CHAPTER- 17
ADVENT OF MODERN PHYSICS

FRAME OF REFERENCE

The position of a point or an object in space is measured (or specified) with respect to some convenient reference the most commonly used reference is the set of rectangular axes x, y & z with respect to which measurements are made is called a frame of reference as shown in figure

Consider a point "P" whose position with respect to origin "O" is given by the position vector "r" this vector is also called displacement vector of the point "P" with respect to origin O whose coordinates are x, y & z

There are two types of frame of reference

1) Internal frame of reference
2) Non- internal frame of reference

INTERNAL FRAME OF REFERENCE:

Frame of reference moving with constant velocity (having zero acceleration) is called an internal frame of reference the name internal frame is given to its because the "law of inertia" hold in it since the first law of inertia thus we may also define inertial frame of reference as that in which the Newton's law are valid

Examples of Inertial Frame of Reference

i) A railway compartment moving with constant velocity
ii) A space ship moving with constant velocity
iii) A car moving with constant velocity
iv) Rectangular axes x, y & z drawn in a frame moving with constant velocity

All inertial frame of reference are equivalent

It can be shown that all inertial frame of reference are equivalent from the point of view of making measurements of physical phenomenon consider two observes in two different inertial frame of reference A and B. They perform as experiment conceiving elastic collision of two bodies in their frames each observer will find that

Initial momentum of the system before collision} = {Final momentum of the system after collusion}

And

{Initial K. E of the system collusion} = {Final K. E. of the system after collusion}

In other words the law of conversation of momentum and K. E will have same from in both the frames thus the two frames are equivalent

NON- INTERTIAL FRAME OF REFERENCE:

A frame of reference moving with some acceleration is called "non inertial frame of reference"

THE PRINCIPLE OF RELATIVITY:

According to this principle "all possible reference frames moving at uniform velocity relative to one another (i.e. inertial frames) are equivalent for all physical laws= mechanical or electromagnetic"

RELATIVISTIC MECHANICS:

It is that branch of physics which deals with bodies moving with velocities comparable with the velocity of light

GEVERAL THEORY OF RELATIVITY:

The part of relativistic mechanics which deals with accelerated motion is called "general theory of relativity"

SPECIAL THEORY OF RELATIVITY:

The part of relativistic mechanics which deals with uniform motion is called "special theory of relativity".

POSTULATES OF SPECIAL THEORY OF RELATIVITY:

1- there is no preferred or absolute inertial frame of reference ie.e all the inertial frames are equivalent or the description of all physical law (Newton's as well as Maxwell's electromagnetic equations).

2- The speed of light in vacuum is the same for all observers in uniform translational relative motion and is independent of the motion of the observer and the source

CONSEQUENCES OF SPECIAL THEORY OR RELATIVITY
OR RESULTS OF SPECIAL THEORY OF RELATIVITY

Following are the results of special theory of relativity

1) Mass Variation: Relativistic Mass of an object increases if it is moving with a relativistic speed with respect to an observer

Explanation:

Mass of an object at rest is called its rest mass "m_o" if the object is moving with a relativistic speed of "v" with respect to an observer it mass increases to "m" is given by

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

Where c = speed of light

The factor $\sqrt{1-\frac{v^2}{c^2}}$ is called "Lorentz factor" or "relativistic factor"

a) If the object is at rest or moving with ordinary velocity then, v=0 or $\frac{v}{c} = 0$ *and* $m = m_o$
b) If the body is moving with a velocity nearly equal to "c" then v = c or $\frac{v}{c} = 1$ *then* $m = \infty$.
c) No material object can have infinite mass therefore it is concluded that "no material object can have a speed equal to the speed of light or exceed the speed of light"

2) Length Contraction: The relativistic length of an object decrease in the direction of motion if it moves with a relativistic speed "v" with respect to an observer its length decreases. The decreased length "L" is given by

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

Where c= speed of light

This phenomenon is called "length Contraction" or Lorentz – Fitzgerald contraction"

3)Time Dilation: Time of an event increases or time interval between two events taking place in a frame of reference is called "proper time" T_o" if this time is measured by an observer moving with relativistic speed "v" then it increases. The increased time "T" is given by

$$T = \frac{T_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

Where C= speed of light

This phenomenon is known as "time dilation"

4- MASS ENERGY RELATION

Mass can be converted into energy and energy can be converted into mass If "m" mass is converted into energy then the energy produced is given by

$$E= mc^2$$

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

$$E = \frac{E_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

EMISSIVE POWER: The number of radiation emitted per second per unit area is called "emissive power"

ABSORPTION POWER: The ratio of the number of radiations absorbed to the number of radiation incident is called "absorption power" (the absorption power of a perfect black body is ONE)

BLACK BODY: A body which can absorb all the radiations indicated upon it is called a "perfect black body"
There is no such a body which can absorb all the radiation for experimental purpose a metallic cavity with blacker walls and fine hole is used when any radiations enters the cavity almost all the radiations are absorbed by the body there is very little chance to escape it out of the cavity

BLACK BODY RADIATOR: When a black body is heated greater than a perpendicular temperature it emits the radiations of all possible wave- lengths such a body is called "black body or cavity radiator"

BLACK BODY RADIATIONS: The radiations in which all possible wavelengths are present is called "black body radiations"

BLACK BODY RADIATIONS CURVES:

With the help of suitable length fitters radiations of particular wavelengths of black body radiations is allowed to fall on detector instruments the total energy of radiation associated with that particular wavelengths and intensity of radiations is measured keeping temperature constant a graph is plotted between wave length "λ" and associated energy "E" of radiation the graph is called "Black Body Radiation Curves"
It is found that in the beginning energy increases with the increase of wavelength "λ" and at a particular wavelength it becomes maximum when wavelength is further increased the energy decreases the wavelength for which energy is maximum is called "wavelength of maximum energy" and is denoted by "λ" it is further found that when temperature of black body radiator is increased "λ" shifts toward shorter wavelength

W1EN'S DISPLACEMENT LAW:

According to this law "wave length of maximum energy "λ" is inversely proportional to the absolute temperature "T" of the black body

i.e. $\lambda_{max} \propto \frac{1}{T}$

$$\lambda_{max} = (\text{constant}) \times \frac{1}{T}$$

Where constant = 0.0029 m. k

STEFAN'S LAW: According to this law "the total energy "E" radiated per second per unit surface area of black body radiator is directly proportional to the fourth power of absolute temperature "T"

i.e. $E \propto T^4$

or $E = \sigma T^4$

Where "σ" is called Stefan – Boltzmann's constant its value os 5.67×10^{-8} watt/m^2. K^4

The above two laws cannot explain energy distribution at different wavelength and temperature in black body radiation curves.

RAYLEIGH – JEAN'S LAW:

This law states that "the energy "E" associated with a particular wave length "λ" is inversely proportional to the fourth power of the wave length"

i.e. $E \propto \frac{1}{\lambda^4}$

Or $E = \text{constant} \times \frac{1}{\lambda^4}$

Or $E \times \lambda^4 = \text{constant}$

This law can explain energy distribution curve at wavelength greater the λ_{max} but wavelength smaller then λ_{max} (i.e. in ultraviolet region) energy E tends to infinity which contrary to the experimental observations this is called ultraviolet catastrophe.

PLANCK'S QUANTUM THEORY:

According to quantum theory "energy is emitted and absorbed in the form of packets of energy called quanta or photon each photon has a particular energy which depends upon the frequency of the photon the greater the frequency "ν" the greater will be the energy "E" i.e.

$E \propto \upsilon$

Or $E = h\upsilon$

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

The energy of "n" photon of same frequency is $E = nh\upsilon$

On the basis of this theory Max Planck explained the black body radiations and derived a formula with the help of his formula a graph was plotted which fits the experimental observation this theory not only avoided ultraviolet catastrophe a new revolution in modern physics.

THE PHOTON:

The photon is a particle that has no charge and no mass it can interact with all charged particle as well as some other neutral ones it is electromagnetic radiation and the carrier of electromagnetic forces every atom is found to emit and absorb photon of the particular energies and frequencies

The energy "E" of a photon is given by

$E = mc^2 = (mc)\,c$ ----------(1)

But mc=p = momentum of the photon

$E = pc$

Also by quantum theory the energy of photon is

$E = h\upsilon$

Comparing eq1 & 2

$pc = h\upsilon$

$p = \frac{h\upsilon}{c}$

As, $c = \upsilon\lambda$

Or $\frac{\upsilon}{c} = \frac{1}{\lambda}$

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

The photon is a stable particle and therefore it does not decay spontaneously into any other particle its life line is therefore infinite so long it does not undergo interaction with other particles.

THE PHOTOELECTRIC EFFECT:

Hertz in 1887 discovered that when ultraviolet light (i.e high frequency light) falls in certain metals electrons are emitted. These electrons are called photoelectrons and this phenomenon is known as photo electric effect.

Experimental observation:

Figure 1 shows a glass vacuum tube having two plates p and c connected to a battery of variable voltage. When light falls on plate p electrons are emitted which moves towards the plate c and the current is detected by the micro ammeter. This is current is called photoelectric current (i). some of the electrons possess small K.E and some possess large K.E. the maximum $K.E_{(max)}$ can be found by reversing the battery i.e by making plate c more and more negative so that a potential is reached at which no electron can reach the plate C. this potential is called stopping potential (V_o) at this potential the maximum K.E of a photoelectron is given by.

$K.E = \frac{1}{2}mv^2 = V_o e$

Where m = mass of an electron

e = charge of an electron

$v = v_{max}$ = maximum velocity of photoelectron.

Explanation with the help of graphs:

Figure 2 shows graph between voltage "V" and photoelectric current "I" for different intensities from these curves it follows that

1) There is a saturation current "I" for different intensities I_1, I_2 and I_3 etc

2) When voltage V= 0 there is some current

3) The stopping potential "V_o" (i.e. negative voltage $-V_o$) is independent of the intensity

Figure 3 shows graph between voltage "V_o" and photoelectric current "I" for different frequencies υ_1 and υ_2 but for the same intensity I from these curves it follows that

1) The saturation current "I" depends upon intensity and not on the frequency of light

2) The stopping potential becomes more negative from ($-V_{o1}$) to (V_{o2}) with the increase of frequency from υ_1 and υ_2 i.e. stopping potential is directly proportional to the frequency

As K. E. max depends upon stopping potential hence it also depends upon frequency thus if a graph is plotted between frequency "υ" and $K.E._{(max)}$ a straight line will be obtained as shown in figure 4 The graph shows that there is a minimum frequency at which K. E. becomes zero below this frequency no electron will escape from the metal surface this minimum frequency is called "threshold frequency" (υ_o) the most significant feature of this graph is that the slope of the line gives the value of Planck's constant "h"

Slope = $\frac{K.E._{max}}{\upsilon - \upsilon_o}$ = h = Planck's constant = 6.63×10^{-34} J.S.

Results of photoelectric effect:

1) Increasing the intensity of the source of light increases the number of photoelectrons but not the velocity with which they leave the surface of the metal

2) For each substance there is a certain frequency called the threshold frequency below which the effect does not occur

3) The higher the frequency of incident light the greater the K. E. of the photoelectrons

Failure of Wave Theory:

Attempts were made to explain photoelectrons effect on the basis of wave theory of light but no successful explanation was obtained due to the following reasons

1) From wave theory there should be no threshold frequency because at a given time electrons might absorbs enough energy from the incident light to escape from the metal surface at any applied frequency

2) The velocity of photoelectrons should depend upon the amplitude of the wave incident on the metal and therefore upon the intensity rather than the frequency

EINSTEIN'S EXPLANATION OF PHOTOELECTRIC EFFECT ON THE BASIS OF QUANTUM THEORY:

In 1905 Einstein explained photoelectric effect on the basis of quantum theory he proposed that

1) An electron either absorbs one whole photon or it absorbs none
2) The chance than an electron may absorb more than one photon is negligible because the number of photons is much lower than the electrons
3) After absorbing a photon an electron either leaves the surface of the metal or dissipates its energy within the metal in such a short time interval that it has almost no chance top absorb a second photon

Thus if the energy of the incident photon is less than the energy required by the electron to overcome the force of attraction which holds the electrons within the metal than the electron will not come out of the metal of the other hand if the energy of photon is greater than the minimum energy required by the electron

Cutoff Wave Length:

The maximum wave length of light at which photoelectric effect takes place is called cutoff wave length

WORK FUNCTION OF METAL:

The minimum energy require to eject an electron from metal surface is called "work function" and is denoted by "ϕ_o" and

$$\phi_o = h\upsilon_o \text{ ----------------------(1)}$$

Where h= Planck's constant

υ_o = Threshold frequency

If the energy "$E = h\upsilon$" of incident photon is greater than the work function "ϕ_o" then a part of it will be used up in ejecting an electron from the metal surface and the remaining energy will be taken up by the electron as K. E.

PHOTOELECTRIC EFFECT EQUATION IN TERMS OF ENERGY:

i.e. $$E - \phi_o = K.E. \text{ -----------------(2)}$$

If the electron is fastest one than its velocity and hence K. E. will be maximum

i.e. $$h\upsilon - \phi_o = \frac{1}{2}mv^2 = K.E._{(max)}$$

PHOTOELECTRIC EFFECT EQUATION IN TERMS OF FREQUENCY:

But putting the value of "ϕ" from eq1 we get

$$\frac{1}{2}mv^2 = h\upsilon - h\upsilon_o$$

$$\frac{1}{2}mv^2 = h(\upsilon - \upsilon_o) \text{ -------------(3)}$$

PHOTOELECTRIC EFFECT EQUATION IN TERMS OF STOPPING POTENTIAL:

$$\text{Since } K.E = \frac{1}{2}mv^2 = V_o e$$

Equation (2) becomes

$$h\upsilon - \phi_o = V_o e \text{ -------------(4)}$$

PHOTOELECTRIC EFFECT EQUATION IN TERMS OF WAVELENGTH:

$$c = \upsilon\lambda \quad \text{then } \upsilon = \frac{c}{\lambda} \text{ and } \upsilon_o = \frac{c}{\lambda_o}$$

$$\frac{1}{2}mv^2 = h\left(\frac{c}{\lambda} - \frac{c}{\lambda_o}\right)$$

$$\frac{1}{2}mv^2 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right) \text{ ------------(5)}$$

Equations (2), (3), (4) and (5) are called "Einstein Photoelectric equation".

PHOTO CELL AND THEIR USES:
The photocell or photo tube consists of an evacuated glass tube fitted with an anode and a concave metallic cathode of an appropriate surface as shown in the figure the material of the cathode can be chosen to respond to the frequency range over which the photo cell operates

Working: When light of suitable frequency fall on the cathode photoelectrons are emitted which are attracted by the positive anode and a current flows in the external circuit the current would cease to flow if the light beam is interrupted

Uses: (1) A simple photocell can be used in any situation where beam of light falling on a cell is interrupted or broken
For example: (a) To count vehicles passing a road or items running on a conveyer belt to leave the metal the emission of electrons takes place immediately

(b) To open door automatically
(c) To operate burglar alarm etc

(2) Photo Conductive Cell: In this cell internal photoelectric effect librates free charge carrier in a material and its electrical conductivity increases as much as 10000 times it is used (i) For detection and measurement of infrared radiations where the wavelength is of the order of 10m (ii) as relays for switching on artificial lightning such as street lights

(3) Photo Voltaic Cell:
Such cells are used as exposure meters to set the aperture of the camera
(4) Photo cells are used for the production of pictures in television cameras and the sound tracks or motion pictures the sound information is stored on the film in the form of spots of varying widths when such a film run between the light source and the photocell variation in light intensity reaching the cell cause pulsations in the current that after being amplified activates a loud speaker and produces sound

THE COMPTION EFFECT:
"When a photon is scattered by an electron the scattered photon has a frequency less than its original frequency or wavelength greater than its original wavelength this phenomenon is called Compton's effect"

PROOF: Suppose a photon of frequency "υ_1" and energy "$h\upsilon_1$" is incident upon an electron at rest on collision the photon looses same energy to the electron let the photon is scattered at an angle "θ" with its original direction with energy "$h\upsilon_2$" and the electron recoils at an angle "ϕ" with the original direction of the photon let "m" be the rest mass of the electron and "m" be its mass after collision when moving with velocity "v"
Energy of the electron before scattering = m_oc^2
Energy of the electron after scattering = mc^2
Energy of the photon before scattering = $h\upsilon_1$
Energy of the photon after scattering = $h\upsilon_2$
By the law of conversation of energy
Total energy before scattering = Total energy after scattering

$$h\upsilon_1 + m_oc^2 = h\upsilon_2 + mc^2$$

$$h\upsilon_1 - h\upsilon_2 = mc^2 - m_oc^2$$

$$h(\upsilon_1 - \upsilon_2) = (m - m_o)\,c^2 \text{ ---------------(1)}$$

Since momentum is a vector quantity therefore we resolve the momentum of photon and electron into components as shown in fig.
Momentum of the electron before scattering along the axis of impact = 0
Momentum of the electron before scattering across the axis of impact = 0

Momentum of the electron after scattering along the axis of impact = mvCosϕ
Momentum of the electron after scattering across the axis of impact = -mvSinϕ
Momentum of the photon before scattering along the axis of impact = $\frac{h\upsilon_1}{c}$
Momentum of the photon before scattering across the axis of impact = 0
Momentum of the photon after scattering along the axis of impact = $\frac{h\upsilon_2}{c}$ Cosθ
Momentum of the photon after scattering across the axis of impact = $\frac{h\upsilon_2}{c}$ Sinθ
Applying law of conservation of momentum along the axis of impact,
Total momentum before impact = Total momentum after impact

$$\frac{h\upsilon_1}{c} + 0 = \frac{h\upsilon_2}{c}\text{Cos}\theta + \text{mvCos}\phi$$

$$\frac{h\upsilon_1}{c} - \frac{h\upsilon_2}{c}\text{Cos}\theta = \text{mvCos}\phi \text{ ----------(2)}$$

Applying law of conservation of momentum across the axis of impact,
Total momentum before impact = Total momentum after impact

$$0 + 0 = \frac{h\upsilon_2}{c}\text{Sin}\theta - \text{mvSin}\phi$$

$$\frac{h\upsilon_2}{c}\text{Sin}\theta = \text{mvSin}\phi \text{ ----------------(3)}$$

To obtain an expression for the final frequency as a function of initial frequency and scattering angle θ. We have to eliminate 'm', 'v' and ϕ from above three equations using the relativistic relations and trigonometry after performing some routine mathematical steps and simplifications we will finally get the following expression,

$$\frac{1}{\upsilon_2} - \frac{1}{\upsilon_1} = \frac{h}{m_o c^2}(1 - Cos\ \theta)$$

$$c\left(\frac{1}{\upsilon_2} - \frac{1}{\upsilon_1}\right) = \frac{h}{m_o c}(1 - Cos\ \theta)$$

$$\left(\frac{c}{\upsilon_2} - \frac{c}{\upsilon_1}\right) = \frac{h}{m_o c}(1 - Cos\ \theta)$$

$$\lambda_2 - \lambda_1 = \frac{h}{m_o c}(1 - Cos\ \theta)$$

This equation is called the famous Compton formula for increase in wavelength of the scattered photon.
This is also called Compton shift in wave length the quantity $\frac{h}{m_o c}$ in the Compton equation is called the Compton wave length and is denoted by $\lambda_c = \frac{h}{m_o c} = 2.426 \times 10^{-12}$ m.

PAIR PRODUCTION:

When an attempt is made to stop a photon near a nucleus it disappears and an photon positron pair is created positron has been indentified to be identical with an electron in mass and carries an equal positive charge and is called the anti particle of electron, this phenomenon is called "pair production" In order to conserve the energy and momentum the pair production occurs near a nucleus which takes the recoil according to the Einstein's equation of energy and photon is thus to create an electron – positron pair an energy equal to $2m_o c^2$ is needed hence if the energy of photon "hυ" is greater than or equal to $2m_o c^2$ then pair production take place if hυ > $2m_o c^2$ = 1.02 MeV is used up in the creation of the pair while the rest of the energy will be taken away by the pair as Kinetic energy

$$h\upsilon = 2m_o c^2 + (K.E.)_{e^-} + (K.E.)_{e^+}$$

In this phenomenon energy is converted into mass therefore this phenomenon is also called "materialization of energy". In this phenomenon charge, energy and momentum all are conserved.

ANNIHILATION OF MATTER:

Annihilation of matter is the reverse process of pair production in this process an electron and position combine to give rise to two gamma ray photons each has energy equal to the rest mass energy of an electron ($m_o c^2$= 0.51 MeV)

In this phenomenon charge, energy and momentum all are conserved the energy conversation equation for the process is

$$2m_o c^2 + (K.E.)_{e^-} + (K.E.)_{e^+} = 2h\upsilon$$

THE WAVE ATURE O PARTICLES AND DE-BROGILE HYPOTHESIS:

Light has dual nature sometimes it behaves like a wave and sometimes it behaves like a particle de Broglie gave an hypothesis that "if light (electromagnetic radiation) can have particle behavior then material particles such as electrons and protons etc can also behave in a wave like manner" thus a particle like electron can process a momentum given by

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

Where λ = wave length associated with the particle

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

It is found that wave length associated with massive bodies is too small that it cannot be measured in the overhand wavelength associated with lighter particles like electron proton etc can be measured

THE DAVISSON AND GERMER EXPERIMENT:

The theoretical prediction of de-Broglie hypothesis $\lambda = \frac{h}{p} = \frac{h}{mv}$ was experimentally confirmed by an experiment conducted by Davisson and Germer their experimental set up was enclosed in a vacuum chamber as shown in the figure electrons were produced by heating a filament the produced electrons were accelerated in the form of a beam by applying a potential "V" and were allowed to strike the nickel crystal measurements were made to count the number of electrons Davisson and Germer reported the unexpected result that electrons reflected very strongly at certain angles only and not at other direction to explain the result they calculated the wavelength "λ" of the matter wave associated with electrons using de-Broglie's relation

The K.E. of an electron of mass 'm' moving with velocity "v" is given by

$$\frac{1}{2} m_o v2 = Ve$$

$$m_o v2 = 2Ve$$

$$(m_o v)^2 = 2m_o Ve$$

$$p = \sqrt{2m_o Ve}$$

Where e= charge of electron

V= accelerating voltage

According to de-Broglie's relation

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

$$\lambda = \frac{h}{\sqrt{2m_o Ve}}$$

The wavelength found from this formula agreed with de- Broglie's prediction

It has been also confirmed that other particles like protons neutron atoms molecules etc as associated with the some wave effects as that of electrons.

THE UNCERTAINTY PRINCIPLE:

The uncertainty principle tells us that it is impossible to know everything about a particle there will be (i) uncertainty about its exact momentum at a given position (ii) Uncertainty about its exact energy at a given time

The Heisenberg uncertainty principle state that "it is impossible to measure with accuracy both position and momentum of accuracy both position and momentum of a particle simultaneously

If "Δy" be the uncertainty in position and "Δp_y" be the uncertainty in momentum of a particle the according to the uncertainty principle

$(\Delta y)\ (\Delta p_y) \geq \frac{h}{2\pi} = 1.05 \times 10^{-34}$ J. S

Similarly along x axis $(\Delta x)\ (\Delta p_x) \geq \frac{h}{2\pi}$

And along z- axis $(\Delta z)\ (\Delta p_z) \geq \frac{h}{2\pi}$

PROOF:

Let us now examine whether the uncertainty condition is consistent with experiment suppose we went to localize a particle in the y- direction

If a particle beam strikes a slit those passing through the slit must have been localized in the region $\Delta y = d$ where d= width of the slit if the particles are ordinary classical they will strike the screen along a thin strip i.e. the projection of the slit on the screen but if a wave crosses a slit then there will be a diffraction pattern wider than the width of the slit projected on the screen

Consider a beam of particles incident on a slit of width "y" the beam after passing through the slit produces diffraction pattern on the screen by formula of diffraction by single slit

$d \sin\theta = m\lambda$

For 1str order minima m=1

$d \sin = \lambda$

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

If θ is small then $\sin\theta \approx \theta$ and $d = \Delta y$

$$\theta = \frac{\lambda}{\Delta y}$$

Initial momentum of the particle along x- axis is "p_x" and along y- axis is "zero" the final momentum "p" can be resolved into two components p_x and p_y

The change in momentum along x- axis

$Px = Px - Px = 0$

The change in momentum along y- axis

$Py = Py - 0 = Py$

From Figure

$$\tan\theta = \frac{Py}{Px}$$

Since θ is small $\tan\theta = \theta$

$$\theta = \frac{Py}{Px}$$

By De- Broglie's relation $Px = \frac{h}{\lambda}$

$$\theta = \frac{Py}{\frac{h}{\lambda}}$$

Or $\theta = (Py)\ \underline{\lambda}$

$$H$$

Comparing eq1 and 2

$$(Py)\frac{\lambda}{h} = \frac{\lambda}{y}$$

$$(Py)(y) = h$$

$$\text{Or } (Py)(y) \geq \frac{h}{2\pi}$$

There is one form of the uncertainty principle another form of uncertainty principles states that "the product of uncertainty in a measured amount of energy "E" and the time available for the measurements "t" is of the order of "h" mathematically

$$(E)(t) \geq h$$

Uncertainty principle is of n importance in our daily lfe because Planck's constant "h" is negligibly small it is important in the case of subatomic particles

To show that $E\,t \geq \frac{h}{2\pi}$

Proof: Special Theory of relativity

$$E = m\,c = m\,cc$$

Multiplying and dividing R.H.S by "m"

$$E = \frac{mc\ mc}{m}$$

But mc = p = change in momentum

And mc = p = momentum

$$E = p\,\frac{p}{m}$$

Multiplying both sides by t

$$E\,t = p\,\frac{p}{m}\,t$$

Where t= Time during which energy is emitted in some atomic process

And $\frac{p}{m} = v$ = velocity

$$E\,t = p\,v\,t$$

But $v\,t = x$

$$E\,t = p\,x$$

Since $p\,x \geq \frac{h}{2\pi}$

$$E\,t \geq \frac{h}{2\pi}$$

Stopping potential: The potential at which no photoelectron can reach the collector plate i.e. photo electric current becomes zero is called "stopping potential" or "stopping voltage"

Threshold Frequency: The minimum frequency of light at which photoelectric effect takes place called "Threshold Frequency"

Work Function: The minimum energy required to eject an electron from metal surface is called "Work Function"