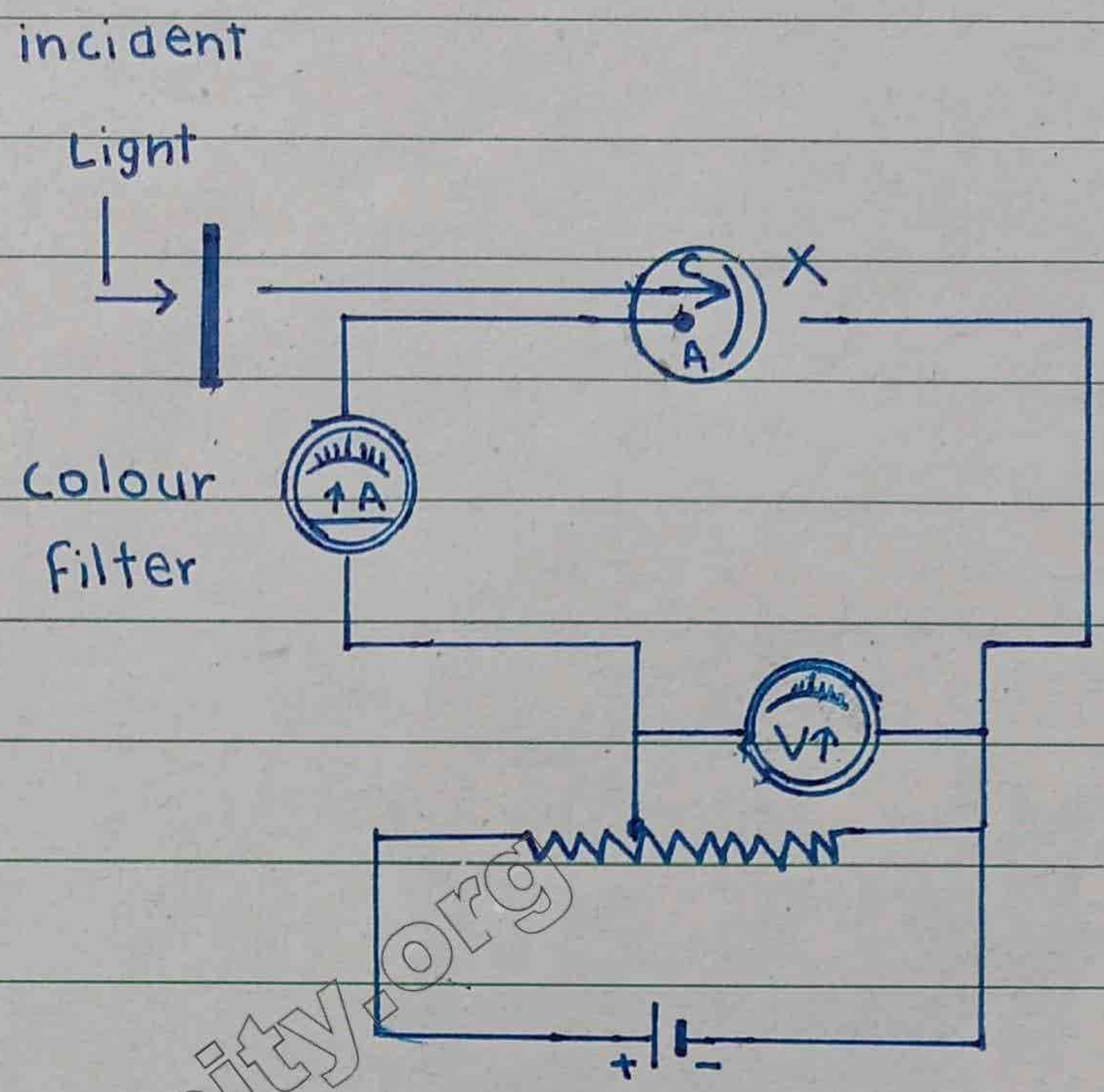
iii) Pair Production:

A very high energy photon such as x-ray on interacting with a nucleus produces production. It vanishes producing electron - positron pair.

Photo electric Effect:

"When light of suitable frequency falls on a metal surface, electrons are emitted from the metal surface, this process is called photo electric effect."

The emitted electrons are called photo electrons.



Experimental Arrangement

An evacuated glass tube x contains two electrodes i.e. A is the anode and C is the cathode.

Anode A is connected to the positive terminal of the battery and cathode c is connected to the negative terminal of the battery.

Light from a monochromatic source falls on the cathode, electrons are emmited and they are attracted by +ve anode. The photo electric current due to these electrons is measured by the ammeter.

If incident light is stopped, then the emission of photo electrons is also stoped. It proves that the flow of current is only due to incident.

Maximum K.E of photoelectrons:

The maximum KE of photoelectrons is found by reversing the connections of the battery in the circuit.

Now the anode A is negative and cathode C is at positive potential.

In this condition the photoelectrons are repelled by anode A and the photoelectric current decreases.

If the anode potential is made more and move negative (with the help of potential divider), photoelectric current decreases.

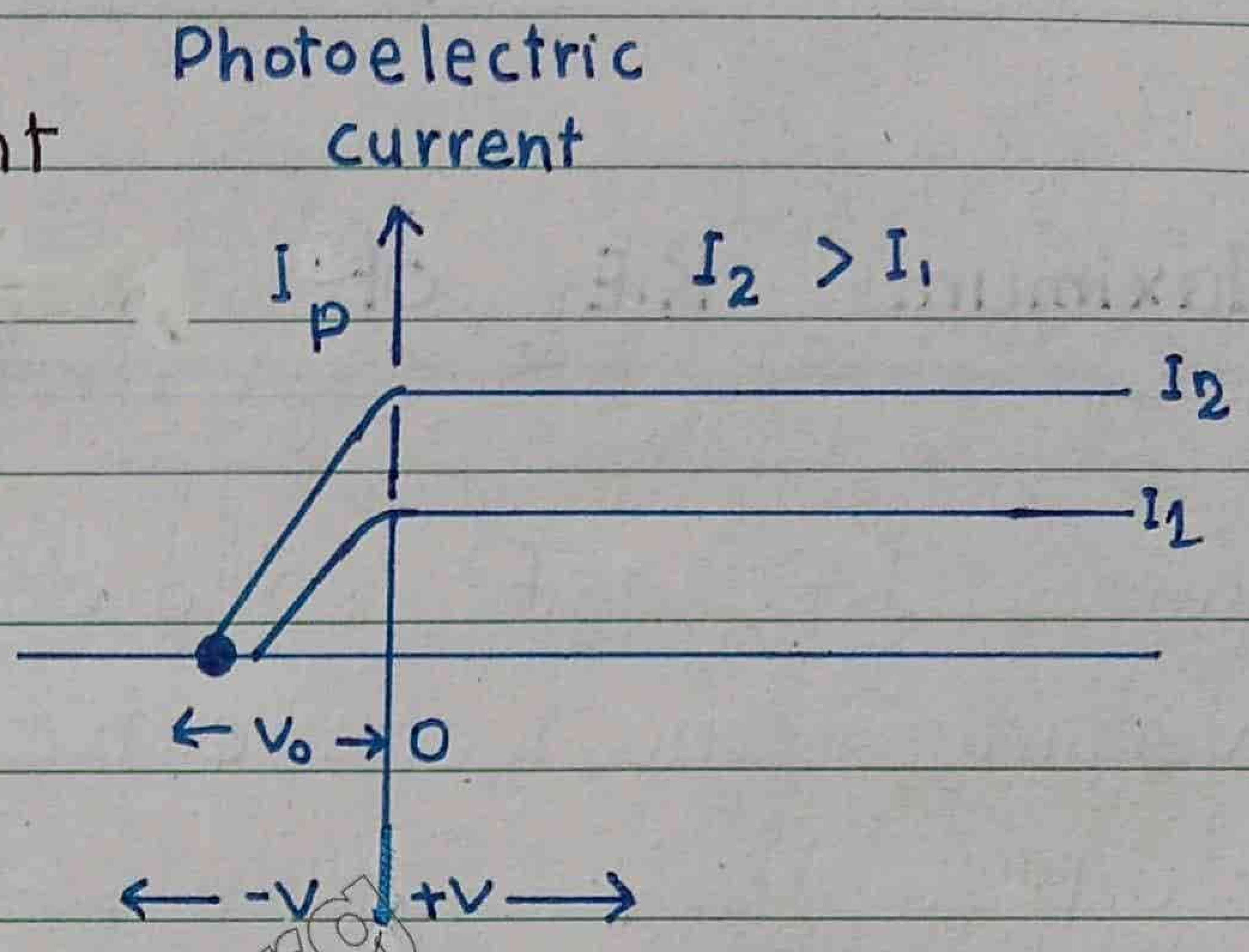
At a certain value of reverse potential photo electric current becomes zero. This potential is called as stopping potential V_o.

The maximum KE of photo electrons is

$$KE_{max} = V_o e.$$

Here m is the mass and e is the charge of an electron.

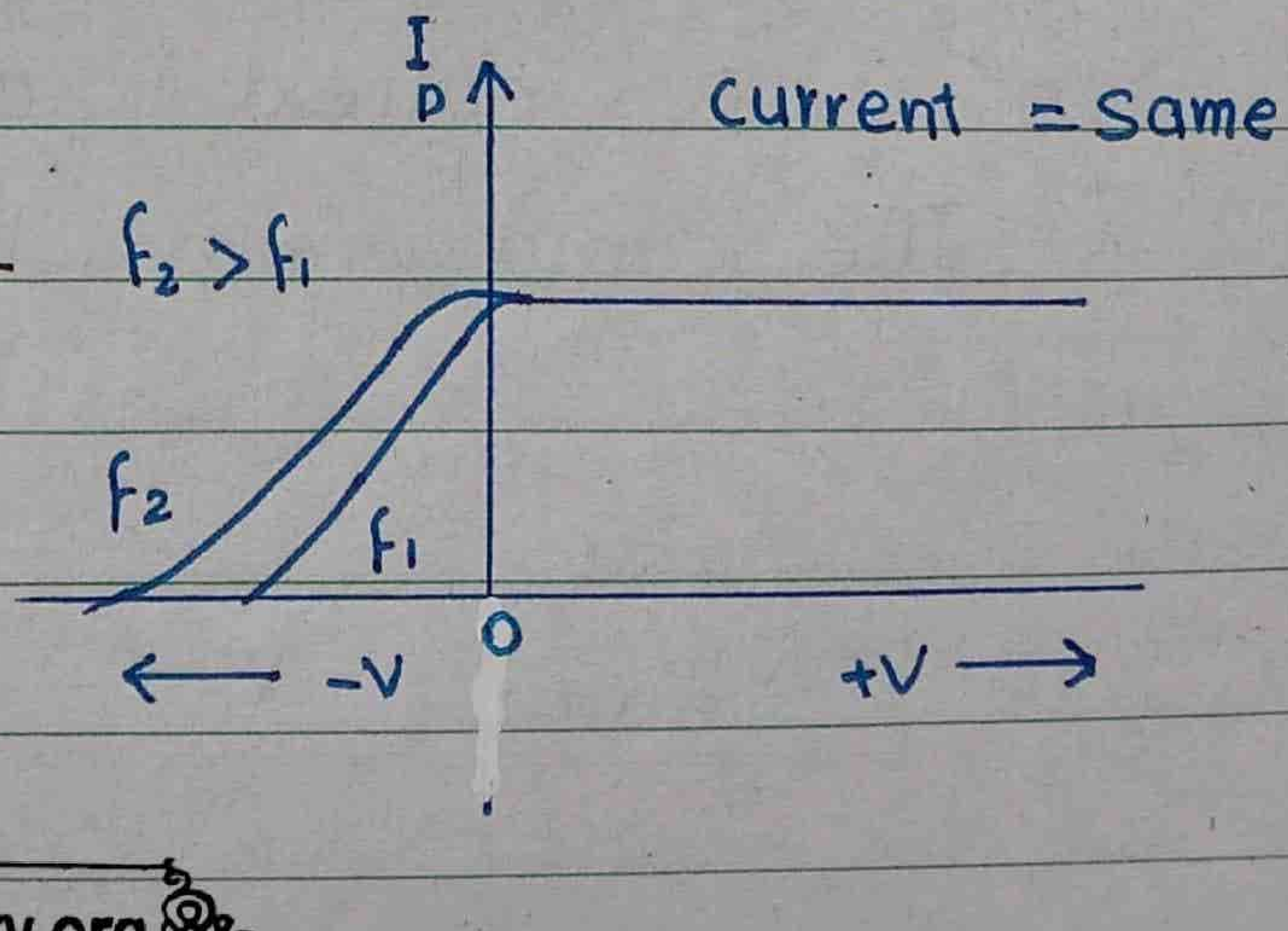
1- If the intensity of light is increased then current also increases but the current will stop for the stopping potential V_0.



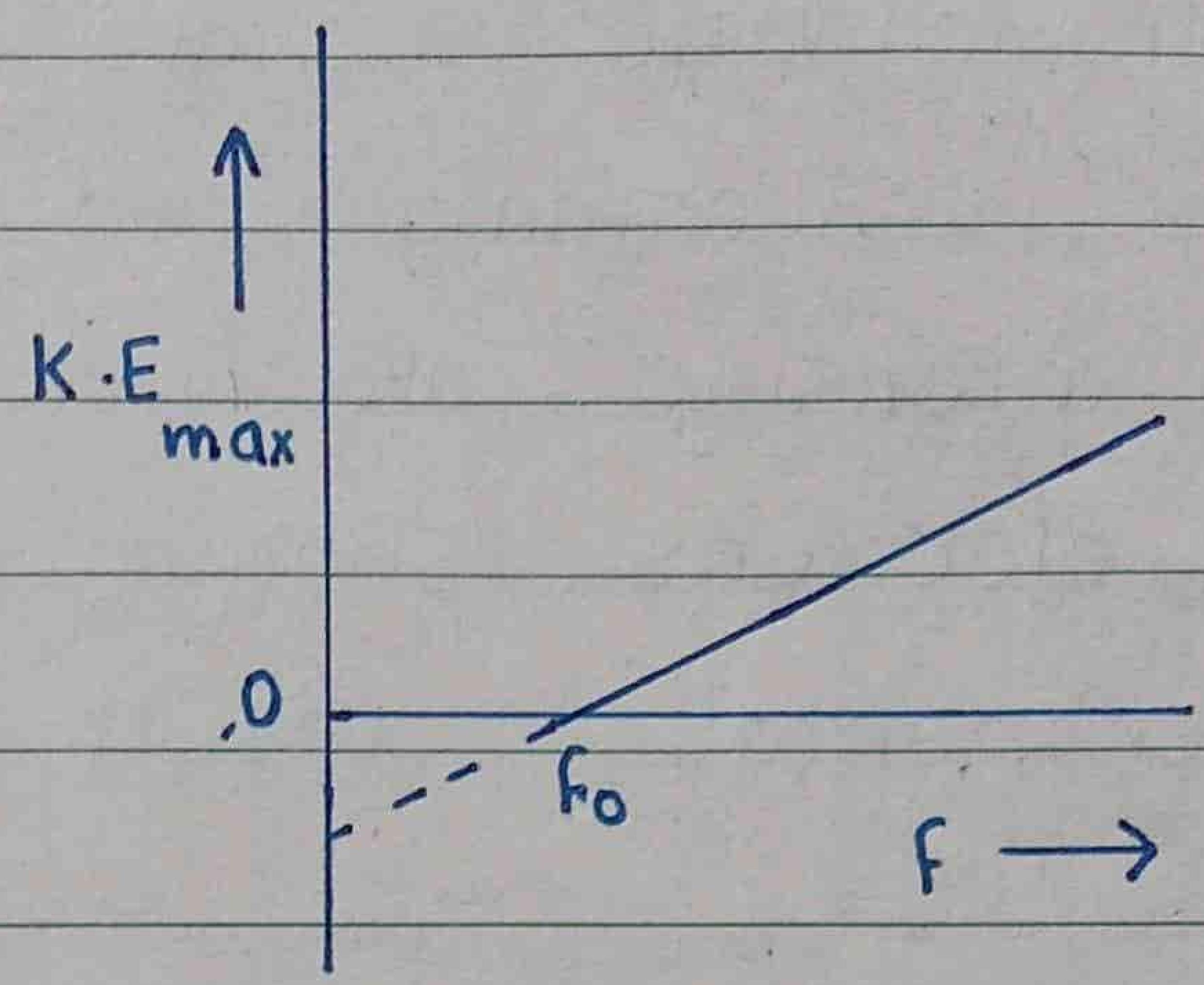
It is clear from the curves of the figure that current increases with the increases of intensity of light ($i,e.$ $I_2 > I_1$) stopping potential V_0 is same.

Here frequency is kept constant.

2- Now the intensity is kept constant. It is clear form the curves that current I_p remains same but stopping potential is different for different frequency of light.



3- From the graph it is clear that Max. K.E increases with the increases of frequency of Light. Below a certain frequency f_o, no photoelectric emission occurs.



Results of the experiment:

1- No photoelectrons are emitted, however intensity of the light may be, if the frequency of the light is smaller than a minimum value called Threshold Frequency = f_o.

[$f < f_o$ No emission]

2- The maximum energy of photo electrons increases by increasing the frequency above the threshold frequency.

[$KE_{max} \propto f$]

3- Threshold frequency f_o is different for different metals.

(i) Electromagnetic wave theory:

These results could not be explained on the basis of electromagnetic wave theory of light.

According to this theory, by increasing the intensity of incident Light, the KE of emitted electrons should increase. This contradicts the experimental result.

(ii) Classical theory:

The classical electromagnetic wave theory cannot explain the threshold frequency f_o.

Explanation on the basis of Quantum theory:

Einstein explained the photoelectric effect on the basis of Quantum theory by taking the idea of quantization of energy. Quantum theory was presented by Max planck.

Einstein assumed that Light consists of Photons and the energy of each photon is given by

$$E = hf$$

h = Planck's constant = 6.63×10^{-34} J×S

f = frequency of the

Work Function:

"Work function ϕ is the minimum amount of energy required to seperate an electron from a metal surface."

Energy of photon = Work Function + $(KE)_{max}$

$$hf = \phi + KE_{max}$$

$$KE_{max} = hf - \phi$$

or

$$\frac{1}{2}mv^2_{max} = hf - \phi$$

This is called Einstein's Photoelectric Equation.

When the KE_{max} of the photoelectrons is zero, the frequency f is equal to threshold frequency f_0.

So

$$0 = hf_0 - \phi$$

$$\phi = hf_0$$

So, Einsten's photoelectric equation can be written as

$$KE_{max} = hf - hf_o$$

Nobel prize:

Albert Einsten was awarded noble prize in physics in 1921 for his explanation of photo electric effect.

Conclusion:

Photoelectric effect cannot be explained on the basis of wave theory of light i.e light consists of waves and energy is uniformly distributed over its wavefront. It can only be explained by assuming light consists of corpuscles of energy known as photons. Thus it shows the corpuscular nature (particle like nature) of light.

Photocell :

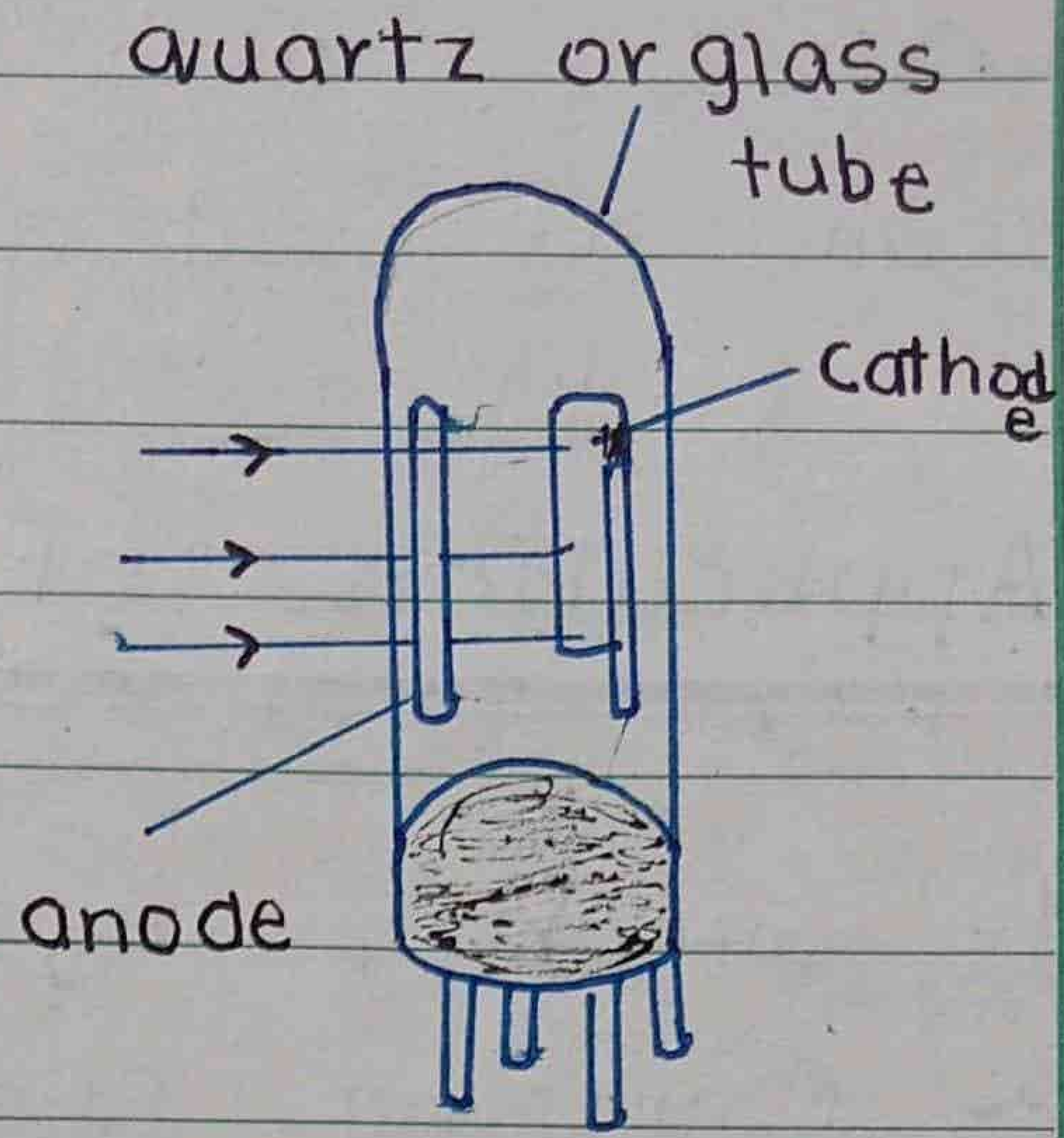
Principle :

A photocell is based on photoelectric effect.

Construction:

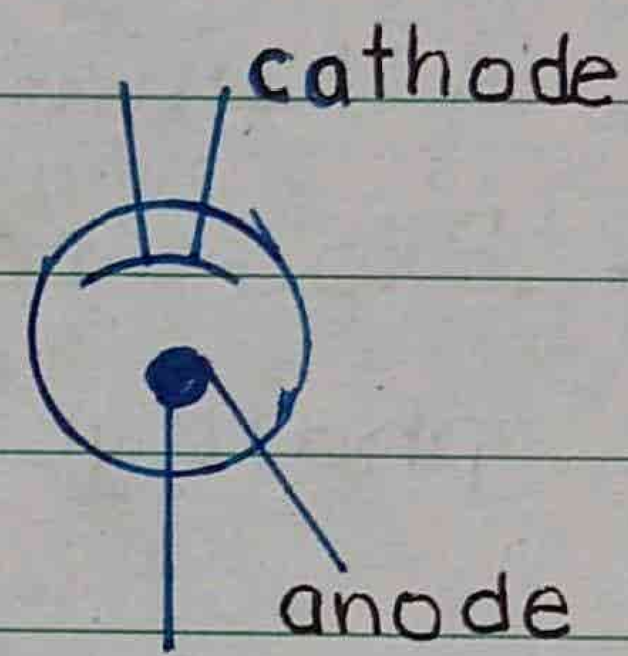
A photocell is shown in fig.

It consists of an evacuated glass tube with anode rod and a cathode of suitable metal surface as shown in Fig.



The material of the cathode:

The material of the cathode is selected to suit the frequency range incident radiation over which the cell is operated.



Visible Light:

Sodium or potassium cathode emits electrons for visible light.

Infrared Light:

Cesium coated oxidized silver emits electrons for infrared light and some other metals respond to ultraviolet radiation.

Working:

When light of suitable frequency falls on the cathode plate electrons are emitted and a current falls in the external circuit which increases with the increase in light intensity.

The current stops when the light beam is cut off.

Application of photo cell:

1- Security System.
2- Counting System.
3- Automatic Door System.
4- Automatic street lighting.
5- Exposure meter for photography.

Compton effect:

Statement:

The process in which the wavelength λ_s of the scattered photon of X-rays is larger than the wavelength of the incident X-ray photon λ_i.

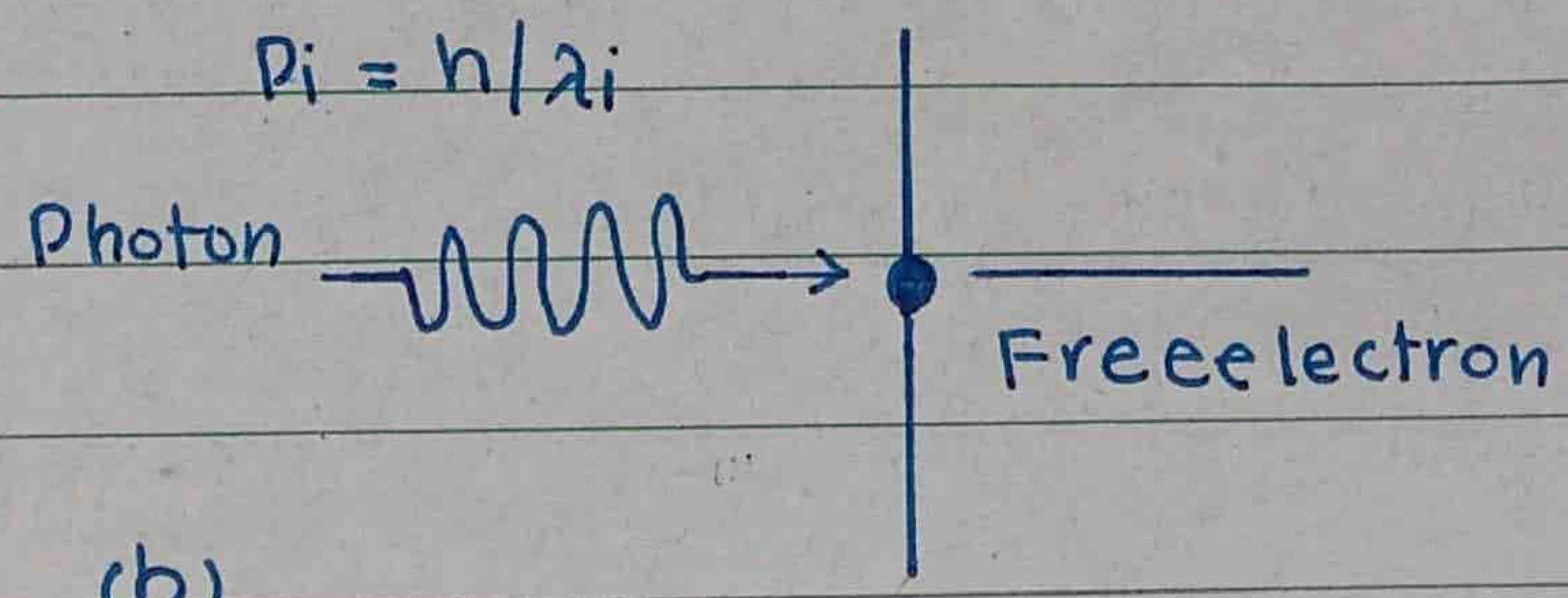
$$\lambda_s > \lambda_i$$

$f' < f$

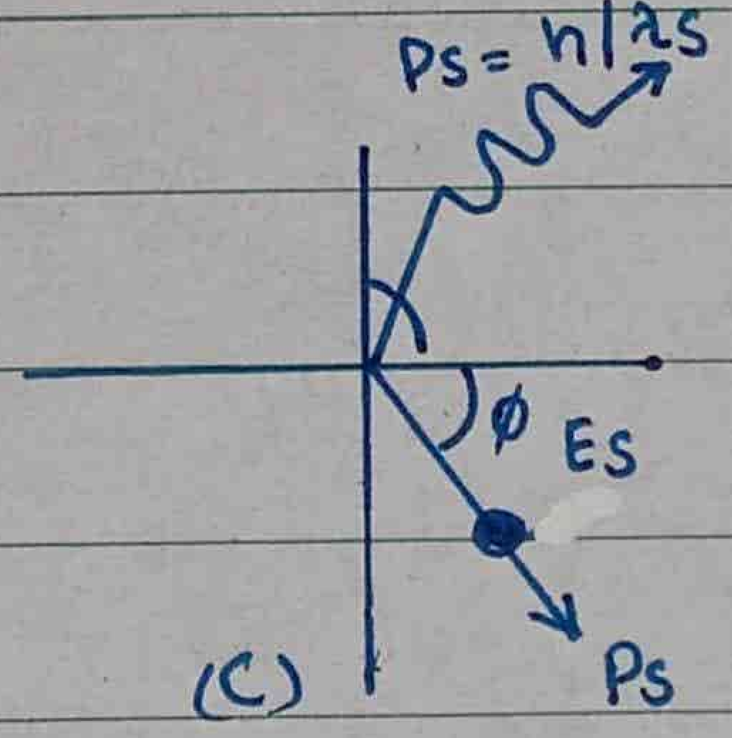
Explanation:

In 1923, Arthur Holy Compton studied the scattering of X-rays by loosly bound electrons from a graphite target as shown in fig. He measured the wavelength of a photon scattered at an angle Q with the orignal direction. He found that the wavelength λ_s of the scattered photon is larger than the wavelength λ_i of incident X-rays.

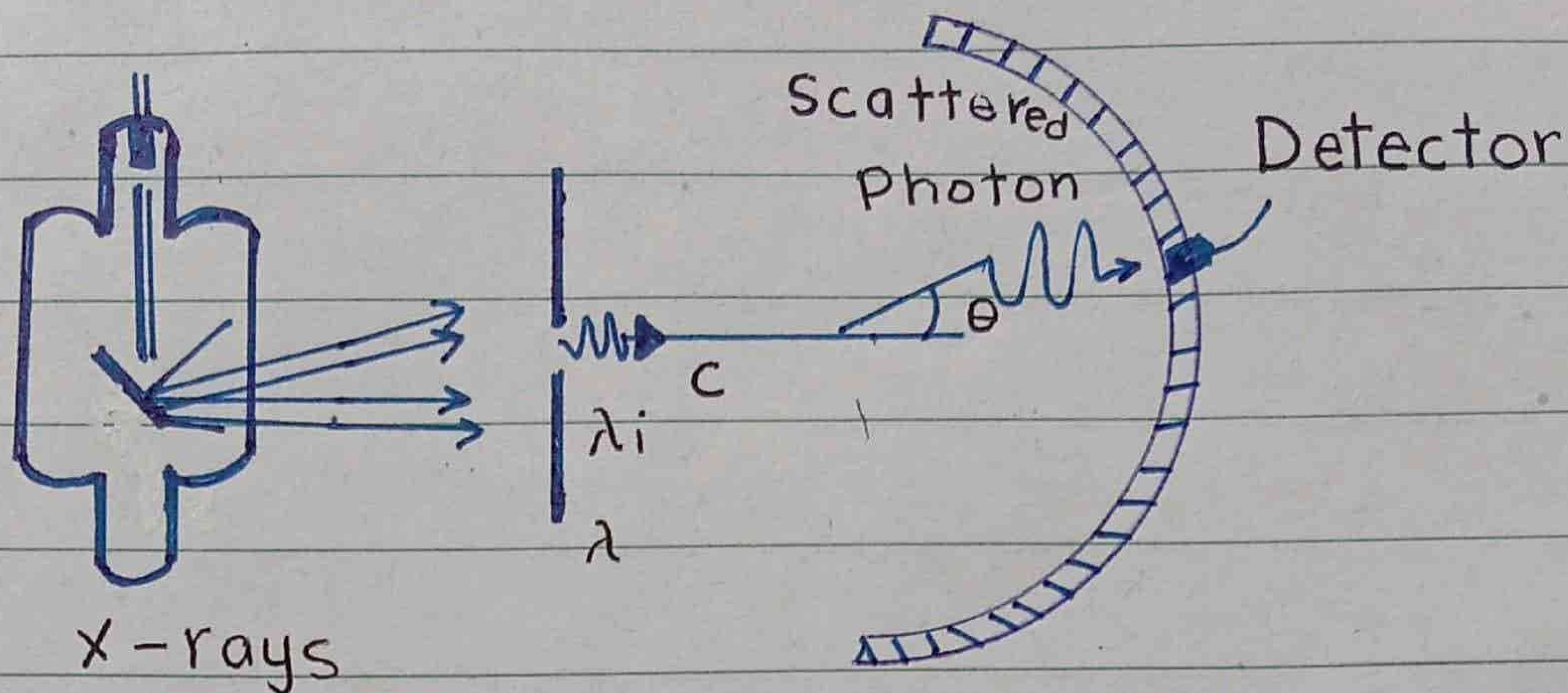
The change of wavelength cannot be explained on the basis of Electromagnetic theory.



A photon collides with an electron



Both are scattered



(a) Compton's scattering experiment.

Compton suggested that X-rays were consisting of photons and the scattering of X-rays is due to collision of photons with electrons inside the graphite target.

During these collision a part of energy and momentum. The photon is scattered with the remaining energy.

Applying law of conservation of energy and momentum, the change of wavelength $\Delta\lambda$ is calculated as;

$$\Delta = \lambda_s - \lambda_i = \frac{h}{m_o c}(1 - \cos\theta)$$

Here

m_o = rest mass of an electron

$m_o = 9.1 \times 10^{-31}$ kg

c = speed of light

$c = 3 \times 10^{8}\ ms^{-1}$

θ = scattering angle of x-rays.

$\Delta\lambda = \lambda' - \lambda$ = Compton's shift in wavelength

Case - 1

when $\theta = 90^\circ$

$$\Delta\lambda = \lambda' - \lambda$$

$$= \frac{h}{m_o c}(1 - \cos\theta)$$

$$= \frac{h}{m_o c}(1 - \cos 90^\circ)$$

$$= \frac{h}{m_o c}(1 - 0)$$

$$\Delta\lambda = \frac{h}{m_o c}$$

This is called compton's wavelength.

Its value

$$\Delta\lambda = \frac{h}{m_o c} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^{8}}$$

$$= 2.43 \times 10^{-12}\ m$$

$$\Delta\lambda = 2.43\ pm$$

$$= 2.43 \times 10^{-12}\ m$$

$$= 0.0243 \times 10^{-10}\ m$$

$$\Delta\lambda = 0.0243\ \mathring{A}$$

This is the value of compton's Wavelength

Case - 2:

When $\theta = 0^\circ$

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

$$= \frac{h}{m_o c}(1 - 1)$$

$$= \frac{h}{m_o c}(0)$$

$$\Delta\lambda = 0$$

case -3:

When $\theta = 180^\circ$

$$\Delta\lambda = \frac{h}{m_o c}(1 - \cos 180^\circ)$$

$$= \frac{h}{m_o c}[1 - (-1)]$$

$$= \frac{h}{m_o c}[1 + 1]$$

$$\Delta\lambda = \frac{2h}{m_o c}$$

This is the maximum shift in wavelength.

Conclusion:

It proves that x-rays photon has particle like nature like other electromagnetic waves.

Noble prize:

A.H. compton was awarded Noble prize in phsics in 1927 for his discovery of this effect.

Pair Production:

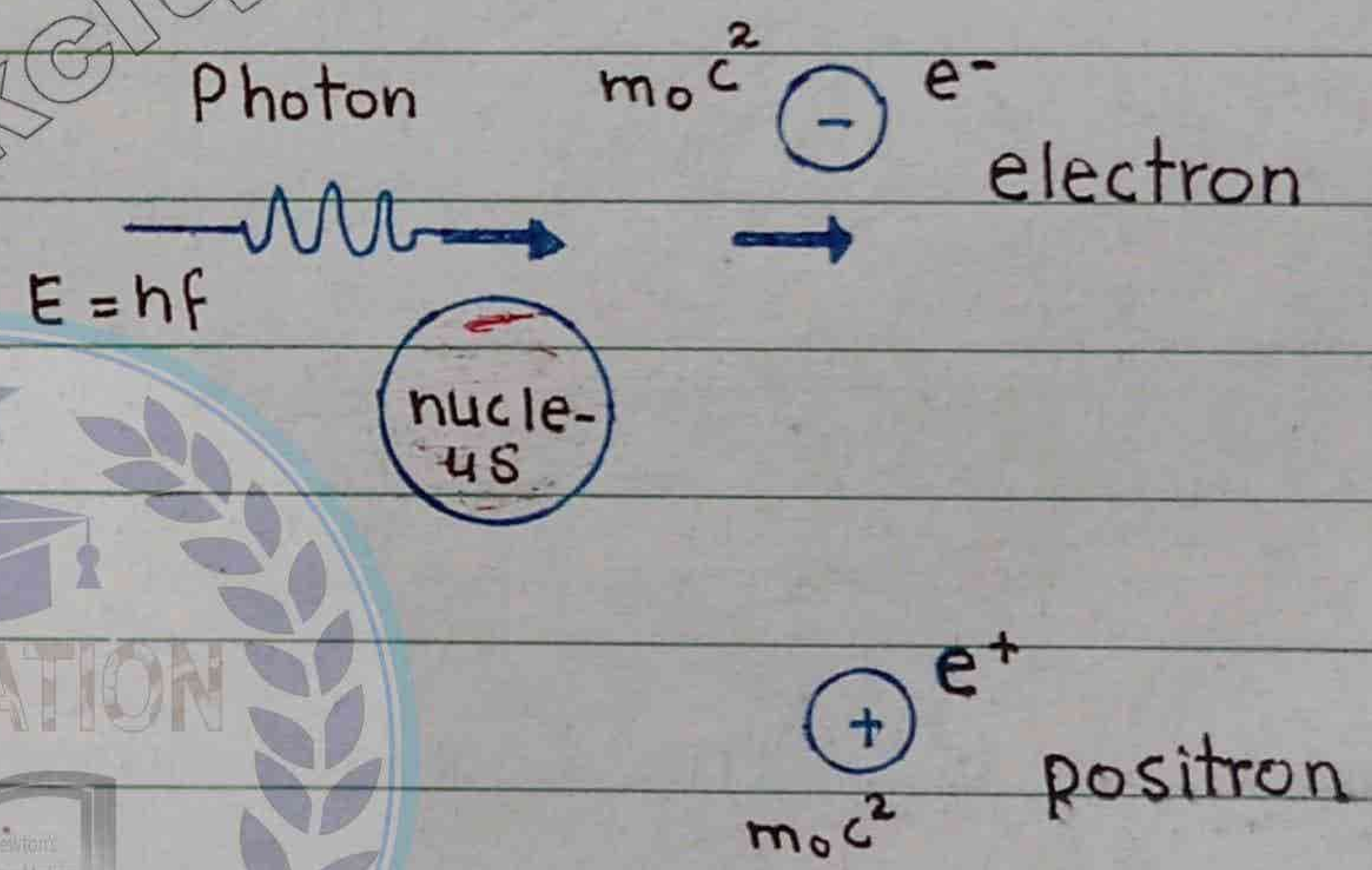
"Conversion of high energy photon (such a ray) into an electron and positron pair is called pair production."

This process taken place in the electric field close to a nucleus."

(Energy ⟶ matter)

Explanation:

Positron is a particle having same mass but equal and opposite charge than that of electron.



Pair Production

i) To conserve charge electron and positron must have equal and opposite charge.

ii) Positron is the anti-particle of electron i.e. anti-electron.

iii) In this process energy is converted into matter $E = mc^2$. So it is called "Materialization of energy."

iv) Rest mass energy of electron $= m_o c^2$

$$m_o c^2 = 9.1 \times 10^{-31} \times (3 \times 10^8)^2 \text{ J}$$

$$= \frac{9.1 \times 10^{-31} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}} \text{ eV}$$

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

$10^6 = \text{M} = \text{Mega}$

$2m_o c^2 = 1.02$ MeV

$$m_o c^2 = 0.51 \times 10^6 \text{ eV}$$

$$m_o c^2 = 0.51 \text{ MeV}$$

$$2m_o c^2 = 2 \times 0.51 \text{ MeV}$$

$$2m_o c^2 = 1.02 \text{ Mev}$$

Conditions for Pair Production:

i) Pair production will occur when the energy of photon is greater than $2m_o c^2$ (1.02 Mev)

$$E > 2m_o c^2$$
$$hf > 2m_o c^2$$

ii) Presence of a nucleus is essential for pair production. Pair production cannot take place in vacuum because there is no heavy nucleus in vacuum.

When the photon energy is greater than $2m_0c^2$ the probability of pair production increases and the surplus energy is taken up electron and positron as their K.E.

Energy of photon = [Energy required for pair production] + [Kinetic energy of electron and positron]

$$hf = 2m_0c^2 + KE_{e^+} + KE_{e^-}$$

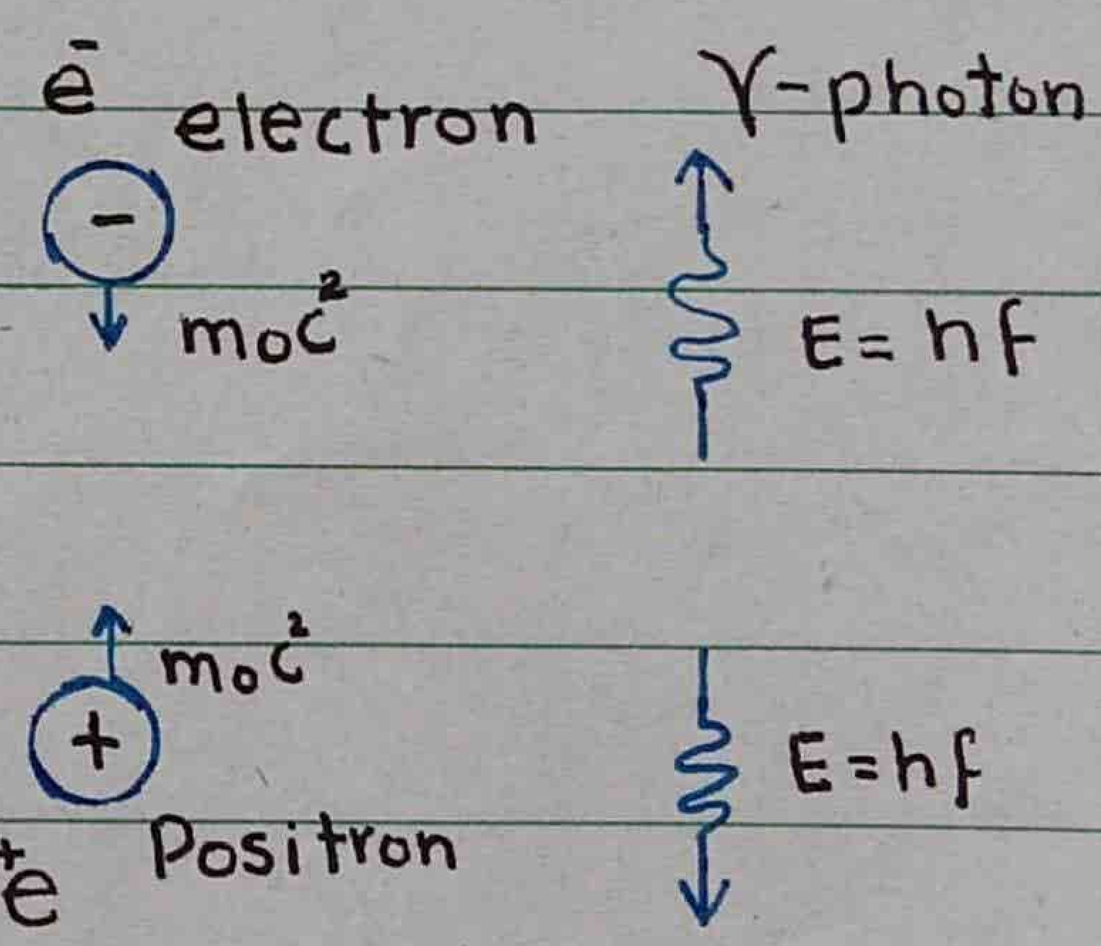
19.6 Annihilation of matter:

Annihilation is the converse of pair production. when an electron and positron (particle and anti-particle) come close, they annihilate (destroy) each other. The matter of the two particles is converted into electromagnetic energy producing two γ-rays photons. This process is called annihilation of matter.

$$e^- + e^+ \longrightarrow \gamma + \gamma \quad (\text{mass or matter} \longrightarrow \text{Energy})$$

The two photons travel in opposite directions to conserve momentum. Each photons has energy 0.51 MeV. equivalent to rest mass energy

$$E = m_o c^2$$



Conversely energy (photon) can be converted into mass (matter)

$$\gamma \longrightarrow e^- + e^+ . \quad (\text{pair production})$$

$$(\text{Energy} \longrightarrow \text{matter})$$

In 1928 Dirac predicted the existance of Positron.

In 1932 Carl and erson discovered positron in the cosmic rays.

1- Every particle has a corresponding anti-particle with the same mass and charge (if it is a charged particle) but of opposite sign.
2- Particle and antiparticles also different in the sign of other quantum numbers.
3- A particle and its antiparticles cannot exist together at one place. That is the particles disapear, their each other, there combined rest energy appear in other forms.

19.7 Wave nature of particles

Light has dual nature. It acts as waves and sometimes it acts as particle.

Dual nature :
- Light has wave nature.
- Light has particle natue.

In 1924, A french physiest Louis de Broglie proposed that particle must also posses dual nature. Sometimes particles show wave nat[illegible]

Momentum of a photon is

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

de Broglie suggested that momentum of a material particle (mv) can be given by the same exprenion

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

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

or

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

This equation gives the wavelength associated with a particle of mass m moving with velocity v.

$\lambda = \frac{h}{p} = \frac{h}{mv}$ is called de Broglies equation.

and λ is called de Broglies wavelength. and these waves are matter waves.

An object of Large mass and ordinary speed:

Consider a rifle bullet of mass 20g (.020kg) and flying with a speed 330 ms^{-1}

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

$$\lambda = \frac{6.63 \times 10^{-34}}{0.20 \times 330}$$

$$\lambda = 1 \times 10^{-34} \, m$$

This wave length is so small that it cannot be measured by any of its effect.

An object of small mass high speed:

Consider an electron moving with a speed of $1 \times 10^{6} m/s$

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

$$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1 \times 10^{6}}$$

$$\lambda = 7 \times 10^{-10} m$$

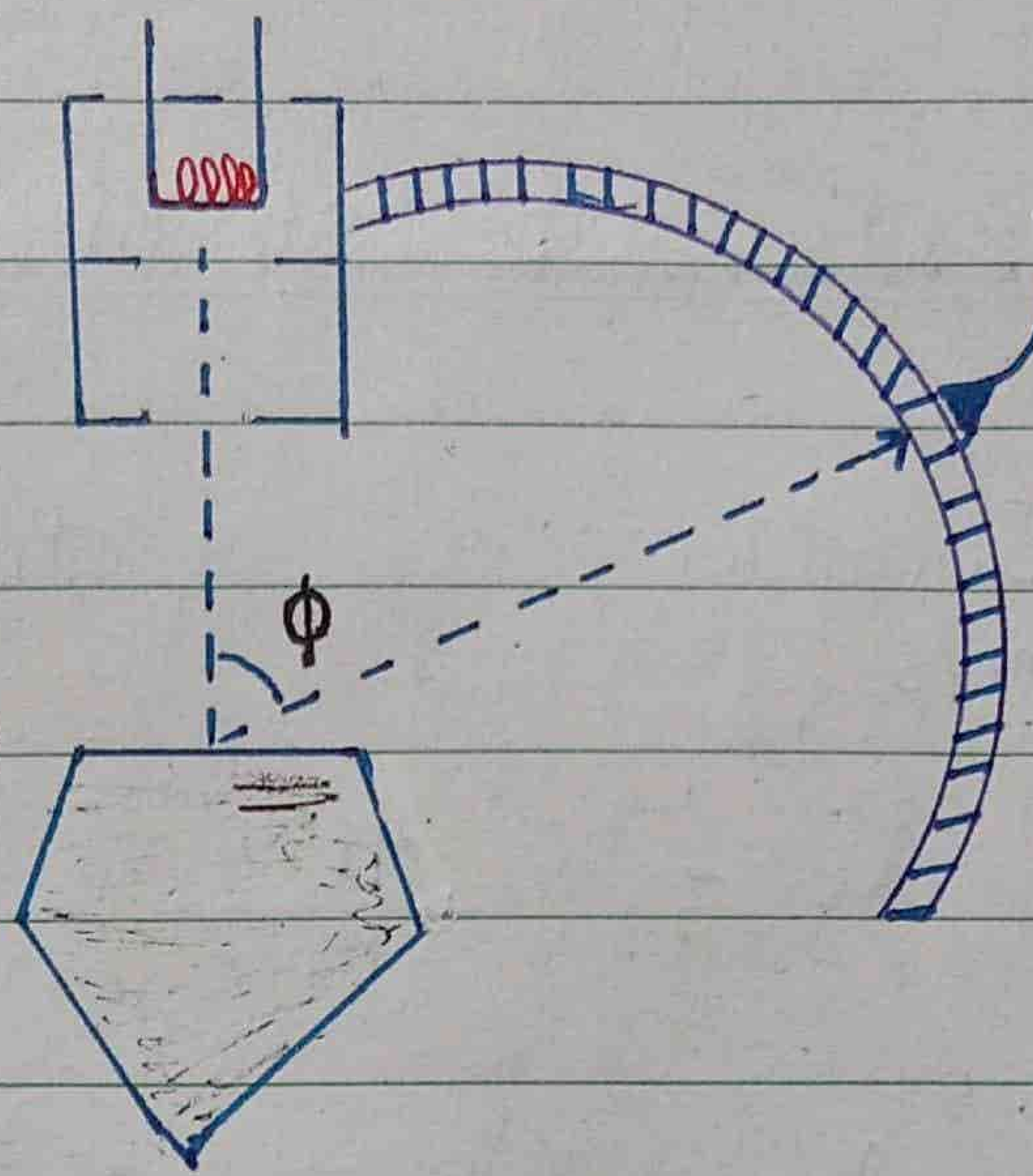
$$\lambda = 7 Å$$

This wave length is in the x-ray range. So, diffraction of measureable while diffraction or interferance effects of bullet are not.

Davison and Germer experiment:

De Broglie Hypothesis was experimentlly proved by Davison and Germer. They showd that electrons particles show diffraction (a wave property) from crystals just as x-rays do.

Experimental Set up:



It is shown in fig.

Electrons from a heated filament are accelerated by an applied voltage V.

The electron beam of energy Ve falls on a nickle crystal.

It is diffracted from the crystal. Then it enters a detector and is recorded as current I.

When V = 54 Volts

$\phi = 65^\circ$ (Glancing angle) for 1^{st} order.

The gain in KE of electrons when it is accelerated through a potential difference V is

$$KE = Ve$$

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

or

$$mv^2 = 2Ve$$

× by m ;

$$m \cdot mv^2 = m \cdot 2Ve$$

$$m^2 v^2 = 2mVe$$

$$mv = \sqrt{2mVe}$$

(i) Using De-Broglie's equation:

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

$$\boxed{\lambda = \frac{h}{\sqrt{2mVe}}}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 54 \times 1.6 \times 10^{-19}}}$$

$$= 1.66 \times 10^{-10}\ m$$

$$\boxed{\lambda = 1.66 \times 10^{-10}\ m}$$

(ii) Using Bragg's equ tion for diffraction:

$$2d \sin\theta = n\lambda$$

d = intermolecular distance

$d = .91 \times 10^{-10} m$

n = 1 for 1^{st} order diffraction.

$$\lambda = \frac{2d \sin\theta}{n}$$

$$\lambda = \frac{2 \times 0.91 \times 10^{-10} \sin 65^\circ}{1}$$

$$\lambda = 1.65 \times 10^{-10} m$$

Result:

As the both wavelengths are approximately same. So,

"Electrons (Particles) wave nature."

Wave particle duality:

i) Interference and diffraction of light show that Light has wave nature.

ii) Photo electric effect and compton effect prove that Light has particle, nature.

So, light (electromagnetic radiations) has dual nature.

Now,

i) While finding the $\frac{e}{m}$ ratio, J.J thomson proved that electrons has particle nature.

ii) Davison and Germer proved that electrons have wave nature.

So, material particles also have dual nature.

Combining the above results;

Matter and radiation have dual 'wave-particle' nature.

This concept is called wave-particle duality.

Neil Bohar pointed out that both wave and particle aspects are required for complete description of both radiation and matter.

Both aspects are always present. But both aspect cannot be revealed simultaneously in a single experiment.

It means that light cannot behave as wave and as particle at the same time in a singal experiment.

This fact is called Bohar's principle of complementarity.

All the micro particles propagate as if as they were waves and exchange energies as if they were particles.

Uses of wave nature of particles:

Energetic particles have very short de Broglies

wavelength.
This is used in many modren devices such as electron microscope.

Electron Microscope

Principle:

Electron microscope makes the practical use of wave nature of electrons.

High energy, fast moving electrons have wavelength which is thousands of time shorter than the wavelength of visible light.

The electron microscope distinguish details not visible with optical microscope.

In an electron microscope electric and magnetic filds are used to focus electrons by means of electromagnetic forces.

Working:

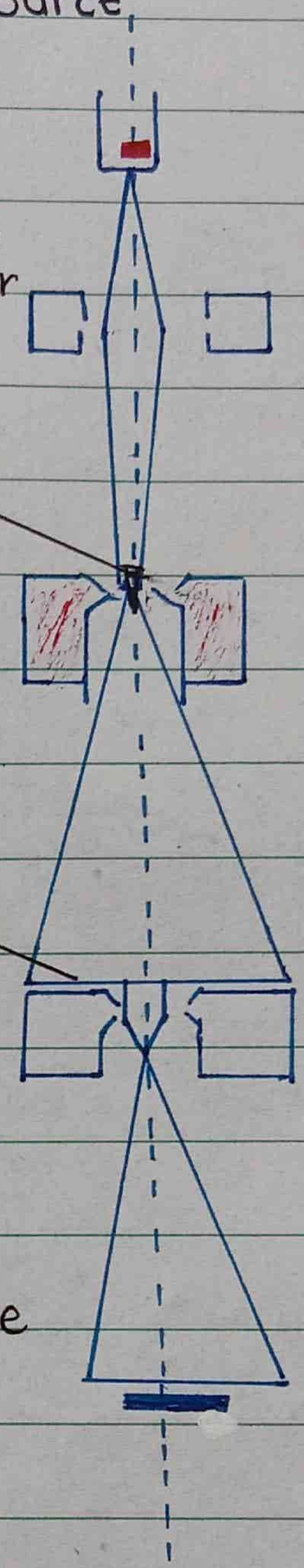
The electrons are accelerated to high energies by applying voltage from 30KV (30000 Volts) to several mega volts. Such high voltages give extremely short wavelength.

High voltages also give the electrons sufficient energy to penetrate the specimem.

Resolution:

A resolution, electron source of 0.5nm to 1nm (0.5×10^{-9} m to 1×10^{-9} m) is possible with a 50 KV resolution of 0.2 μm.

Schematic digram of the electron microscope shown in fig.



Electron microscope
(Block Diagram).

Magnetic conducting Lens:

They concentrate the beam from an electron gun onto the Specimen.

Specimen:

Electrons are scattered are out of the beam from the thicker part of the specimen. The transmitted beam has spatial differences in density, that correspond to the features of the specimen.

Objective and Intermediate Lenses:

They produce a real intermediate image.

Projection Lens:

It forms the final image on a flourescent screen or photographed on special film known as electron micrograph.

Scanning electron microscope:

A three dimersional image of remarkable quality can be achieved by modren version is called Scanning electron microscopes.

19.8 Uncertainty principle:

Position and momentum of a particle cannot both be measured simultaneously with perfect accuracy even with an ideal instrument. There is always a fundomental uncertainy due to wave-particle-duality of matter and radiation.

This principle was first proposed by Werner Heisenberg in 1927.

So, it is called Heisenberg's uncertainty principle.

Two Forms.

1- Uncertainty in position and momentum:

Statement:

"It states that the product of uncertainy in momentum Δp of a body at some instant and the uncertainty in its position Δx at the same instant is approximately equal to plank's constant."

$$\Delta p \cdot \Delta x \approx h$$

Explanation:

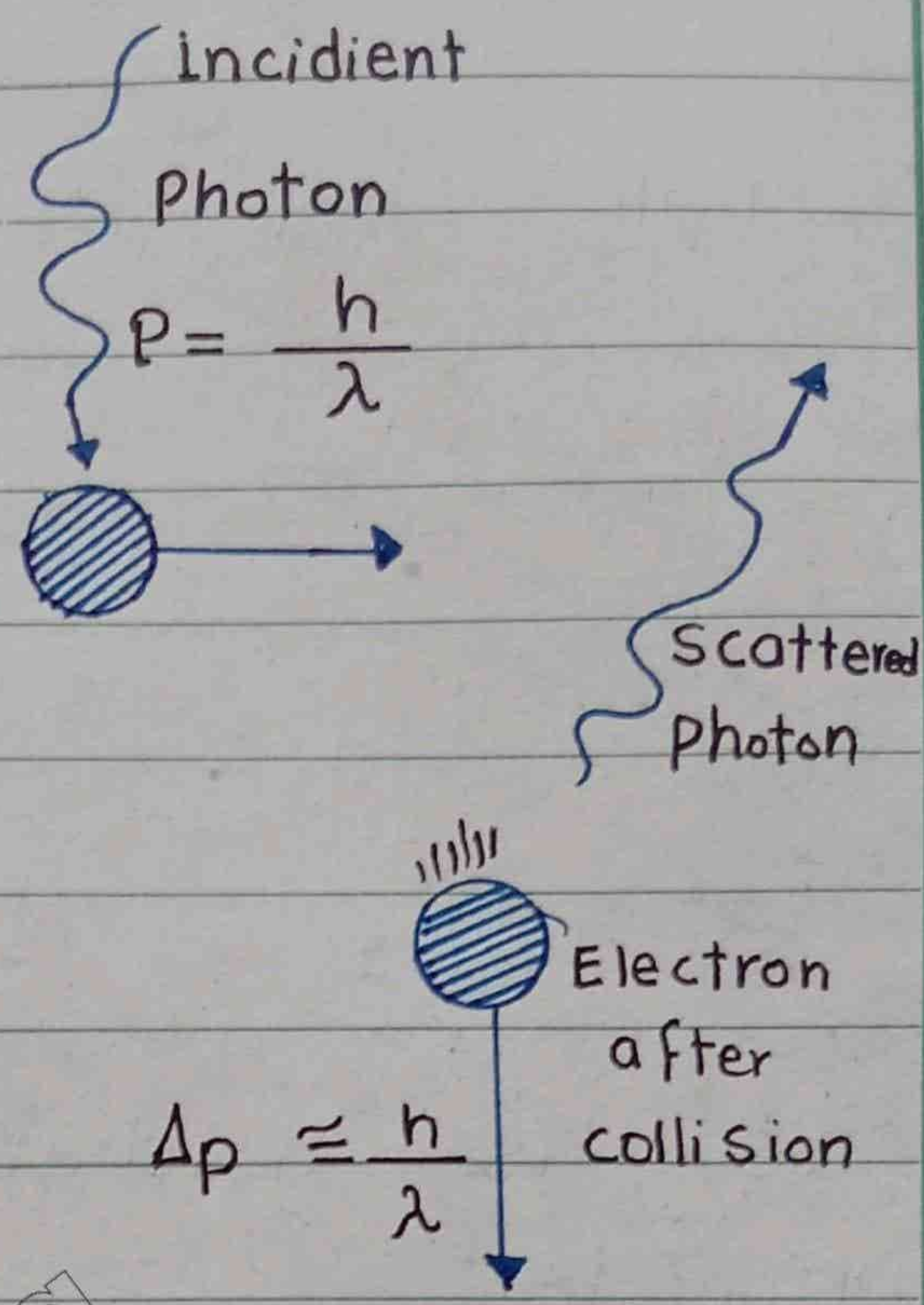
In order to see an electron, we use light, photon of wavelength λ and momentum $p = \frac{h}{\lambda}$.

When the photon strikes the electron, the photon is scattered and the original momentum of photon is changed as shown in fig.

We cannot predict the exact change in the momentum. But at the most the photon can transfer all its momentum $\frac{h}{\lambda}$ to the electron

So, the uncertainty in the momentum of electron is

$$\Delta p \approx \frac{h}{\lambda} \quad \rightarrow (1)$$



In order to reduce the uncertainty in momentum we must use light of large wavelength.

Now, the uncertainty in determining the position Δx of the electron is of the wave length of light.

$$\Delta x \approx \lambda \quad \rightarrow (2)$$

This is the uncertainty in position of electron.

In order to decrease the uncertainty in position Δx of electron we must use light of short wavelength.

If we use light of short wave-length, the uncertainty in position Δx of electron decreases (accuracy increases), but at the same time the uncertainty in momentum Δp increases (accuracy decreases)

Multiply eq (1) and eq (2)

$$\Delta p \, \Delta x \approx \frac{h}{\lambda} \times \lambda$$

$$\Delta p \Delta x \approx h$$

This is mathemetical form of uncertainty principle.

2- Uncertainty in Energy and time:

Statement:

"It states that uncertainty in the measured amount of energy and the time interval during which it is measured is approximately equal to plank's constant."

$$\Delta E \, \Delta t \approx h$$

The move accurately we determine energy of a particle, the move uncertainty will be in time during which it has that energy.

According to Heisenberg's more careful caculations, he found that at the very best

$$\Delta p . \Delta t \geq \hbar$$

$$\Delta E . \Delta t \geq \hbar$$

Where

$$\hbar = \frac{h}{2\pi} = \frac{6.63 \times 10^{-34} J \times S}{2 \times 3.14}$$

$$\hbar = 1.05 \times 10^{-34} \; J \times S$$

Nobel prize:

Werner Karl Heisenberg received Nobel prize for physics in 1932 for the developement of Quantum mechanics.

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Chapter = 19

Questions

Question = 1

Answer:

1 - Force
2 - Acceleration
3 - Speed of Light
$c = 3 \times 10^8$ m/s = constant

According to the postulate of special theory of relativity speed of light c is constant. It does not depend on the relative motion of the source and observe.

Question = 2

Answer:

The dialtion is an actual process.

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

So time really passes more slowly in moving system.

Question 19.3

Answer :

(a) The pulse rate of the person who is travelling in a spaceship is not changed with respect to the clock inside the spaceship because he is at rest w.r.t the ship. (The velocity of the person w.r.t. the spaceship is zero.)

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

$$t = \frac{t_o}{\sqrt{1 - \frac{0}{c^2}}}$$

$$t = \frac{t_o}{\sqrt{1 - 0}}$$

$$t = \frac{t_o}{\sqrt{1}}$$

$$t = t_o$$

(b) When the person is moving with very high speed w.r.t the man at rest on earth, then according to his observation the pulse rate of the man on the earth will decrease, due to time dialation.

Question 19.4

Answer:

If $c = \infty$

$$\frac{v^2}{c^2} = \frac{v^2}{\infty} = 0.$$

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$m = \frac{m_o}{\sqrt{1-0}}$$

$$m = \frac{}{\sqrt{1}}$$

$$m = m_o$$

$$L = L_o\sqrt{1-\frac{v^2}{c^2}}$$

$$L = L_o\sqrt{1-0}$$

$$L = L_0\sqrt{1}$$

$$L = L_0$$

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$t = \frac{t_0}{\sqrt{1-0}}$$

$$t = \frac{t_0}{\sqrt{1}}$$

$$t = t_0$$

If c is infinity, there is no change in mass, length, time.

Question 19.5

Answer:

According to the special theory of relativity, the variation of mass is due to motion and not due to position.

As the compressed spring does not move there is no change in mass

Elastic PE of a compressed spring increases

Question 19.6

Answer:

At low temperature a body emits radiations which are of long wavelength. The longest visible radiation is red. So it is appears first red. As the temperature is increased the shorter wavelength radiation emitted.

Question 19.7

Answer:

By Stephen's - Boltzman Law.

$E \propto T^4$ or $E = \sigma T^4$

If temperature T is doubled

$E \propto (2T)^4$

$E \propto 2^4 T^4$

$E \propto 16T^4$

The total radiations become 16 times greater.

Question 19.8

Answer:

As

$E = hf$ For single photon

$E = nhf$ For n photons.

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

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

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

$$n \propto \lambda$$

For longer wavelength λ, number of photons is greater

$$\lambda_{red} > \lambda_{blue}$$

$$n_{red} > n_{blue}$$

So red light contains more number of photons.

Question 19.9

Answer:

$$E = hf$$

or $$E = h\frac{c}{\lambda}$$

$$E \propto \frac{1}{\lambda}$$

hc = constant

also

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

or

$$p \propto \frac{1}{\lambda}$$

Shorter wavelength (higher frequency) photon has Larger energy and Larger momentum.

λ_{blue} = Smallest

$\lambda_{blue} = 400\,nm$

$\lambda_{red} = 700\,nm$

So, blue Light photon has Larger energy and Larger momentum.

Question 19.10

Answer:

The frequency of radio waves is less than that of X-rays.

As

$$E = hf$$

$$E \propto hf$$

Radio waves have the lower energy quanta (photons). Their energy $\approx 10^{-10}$ eV or 10^{-8} eV.

Question 19.11

Answer:

Brightness does not depend upon the frequency of photons.

Brightness depends upon the intensity of light, So brightness depends upon the number of photons.

Question 19.12

Answer:

Infra red light photons have smallar frequency smaller energy than those of ultra violet.

So, when infrared light falls on the atoms of a dye, they might excite the atoms of the die but during de-excitation the frequency emitted by the atoms are below the frequency of visible spectrum.

So, no visible light is emitted.

Question 19.13

Answer:

Yes,

Bright light means more intensity. As the number of electron ejected from the metal surface depends on the intensity of light, so, bright light being more intence will eject more electrons than the dimmer Light having less intensity.

Question 19.14

Answer:

No,

As the number off electrons ejected from a metal Surface depends upon the intensity of light and not on the frequency of Light.

So, the higher frequency light will not eject greater number of electrons than low frequency.

Question 19.15

Answer:

Yes,

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As

$$E = mc^2 = mc \cdot c$$

$$E = pc$$

momentum of photon $p = \frac{E}{c}$

When light (photons) shines on a metal of photons is transferred to the metal surface.

Question 19.16

Answer:

As

$$E = hf \quad \text{or} \quad E \propto f$$

$\lambda_{red} = 700nm$

$\lambda_{blue} = 400nm.$

Red light has smallest frequency in the visible light.
So, it has smallest energy in the visible light.

Hence, it cannot effect the photograph film.

Question 19.17

Answer:

As

$$E = pc$$

or $\qquad$ C = constant

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

$$P \propto E$$

When,

Photon A has twice energy of photon B.

Photon A has twice momentum of photon B.

Ratio = 2:1

$$E_A : E_B$$

$$2 : 1$$

So

$$P_A : P_B$$

$$2 : 1$$

Question 19.18

Answer:

For compton scattering it is necessary that the energy of the photon should be much greater than the binding energy of the electron.

$hf >> \phi$

ϕ = binding energy of electron

ϕ = work function of the metal.

Visible light photons have smaller energy and smaller frequency.

So, compton effect is not observed.

X-ray photons have very large frequency and very large energy, so, compton effect is observed by x-rays.

Question 19.19

Answer:

No,

Pair production can take place near a nucleus to conserve momentum. In vacuum there is no nucleus, So pair production cannot take place in vacuum.

Question 19.20

Answer:

A single electron cannot be created from energy.

creation of single electron is against the law of conservation of charge.

Question 19.21

Answer:

If electrons behave only, like particles, interference, which is a wave property cannot take place.
So, the electrons would pass through the slit straight and will produce the exact image of the slit.

No,
interference patteren would be observed.

Question 19.22

Answer:

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

h = constant
λ = same

$$v = \frac{h}{m\lambda}$$

$$v \propto \frac{1}{m}$$

mass of electron is smaller than mass of proton.
Velocity of electron will be greater than

that of proton.

$$V_e > V_p$$

As

$$m_e < m_p.$$

Question 19.23

Answer:

According to de Broglie

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

The value of $h = 6.63 \times 10^{-34}$ Jxs. It is very small. due to small velocity and large mass of cricket ball.

$$\lambda = \text{very small}$$

λ is so small that it cannot be measured.

Question 19.24

Answer:

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

x by m $$mv^2 = 2E$$

$$m^2v^2 = 2mE$$

$$mv = \sqrt{2mE}$$

As

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

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

As, h = constant

E = same

$$\lambda \propto \frac{1}{\sqrt{m}}$$

Heaviest particle has smaller wavelength.

m = mass of alpha-particle is greatest.

λ = wavelength of alpha is shortest.

Question 19.25

Answer:

(i) Light behaves as waves when its frequency is small and wavelength is Long.

(ii) Light waves behave like particles when its frequency is Large and wave length small.

Question 19.26

Answer:

(i) Electron microscope has Large resolution. (1nm - 0.5 nm) optical microscope has small resolution (0.2 μm).

(ii) High energy electrons penetrate in the specimen, so internal structure of the specimen can be obtained, which is not possible by optical microscope.

Question 19.27

Answer:

According to the Heisenberg's uncertainity principle

$$\Delta p \Delta x \approx h.$$

Position and momentum of an electron cannot be both measured with perfect accuracy. If a measurement shows precise position of an electron, the momentum of electron will not be precise.

Chapter = 19

Examples

Example 19.1

Solution:

$t_o = 3s$

$V = 0.95c$

$t = ?$

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

$$t = \frac{3}{\sqrt{1 - \frac{(0.95c)^2}{c^2}}}$$

$$t = \frac{3}{\sqrt{1 - \frac{(.95)^2 c^2}{c^2}}}$$

$$t = \frac{3}{\sqrt{1 - (0.95)^2}}$$

$$t = 9.6s$$

Example 19.2

Solution :

$L_o = 1\,m$

$v = 0.75c$

$L = ?$

$$L = L_o\sqrt{1 - \frac{v^2}{c^2}}$$

$$L = 1 \times \sqrt{1 - \frac{(.75c)^2}{c^2}}$$

$$L = \sqrt{1 - \frac{(0.75)^2 c^2}{c^2}}$$

$$L = \sqrt{1 - (0.75)^2}$$

$$L = 0.66\,m$$

Example 19.3

Solution:

$$m = ?$$

$$v = 0.8c$$

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

$$m = \frac{m_o}{\sqrt{1 - \frac{(0.8c)^2}{c^2}}}$$

$$m = \frac{m_o}{\sqrt{1 - (0.8)^2}}$$

$$m = \frac{1}{\sqrt{1 - (0.8)^2}} \times m_o$$

$$m = 1.67 m_o$$

Example 19.4

Solution:

$T = 37^\circ C$

$T = 37 + 273$

$T = 310 K$

Wein's constant $= 2.9 \times 10^{-3}$ mK

$\lambda_{max} = ?$

$\lambda_{max} \times T = \text{constant}$

$\lambda_{max} = \frac{\text{constant}}{T}$

$\lambda_{max} = \frac{2.9 \times 10^{-3}}{310}$

$\lambda_{max} = 9.35 \times 10^{-6}$ m

$\lambda_{max} = 9.35\ \mu m$

This radiation lies in the invisible infrared region and independent of skin colour.

Example 19.5

Solution:

$\lambda = 1240 \text{ nm}$

$\lambda = 1240 \times 10^{-9} \text{ m}$

$E = ?$

$E = hf$

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

$$f\lambda = c$$

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

$$f_0 = \frac{c}{\lambda_0}$$

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1240 \times 10^{-9}}$$

$E = 1.6 \times 10^{-19} \text{ J}$

[$1\text{eV} = 1.6 \times 10^{-19} \text{J}$]

$E = 1.0 \text{ eV}$

Example 19.6

Solution:

(a) $\lambda = 300\,nm$

$$\lambda = 300 \times 10^{-9}\,m$$

$$E = hf$$

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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{300 \times 10^{-9}}\,J$$

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

$$E = 6.63 \times 10^{-19}\,J$$

$$E = \frac{6.63 \times 10^{-19}}{1.6 \times 10^{-19}}\,eV$$

$$E = 4.14\,eV$$

$$KE_{max} = hf - \phi$$

$$KE_{max} = 4.14\,eV - 2.46\,eV$$

$$KE_{max} = 1.68\,eV$$

(b)

$$\phi = 2.46\,eV$$

$$\phi = 2.46 \times 1.6 \times 10^{-19}\,J$$

$$\phi = 3.94 \times 10^{-19}\,J$$

As

$$\phi = hf_o$$

$$\phi = h\frac{c}{\lambda_o}$$

$$\lambda_o = \frac{hc}{\phi}$$

$$\lambda_o = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{3.9 \times 10^{-19}}$$

$$\lambda_o = 505\,nm$$

$$f\lambda = c$$

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

$$f_o = \frac{c}{\lambda_o}$$

Example 19.7

Solution:

$$E = 50\,keV$$

$$E = 50 \times 10^{3} \times 1.6 \times 10^{-19}\,J$$

$$E = hf$$

$$f\lambda = c$$

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

$$f_o = \frac{c}{\lambda_o}$$

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

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

$$\lambda = \frac{6.63\times10^{-34}\,Js \times 3\times10\,ms^{-1}}{50\times10^{3}\times1.6\times10^{-19}\,J}$$

$$\lambda = 0.0248\,nm$$

$$\lambda' - \lambda = \frac{h}{mc}(1 - \cos 45^\circ)$$

$$\lambda' - \lambda = \frac{6.63\times10^{-34}\,Js}{9.1\times10^{-31}\,kg\times3\times10^{8}\,ms^{-1}}(1 - 0.707)$$

$$\lambda' - \lambda = 0.2429\times10^{-11}\,m\times0.293$$

$$\lambda' - \lambda = 0.0007\,nm$$

$$\lambda' = \lambda + 0.0007\,nm$$

$$\lambda' = 0.0248\,nm + 0.0007\,nm$$

$$\lambda' = 0.0255\,nm$$

Example 19.8

Solution:

$$m = 5.0\,mg$$

$$m = 5 \times 10^{-3}\,g$$

$$m = 5 \times 10^{-3} \times 10^{-3}\,kg$$

$$m = 5 \times 10^{-6}\,kg$$

$$v = 8\,ms^{-1} \quad , \quad h = 6.63 \times 10^{-34}\,J \times s$$

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

$$\lambda = \frac{6.63 \times 10^{-34}}{5 \times 10^{-6} \times 8.0}$$

$$\lambda = 1.66 \times 10^{-29}\,m.$$

Such a small wavelength cannot be measured.

Example 19.9

Solution:

$m = 9.1 \times 10^{-31}\ kg$

$V = 50\ volts$

$e = 1.6 \times 10^{-19}\ C$

$\lambda = ?$

$KE = Ve$

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

$mv^2 = 2Ve$

x by m both sides

$m^2v^2 = 2mVe$

$p^2 = 2mVe$

$mv = p$

$p = \sqrt{2mVe}$

$m^2v^2 = p^2$

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

$$\lambda = \frac{h}{\sqrt{2mVe}}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 50 \times 1.6 \times 10^{-19}}}$$

$$\lambda = 1.74 \times 10^{-10} \text{ m.}$$

Example 19.10

Solution:

$$\Delta t \approx 10^{-8} s$$

$$\Delta E = ?$$

$$\hbar = 1.05 \times 10^{-34} \text{ Js}$$

$$\Delta E \Delta t \approx \hbar$$

$$\Delta E = \frac{\hbar}{\Delta t}$$

$$\Delta E = \frac{1.05 \times 10^{-34}}{10^{-8}}$$

$$\boxed{\Delta E = 1.05 \times 10^{-26}\ J}$$

Example 19.11

Solution:

$$\Delta x = 1.0 \times 10^{-14}\ m$$

$$\Delta v = ?$$

$$\frac{h}{2\pi} = \hbar$$

$$\hbar = 1.05 \times 10^{-34}\ J \times s$$

$$\Delta p \Delta x \approx \hbar$$

$$\Delta p \approx \frac{\hbar}{\Delta x}$$

$$\Delta (mv) \approx \frac{\hbar}{\Delta x}$$

$$\Delta v \approx \frac{\hbar}{m \Delta x} = \frac{1.05 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.0 \times 10^{-14}}$$

$$\Delta v \approx 1.15 \times 10^{10} \ m/s$$

$$[c = 3 \times 10^{8} ms^{-1}]$$

$$1.15 \times 10^{10} \ m/s > 3 \times 10^{8} ms^{-1}$$

As

$\Delta v > c$ which is not posible.

So, an electron cannot be found inside a nucleous.

Chapter 19

Problems

Problem 19.1

Solution:

$t_o = 2.6 \times 10^{-8}$ s

$t = ?$

$v = 0.95c$

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t = \frac{2.6 \times 10^{-8}}{\sqrt{1 - \frac{(0.95c)^2}{c^2}}}$$

$$t = \frac{2.6 \times 10^{-8}}{\sqrt{1 - \frac{(0.95)^2 c^2}{c^2}}}$$

$$t = \frac{2.6 \times 10^{-8}}{\sqrt{1 - (0.95)^2}}$$

$$t = 8.3 \times 10^{-8}\ \text{s}$$

time interval is dialated

Problem 19.2

Answer:

$m_o = 70 kg$

$v = 0.8c$

$m = ?$

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

$$m = \frac{70}{\sqrt{1 - \frac{(0.8)^2 c^2}{c^2}}}$$

$$m = \frac{70}{\sqrt{1 - (0.8)^2}}$$

$$m = 116.7 \text{ kg}$$

mass is increased.

Problem 19.3

Solution:

(a)

$E = ?$

$E = hf$

$h = 6.63 \times 10^{-34}\ Js$

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

For

$\lambda = 100 m$

$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{100}$

$E = 1.98 \times 10^{-27}$

$(1ev = 1.6 \times 10^{-19} J)$

$E = \frac{1.98 \times 10^{-27}}{1.6 \times 10^{-19}} eV$

$E = 1.24 \times 10^{-8}\ eV.$

(b)

For $\lambda = 550\ nm$

$\lambda = 550 \times 10^{-9}\ m$

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

$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{550 \times 10^{-9}}$

$E = 3.6 \times 10^{-19} J$

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

$$E = \frac{3.6 \times 10^{-19}}{1.6 \times 10^{-19}} eV$$

$$E = 2.26 eV$$

(C)

For $\lambda = 0.2 nm$

$$\lambda = 0.2 \times 10^{-9} m$$

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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{0.2 \times 10^{-9}}$$

$$E = 9.945 \times 10^{-16} J$$

$$E = \frac{9.945 \times 10^{-16}}{1.6 \times 10^{-19}} eV$$

$$E = 6215 eV$$

$$E \cong 6200 eV$$

Problem 19.4

Solution:

$$\lambda = 577 nm$$

$$\lambda = 577 \times 10^{-9} m$$

$$V_o = 0.25 \text{ volts}$$

(a) $KE_{max} = ?$

(b) $\phi = ?$ $\quad e = 1.6 \times 10^{-19} C$.

(a)

$$KE_{max} = V_o e$$

$$KE_{max} = 0.25 \times 1.6 \times 10^{-19}$$

$$KE_{max} = 4 \times 10^{-20} J$$

(b) $KE_{max} = hf - \phi$

$$KE_{max} = h\frac{c}{\lambda} - \phi$$

$$\phi = \frac{hc}{\lambda} - KE_{max}$$

$$\phi = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{577 \times 10^{-9}} - 4 \times 10^{-20}$$

$$\phi = 3.45 \times 10^{-19} J - 4 \times 10^{-20} J$$

$$\phi = 3.047 \times 10^{-19} J$$

$$\phi = \frac{3.047 \times 10^{-19}}{1.6 \times 10^{-19}} eV$$

$$\boxed{\phi = 1.90 eV}$$

Problem 19.5

Solution:

$$\lambda = 22 pm$$

$$\lambda = 22 \times 10^{-12} m$$

$$\theta = 85^\circ$$

$$\Delta\lambda = ?$$

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

$$\Delta\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^{8}}(1 - \cos 85^\circ)$$

$$\Delta\lambda = 2.428 \times 10^{-12}(1 - 0.087)$$

$$\Delta\lambda = 2.2 \times 10^{-12}\ m$$

$$\boxed{\Delta\lambda = 2.2pm}$$

Problem 19.6

Solution:

$$E = 90 KeV$$

$$E = 90 \times 10^{3} eV$$

$$= 90 \times 10^{3} \times 1.6 \times 10^{-19} J$$

$$E = hf$$

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

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

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{90 \times 10^{3} \times 1.6 \times 10^{-19}}$$

$$\lambda = 13.8 \times 10^{-12}\ m$$

$$\lambda = 13.8 nm$$

$$\lambda' - \lambda = \frac{h}{m_o c}(1 - \cos\theta)$$

(a)

For $\theta = 30^\circ$

$$\lambda' = \lambda + \frac{h}{m_o c}(1 - \cos\theta)$$

$$\lambda' = 13.8 \times 10^{-12} + \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^{8}}(1 - \cos\theta)$$

$$\lambda' = 13.8 \times 10^{-12} + 2.428 \times 10^{-12}(1 - .86)$$

$$\lambda' = 14.1 \times 10^{-12}$$

$$\lambda' = 14.1\ \text{pm.}$$

(b)

For $\theta = 60^\circ$

$$\lambda' = \lambda + \frac{h}{m_o c}(1 - \cos 60^\circ)$$

$$\lambda' = 13.8 \times 10^{-12} + \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^{8}}(1 - 0.5)$$

$$\lambda' = 13.8 \times 10^{-12} + 2.428 \times 10^{-12}(0.5)$$

$$\lambda' = 15 \times 10^{-12}\ m$$

$$\boxed{\lambda' = 15\ pm}$$

Problem 19.7

Solution:

$$L = ?$$

$$E = 0.5\ MeV$$

$$E = 0.5 \times 10^{6}\ eV$$

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

$$E = 0.5 \times 10^{6} \times 1.6 \times 10^{-19}$$

$$E = hf$$

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

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

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{0.5 \times 10^{6} \times 1.6 \times 10^{-19}}$$

$$\lambda = 2.44 \times 10^{-12}\ m$$

Problem 19.8

Solution:

$$\lambda = ?$$

(a)

$$m = 140 g$$

$$m = \frac{140}{1000} kg$$

$$m = 0.140 kg$$

$$V = 40 ms^{-1}$$

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

$$\lambda = \frac{6.63 \times 10^{-34}}{0.140 \times 40}$$

$$\lambda = 1.18 \times 10^{-34} m$$

Such a small value of λ cannot be measured.

(b)

$$m = 1.67 \times 10^{-27} kg$$ (man of proton)

$$v = 0 ms^{-1}$$

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

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$$\lambda = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 40}$$

$$\lambda = 9.92 \times 10^{-9}\ m$$

$$\lambda = 9.92\ nm$$

(c)

$m = 9.1 \times 10^{-31}\ kg$ (mass of electron)

$v = 40\ ms^{-1}$

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

$$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 40}$$

$$\lambda = 1.82 \times 10^{-5}\ m.$$

Problem 19.9

Solution:

$\lambda = ?$

$KE = 120\ eV.$

$$KE = 120 \times 1.6 \times 10^{-19}\,J$$

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

$$mv^2 = 2KE$$

x by m

$$m^2v^2 = 2mKE$$

$$p = mv$$

$$p = 2mKE$$

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

$$\lambda = \frac{h}{\sqrt{2mKE}}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 120 \times 1.6 \times 10^{-19}}}$$

$$\lambda = 1.12 \times 10^{-10}\,m$$

$$\boxed{\lambda = 1.12\,A^\circ}$$

Problem 19.10

Solution:

$$\Delta x = 1.0 \times 10^{-10}\ m$$

$$\Delta v = ?$$

$$\Delta x\, \Delta p = h$$

$$\Delta p = \frac{h}{\Delta x}$$

$$\Delta (mv) = \frac{h}{\Delta x}$$

$$m \Delta v = \frac{h}{\Delta x}$$

$$\Delta v = \frac{h}{m \Delta x}$$

$$\Delta v = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.0 \times 10^{-10}}$$

$$\Delta v = 7.29 \times 10^{6}\ m/s$$