Unit - 4

Basic Quantum Physics.

Electron theory of metals.

Classical free electron theory	Quantum free e^- theory	Band theory (or) Brillouin Zone Theory
↓	↓	↓
Macroscopic theory	Microscopic theory	Periodic potential of electron theory
↓	↓	↓
1900 - Drude & Lorentz	1928 - Sommerfeld	1928 - Bloch.

2(or)4m **Success of classical free electron theory:**

* It verifies ohm's law
* It explain electrical and thermal conductivity of metals
* It is used to derive Wiedemann - Franz law.
* The optical properties of metals can be explained using this theory.

2(or)4m **Failure of classical free electron theory**

* It is macroscopic theory
* It cannot be explained compton, photo-electric effect, paramagnetism, ferromagnetism, etc,...

2m Photon:

It is photon (or) discrete energy values in the form of small packets (or) bundles (or) quantas of definite frequency ~~of~~ or wavelength

2m Properties of photon

* Photons are similar to that of electrons
* They do not ionize gas
* The energy and momentum of the photon is given by.

$$E = h\nu$$

$$P = mc$$

where

* $h \rightarrow$ planck's constant
* $\nu \rightarrow$ frequency
* $m \rightarrow$ mass of particle
* $c \rightarrow$ velocity of light particle

2m De-Broglie (or) Matter waves

* The waves associated with the matter particles are called matter waves (or) de-Broglie waves

$$\lambda = \frac{h}{p} \quad \text{or} \quad \lambda = \frac{h}{mv}$$

2m Properties

* Matter waves are not electromagnetic waves.
* lighter particle will have high wavelength
* particles moving with less velocity will have high wavelength
* The velocity of a matter is not a constant.

Other forms of de-Broglie wavelength

(i) de-Broglie wavelength interms of Energy

W.K.T

$$KE_{(E)} = \frac{1}{2}mv^2 \longrightarrow (1)$$

multiple 'm' on both side

$$Em = \frac{1}{2}m^2v^2$$

$$m^2v^2 = 2Em$$

$$mv = \sqrt{2Em} \longrightarrow (2)$$

$\therefore$ de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2mE}}$ $\left(\because \lambda = \frac{h}{mv}\right)$ $\longrightarrow (3)$

(ii) de-Broglie wavelength interms of Voltage

kinetic energy of particle $= \frac{1}{2}mv^2 \longrightarrow (4)$

W.K.T

$$\text{energy} = eV \longrightarrow (5)$$

equating equation (4) & (5)

$$\frac{1}{2}mv^2 = eV \longrightarrow (6)$$

multiple 'm' on both side

$$\frac{1}{2}m^2v^2 = eV.m$$

$$m^2v^2 = 2meV$$

$$mv = \sqrt{2meV} \longrightarrow (7)$$

we know that

$\therefore$ de-Broglie wavelength $\lambda = \frac{h}{mv} \longrightarrow (8)$

sub eqn (7) in (8)

de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2meV}} \longrightarrow (9)$

(iii) de-Broglie wavelength interms of temperature.

When a particle like neutron is in thermal equilibrium at temperature T, then they possess Maxwell distibution of velocity.

Kinetic Energy $E_k = \frac{1}{2} m v_{rms}^2 \longrightarrow (10)$

where

$V_{rms} \longrightarrow$ root mean square velocity of particle

$$\text{Energy} = \frac{3}{2} k_B T \longrightarrow (11)$$

where

$k_B \rightarrow$ Boltzmann constant

Equating eqn (10) & (11)

$$\frac{1}{2} m v^2 = \frac{3}{2} k_B T$$

multiple 'm' on both side

$$m^2 v^2 = 3 m k_B T$$

$$m v = \sqrt{3 m k_B T} \longrightarrow (12)$$

sub eqn (12) in (8)

$\therefore$ de-Broglie wavelength $\lambda = \frac{h}{\sqrt{3 m k_B T}}$

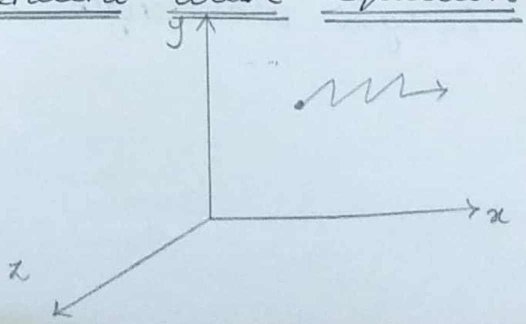
16m Schroedinger wave equation

- Time independent
- Time dependent

It is described the wave nature of particle in mathematical form.

Schroedinger:

Time Independent wave equation



classical differential equation

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} = \frac{1}{v^2}\frac{\partial^2 \psi}{\partial t^2} \longrightarrow (1)$$

where,

$$\nabla^2 \psi = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \text{ (Laplacian operator)}$$

$$\nabla^2 \psi = \frac{1}{v^2}\frac{\partial^2 \psi}{\partial t^2} \longrightarrow (2)$$

$\psi \longrightarrow$ wave function

$v \longrightarrow$ wave velocity

solution of equation (2)

$$\psi = \psi_0 e^{-i\omega t} \longrightarrow (3)$$

Diff eqn (3) w.r.t 't'

$$\frac{\partial \psi}{\partial t} = \psi_0 e^{-i\omega t} \cdot (-i\omega)$$

Again diff w.r.t 't'

$$\frac{\partial^2 \psi}{\partial t^2} = \psi_0 e^{-i\omega t} \cdot (-i\omega)(-i\omega)$$

$$= \underbrace{\psi_0 e^{-i\omega t}}_{\psi} (i^2 \omega^2)$$

$$\frac{\partial^2 \psi}{\partial t^2} = -\omega^2 \psi \longrightarrow (4) \quad (i = -1)$$

sub eqn (4) in (2)

$$\nabla^2 \psi = -\frac{\omega^2}{v^2}\psi$$

$$\nabla^2 \psi + \frac{\omega^2}{v^2}\psi = 0 \longrightarrow (5)$$

We know that

$$\omega = 2\pi\nu$$

frequency $\nu = \frac{v}{\lambda}$

$$\omega = 2\pi \frac{v}{\lambda}$$

$$\frac{\omega}{v} = \frac{2\pi}{\lambda}$$

squaring on both side

$$\frac{\omega^2}{v^2} = \frac{4\pi^2}{\lambda^2} \longrightarrow (6)$$

sub eqn (6) in eqn (5)

$$\nabla^2\psi + \frac{4\pi^2}{\lambda^2}\psi = 0 \longrightarrow (7)$$

By using De-Broglie (λ)

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

squaring on both side

$$\lambda^2 = \frac{h^2}{m^2v^2} \longrightarrow (8)$$

sub eqn (8) in (7)

$$\nabla^2\psi + \frac{4\pi^2}{h^2/m^2v^2}\psi = 0$$

$$\nabla^2\psi + \frac{4\pi^2 \cdot m^2v^2}{h^2}\psi = 0 \longrightarrow (9)$$

Total energy = potential energy + kinetic energy

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

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

$$2(E-V) = mv^2$$

multiple 'm' on both side

$$2m(E-V) = m^2v^2 \longrightarrow (10)$$

sub eqn (10) in (9)

$$\nabla^2\psi + \frac{4\pi^2 \cdot 2m(E-V)}{h^2}\psi = 0 \longrightarrow (11)$$

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

$$\hbar^2 = \frac{h^2}{4\pi^2}$$

$$\nabla^2\psi + \frac{2m(E-V)}{\hbar^2}\psi = 0$$

$$E\psi = \frac{-\hbar^2}{2m}\nabla^2\psi + V\psi$$

Schroedinger time dependent equation:

The solution of classical diffe eqn

$$\psi = \psi_0 e^{-i\omega t} \longrightarrow (1)$$

diff eqn (1) with respect to 't'

$$\frac{\partial\psi}{\partial t} = -i\omega \cdot \psi_0 e^{-i\omega t}$$

Angular frequency $\omega = 2\pi\nu$

$$\frac{\partial\psi}{\partial t} = -i2\pi\nu\psi \longrightarrow (2)$$

photon energy $E = h\nu$

$$\nu = \frac{E}{h}$$

$$\frac{\partial\psi}{\partial t} = -i2\pi\left(\frac{E}{h}\right)\psi \qquad (\because h = 2\pi\hbar)$$

$$\frac{\partial\psi}{\partial t} = \frac{-iE\psi}{\hbar}$$

$$\frac{\partial\psi}{\partial t} = -i\frac{E}{\hbar}\psi \longrightarrow (3)$$

multiple 'i' on both side

$$i\frac{\partial\psi}{\partial t} = -i \times i\frac{E}{\hbar}\psi$$

$$i\frac{\partial\psi}{\partial t} = -i\frac{E}{\hbar}\psi$$

$$i\frac{\partial\psi}{\partial t} = \frac{E\psi}{\hbar}$$

$$i\hbar\frac{\partial\psi}{\partial t} = E\psi \longrightarrow (4)$$

Schrondinger time independent equation

$$E\psi = -\frac{\hbar^2}{2m}\nabla^2\psi + \nabla\psi \longrightarrow (5)$$

sub eqn (B) in eqn (A)

$$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi$$

$$\left(i\hbar \frac{\partial}{\partial t}\right) \psi = \left(-\frac{\hbar^2}{2m} \nabla^2 + V\right) \psi$$

$$E\psi = H\psi$$

$E\psi$ = Energy operator

$H\psi$ = Hamiltonian operator.

16m

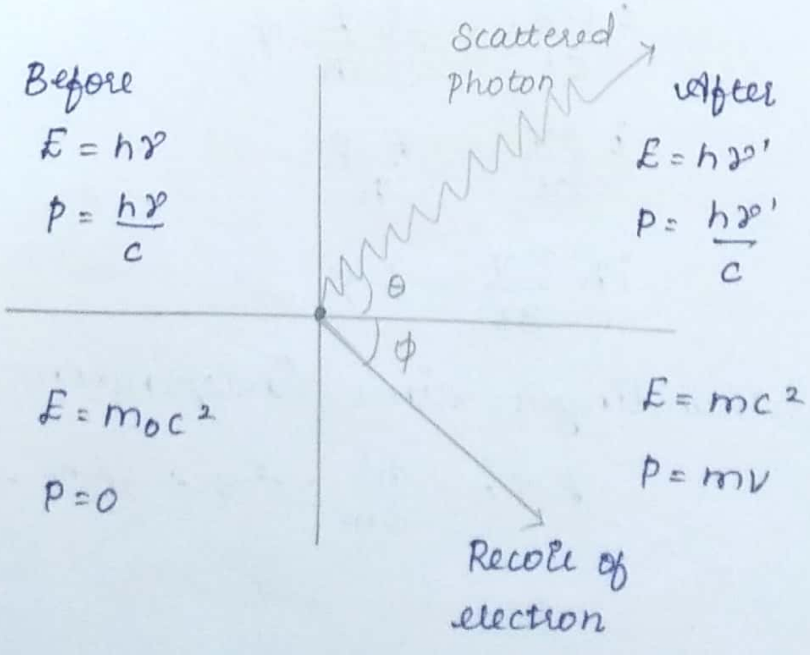
Compton Effect

* The beam of x-rays is scattered by a substance at low atomic number by the scattered radiation consists of two components

* Same frequency (or) wavelength
* lower frequency (or) higher wave length

* The changing wavelength of scattered radiation is known as compton shift

$$\Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$$



	Before collision		After collision	
	photon	Electron	photon	Electron
Energy	$h\nu$	$M_0 c^2$	$h\nu'$	Mc^2
momentum x - axis	$h\nu/c$	0	$\frac{h\nu'}{c}\cos\theta$	$mv\cos\phi$
momentum Y - axis	0	0	$\frac{h\nu'}{c}\sin\theta$	$-mv\sin\phi$

Before collision

Energy of incident photon $= h\nu$

Energy of electron at rest $= m_0c^2$

Total energy $= h\nu + m_0c^2 \longrightarrow (1)$

After collision

The energy of scattered photon $= h\nu'$

The energy of scattered electron $= mc^2$

Total energy $= h\nu' + mc^2 \longrightarrow (2)$

Applying law of conservation of energy

eqn (1) = eqn (2)

$$h\nu + m_0c^2 = h\nu' + mc^2$$

$$mc^2 = h\nu + m_0c^2 - h\nu'$$

$$mc^2 = h(\nu - \nu') + m_0c^2 \longrightarrow (3)$$

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Before collision

Momentum of photon - x axis = $\frac{h\nu}{c}$

Momentum of electron - y axis = 0

Total momentum = $\frac{h\nu}{c} + 0$ ⟶ (4)

After collision

Momentum of scattered photon - x axis $= \frac{h\nu'}{c}\cos\theta$

Momentum of electron - x axis $= mv\cos\phi$

Total momentum $= \frac{h\nu'}{c}\cos\theta + mv\cos\phi$ ⟶ (5)

Applying law of conservation of momentum:

eqn (4) = eqn (5)

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\theta + mv\cos\phi$$

$$\frac{h\nu}{c} - \frac{h\nu'}{c}\cos\theta = mv\cos\phi$$

$$\frac{h}{c}(\nu - \nu'\cos\theta) = mv\cos\phi$$

$$h(\nu - \nu'\cos\theta) = mcv\cos\phi \longrightarrow (6)$$

Before collision

Momentum of photon along y-axis = 0

Momentum of electron along y-axis = 0

Total Momentum = 0 ⟶ (7)

After collision

Momentum of scattered photon - y axis $= \frac{h\nu'}{c}\sin\theta$

Momentum of electron $= mv\sin\phi$

Total momentum $= \frac{h\nu'}{c}\sin\theta - mv\sin\phi$ ⟶ (8)

Applying law of conservation of momentum

eqn (7) = eqn (8)

$$0 = \frac{h\nu'}{c}\sin\theta - mv\sin\phi$$

$$mv\sin\phi = \frac{h\nu'}{c}\sin\theta$$

$$mcv\sin\phi = h\nu'\sin\theta \longrightarrow (9)$$

square and add eqn (9) & (6)

$$m^2c^2v^2\sin^2\phi + m^2c^2v^2\cos\phi = h^2\nu'^2\sin^2\theta + h^2(\nu - \nu'\cos\theta)^2$$

$$m^2c^2v^2[\sin^2\phi + \cos^2\phi] = h^2\nu'^2\sin^2\theta + h^2(\nu^2 + \nu'^2\cos^2\theta - 2\nu\nu'\cos\theta)$$

$$= h^2\nu'^2\sin^2\theta + h^2\nu^2 + h^2\nu'^2\cos^2\theta - 2h\nu\nu'\cos\theta$$

$$= h^2\nu'^2[\sin^2\theta + \cos^2\theta] + h^2\nu^2 - 2h\nu\nu'\cos\theta$$

$$m^2c^2v^2 = h^2[\nu'^2 + \nu^2 - 2\nu\nu'\cos\theta] \quad (10)$$

Eqn (3) $\Rightarrow$ square on both side

$$(mc^2)^2 = [h(\nu - \nu') + m_0c^2]^2$$

$$m^2c^4 = h^2(\nu - \nu')^2 + m_0^2c^4 + 2h(\nu - \nu')m_0c^2 \quad (11)$$

eqn (11) − eqn (10)

$$m^2c^4 - m^2c^2v^2 = h^2(\nu - \nu')^2 + m_0^2c^4 + 2h(\nu - \nu')m_0c^2 - h^2(\nu^2 + \nu'^2 - 2\nu\nu'\cos\theta)$$

$$m^2c^2[c^2 - v^2] = h^2(\nu^2 + \nu'^2 - 2\nu\nu') + m_0^2c^4 + 2h(\nu - \nu')m_0c^2 - h^2\nu^2 - h^2\nu'^2 + 2h^2\nu\nu'\cos\theta$$

$$= \cancel{h^2\nu^2} + \cancel{h^2\nu'^2} - 2h^2\nu\nu' + m_o^2c^4 + 2h(\nu-\nu') m_oc^2 - \cancel{h^2\nu^2} - \cancel{h^2\nu'^2} + 2h^2\nu\nu'\cos\theta$$

$$m^2c^2(c^2-v^2) = -2h^2\nu\nu'[1-\cos\theta] + 2h(\nu-\nu')m_oc^2 + m_o^2c^4 \longrightarrow (12)$$

Relativity mass formula

$$m = \frac{m_o}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} \qquad m^2 = \frac{m_o^2c^2}{c^2-v^2}$$

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

multiple c^2 on both side

$$m^2c^2(c^2-v^2) = m_o^2c^4 \longrightarrow (13)$$

sub eqn (13) in eqn (12)

$$\cancel{m_o^2c^4} = -2h^2\nu\nu'[1-\cos\theta] + 2h(\nu-\nu')m_oc^2 + \cancel{m_o^2c^4}$$

$$2h^2\nu\nu'[1-\cos\theta] = 2h(\nu-\nu')m_oc^2$$

$$h\nu\nu'[1-\cos\theta] = m_oc^2(\nu-\nu')$$

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

$$\frac{h}{m_oc^2}(1-\cos\theta) = \frac{1}{\nu'} - \frac{1}{\nu} \longrightarrow (14)$$

eqn (14) $\Rightarrow$ multiple 'c' on both side

$$\frac{hc}{m_oc^2}(1-\cos\theta) = \frac{c}{\nu'} - \frac{c}{\nu} \qquad \left(\because \frac{c}{\nu} = \lambda;\ \frac{c}{\nu'} = \lambda'\right)$$

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

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

special case:

case : I $\quad \theta = 0$

$h = 0.625 \times 10^{-34}$

$c = 3 \times 10^{8}$

$m_0 = 9.11 \times 10^{-31}$

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

$$= \frac{6.625 \times 10^{-34}(1-1)}{9.11 \times 10^{-31} \times 3 \times 10^{8}} \qquad \cos 0^\circ = 1$$

$\Delta\lambda = 0$

case 2 $\quad \theta = 90^\circ$

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos 90^\circ)$$

$$= \frac{6.625 \times 10^{-34}}{3 \times 10^{8} \times 9.11 \times 10^{-31}}(1-0)$$

$\Delta\lambda = 0.024$ Å

case 3 $\quad \theta = 180^\circ$

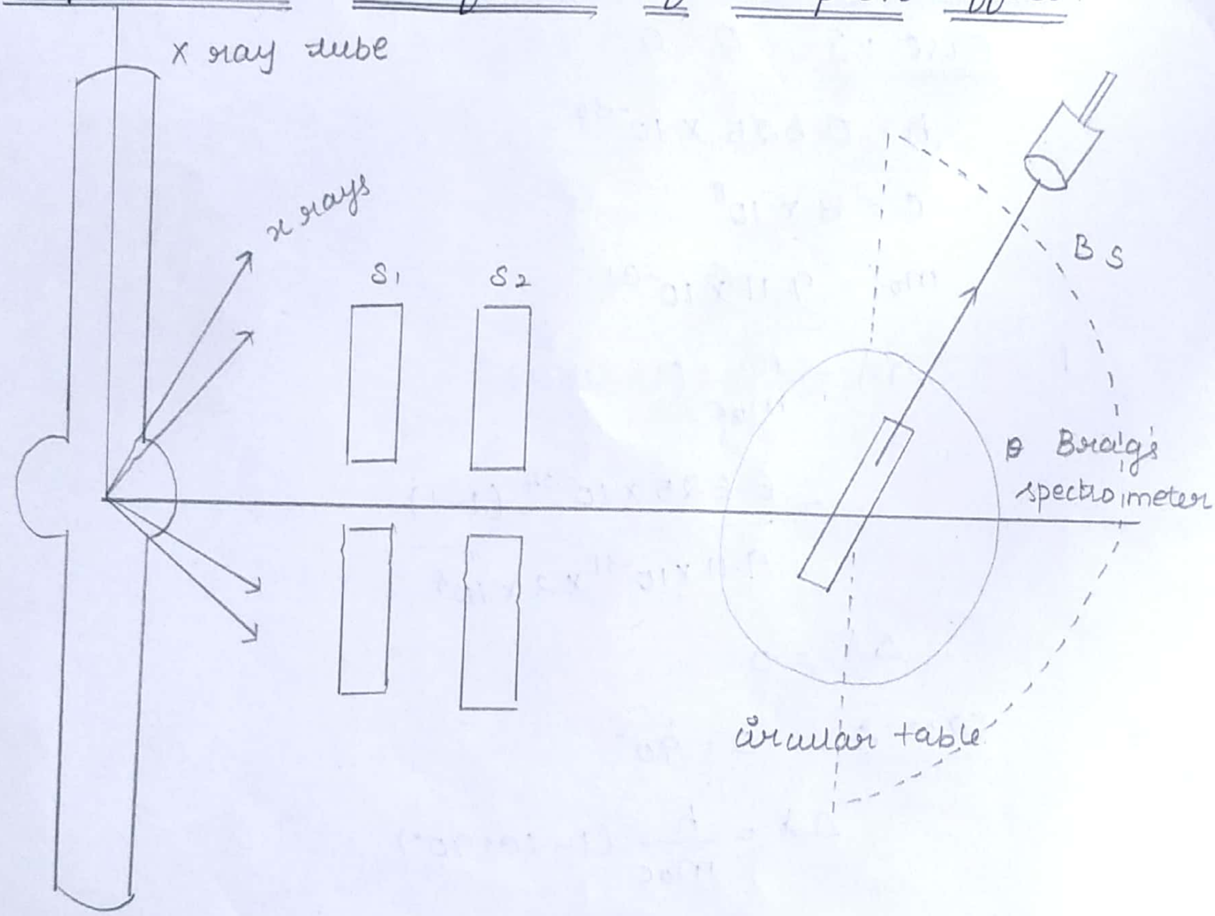
$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos 180^\circ)$$

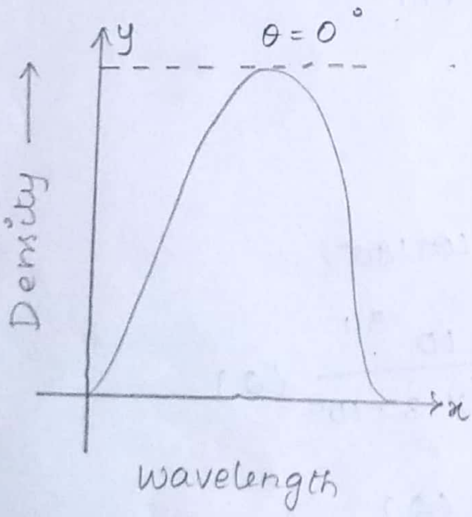
$$= \frac{6.625 \times 10^{-34}}{9.11 \times 10^{-31} \times 3 \times 10^{8}}(2) \qquad \cos 180^\circ = -1$$

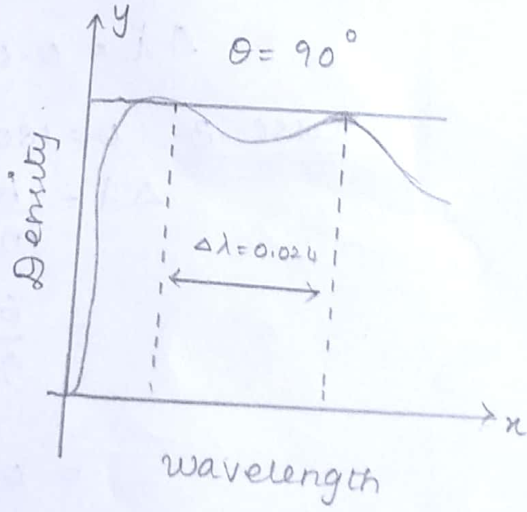
$= 0.0242\,(2)$

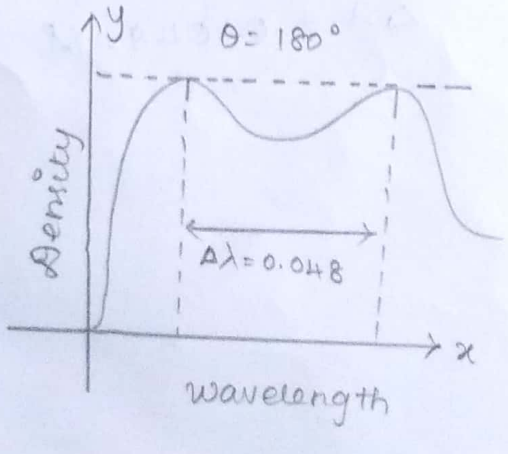
$\Delta\lambda = 0.0484$ Å

Experimental Verification of compton effect:









16m

Application of schroedinger wave equation

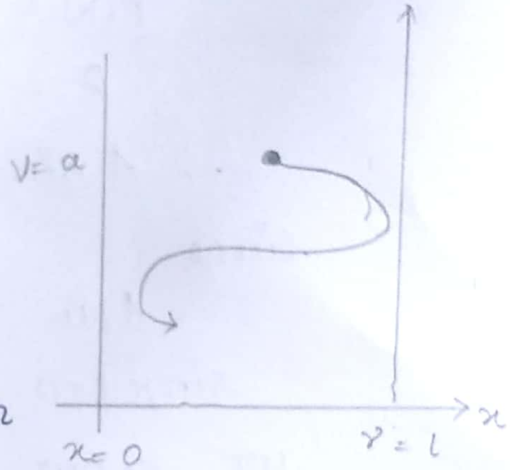
8

1D-potential box.

Boundary condition,

$x = 0 \quad V = \infty \longrightarrow (1)$

$x = l \quad V = \infty \longrightarrow (2)$



The 1D-schroedinger time independent wave equation

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E-V)\psi = 0 \longrightarrow (3)$$

since potential energy V=0

from eqn(3)

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}E\psi = 0$$

Let

$$k^2 = \frac{2mE}{\hbar^2} \longrightarrow (4)$$

$$\frac{d^2\psi}{dx^2} + k^2\psi = 0 \longrightarrow (5)$$

The solution of equation (5)

$$\psi(x) = A\sin kx + B\cos kx \longrightarrow (6)$$

Boundary condition -1

$x = 0 \quad V = 0$

from equation (6)

$$\psi(x) = A\sin k(x) + B\cos k(x)$$

$$0 = 0 + B(1)$$

$$B = 0$$

Boundary condition - 2

$x = L \quad V = \infty \quad B = 0 \quad \psi(x) = 0$

from eqn (6)

$$\Psi(x) = A \sin k(x) + B \cos k(x)$$

$$0 = A \sin k(l) + 0$$

$$\therefore A \sin kl$$

since

$$A \neq 0$$

$$\sin kl = 0$$

we know that

$$\sin n\pi = 0$$

$$\sin kl = \sin n\pi$$

$$kl = n\pi$$

$$k = \frac{n\pi}{l} \longrightarrow (8)$$

sub eqn (7) & (8) in eqn (6)

$$\Psi(x) = A \sin\left(\frac{n\pi x}{l}\right) \longrightarrow (9)$$

Energy of the particle (electron)

from eqn (4)

$$k^2 = \frac{2mE}{\hbar^2}$$

$$k^2 = \frac{2mE}{\frac{h^2}{4\pi^2}} \Rightarrow \frac{2mE \cdot 4\pi^2}{h^2}$$

$$k^2 = \frac{8\pi^2 mE}{h^2} \longrightarrow (10)$$

squaring equation (8)

$$k^2 = \frac{n^2\pi^2}{l^2}$$

comparing equation (10) & (11)

$$\frac{n^2\pi^2}{l^2} = \frac{8\pi^2 mE}{h^2}$$

$$E = \frac{n^2h^2}{8ml^2} \longrightarrow (12)$$

Normalization of wave function

$$P = \int_0^l |\psi(x)|^2 dx = 1 \longrightarrow (13)$$

sub eqn (9) in eqn (15)

$$P = \int_0^l \left|A \sin \frac{n\pi x}{l}\right|^2 dx = 1$$

$$P = A^2 \int_0^l \sin^2\left(\frac{n\pi x}{l}\right) dx = 1$$

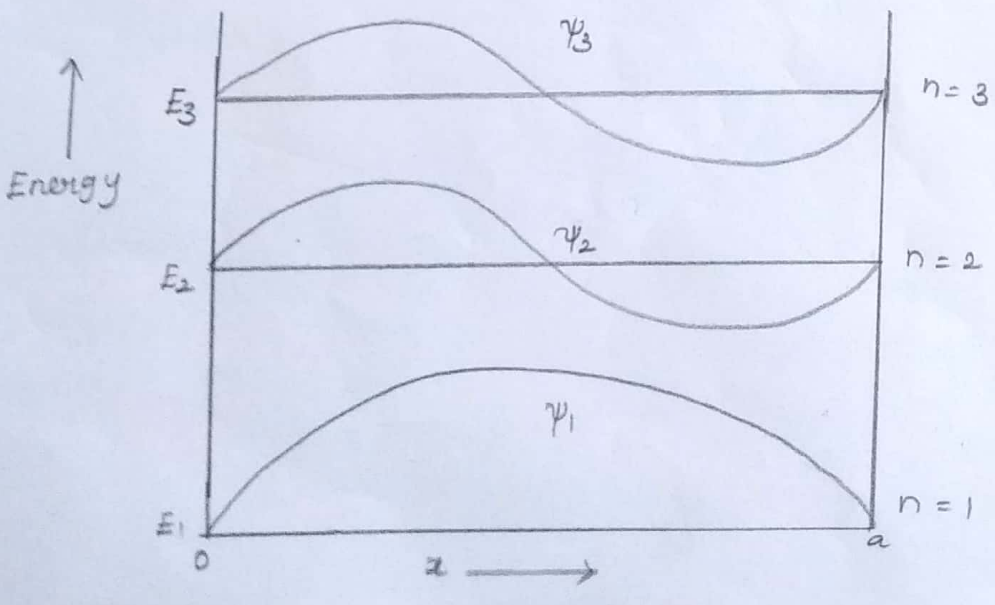
$$\therefore \int_0^l \sin^2\left(\frac{n\pi x}{l}\right) dx = l/2$$

$$\frac{A^2 l}{2} = 1$$

$$A^2 = \frac{2}{l} \Rightarrow A = \sqrt{\frac{2}{l}}$$

sub (A) value in eqn (9)

$$\psi(x) = \sqrt{\frac{2}{l}} \sin\left(\frac{n\pi x}{l}\right)$$



Probability Density

* It is denoted as $P(x,t)\,dx$ which means the probability that the particle will be between position x and $x+dx$ at time t.

* A probability density describes how likely it is that a particle will be in particular position at a particular time.

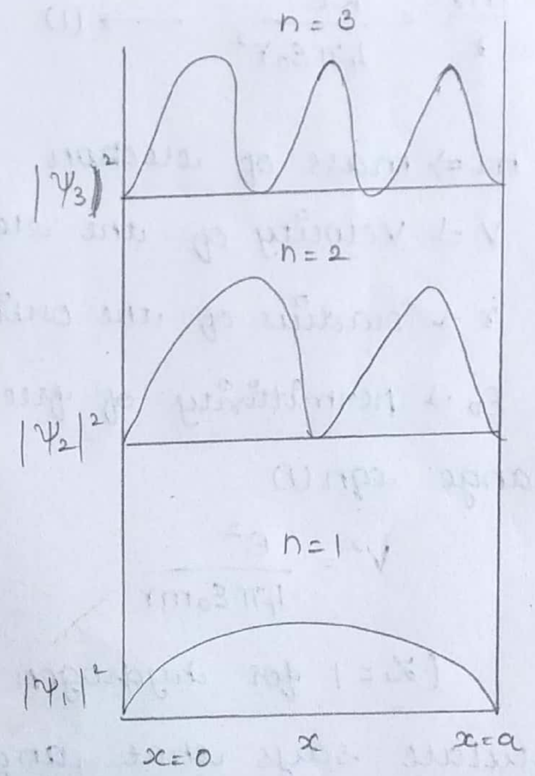
We know that $\psi_n = \sqrt{\frac{2}{a}} \sin\left(\frac{n\pi x}{a}\right)$

* probability of finding the particle between positions x and $x+dx$ is given by

$$P(x) = |\psi_n|^2 dx = \frac{2}{a} \sin^2\left(\frac{n\pi x}{a}\right) dx$$

$\therefore$ probability density, $P(x) = \frac{2}{a} \sin^2\left(\frac{n\pi x}{a}\right)$

* For $n=1$ (lowest energy state), $x = \frac{a}{2}$
* For $n=2$ (next energy state), $x = \frac{a}{4}$ & $\frac{3a}{4}$



12m

Correspondence principle

In 1932 Niels Bohr proposed a correspondence principle.

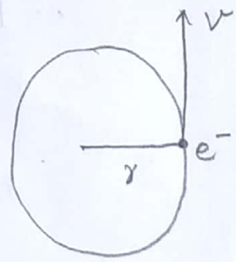
Statement

The principle states that for large quantum numbers, quantum physics gives the same results as those of classical physics.

Proof

According to classical electro-magnetic theory, an electron revolving in a circular orbit radiates electro-magnetic waves. The frequency of em wave is equal to the frequency of resolution of electron

centripetal force of resolving electron $\Big\}$ = columbic attraction between electron & proton



$$\frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2} \longrightarrow (1)$$

Where,

$m \Rightarrow$ mass of electron

$V \Rightarrow$ velocity of the electron

$r \Rightarrow$ radius of the orbit

$\varepsilon_0 \Rightarrow$ permittivity of free space

Rearrange eqn (1)

$$V^2 = \frac{e^2}{4\pi\varepsilon_0 m r}$$

($Z = 1$ for hydrogen atom)

Bohr's postulate says that angular momentum is quantized

i.e., $mvr = \frac{nh}{2\pi} \longrightarrow (2)$

squaring on both sides, we have

$$m^2 v^2 r^2 = \frac{n^2 h^2}{4\pi^2} \longrightarrow (4)$$

sub eqn (2) in (4)

$$r = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2} \longrightarrow (5)$$

The frequency of revolution of electron

$$f = \frac{v}{2\pi r} \longrightarrow (6)$$

sub v from eqn (2)

$$f = \frac{1}{2\pi} \frac{e}{\sqrt{(4\pi\varepsilon_0 m r)}\, r} \longrightarrow (7)$$

$$= \frac{1}{2\pi} \frac{e}{(4\pi\varepsilon_0 m)^{1/2} r^{3/2}}$$

sub r from eqn (5)

$$= \frac{1}{2\pi} \cdot \frac{e}{(4\pi\varepsilon_0 m)^{1/2} \left(\frac{n^2 h^2 \varepsilon_0}{\pi m e^2}\right)^{3/2}}$$

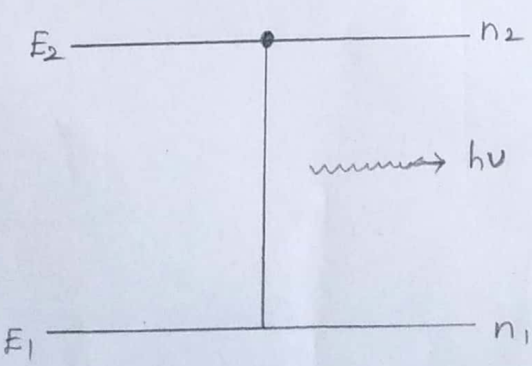
$$f = \frac{m e^4}{4 \varepsilon_0^2 h^3} \cdot \frac{1}{n^3} \longrightarrow (8)$$

According to Bohr's theory, the radiation is emitted when electron jumbs between energy levels.

The frequency of radiation is given by

$$\nu = \frac{m e^4}{8 \varepsilon_0^2 h^3} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \longrightarrow (9)$$

where n_1 & n_2 are the quantum number corresponding to lower and higher energy levels



2marks.

1. Physical significance of wave function:

ψ is a complex quantity

It relates the particles and the wave statistically

It give the information about the particle behaviour

$\iiint \psi^* \psi \, dx = 1$ particle present

$\iiint \psi^* \psi \, dx = 0$ particle absent

2. What is mean by degenerate and non-degenerate states?

Degenerate

We have same energy eigen value but different eigen function it is known as degenerate state:

Example:

ψ_{12}, ψ_{112}

Non-degenerate

We have same energy eigen value and eigen function it is known as non-degenerate state

Example:

ψ_{111}, ψ_{222}.

3. Define Eigen values and Eigen function

Eigen values:

It is defined as energy of the particle and is denoted by the letter E_n

Eigen function

It is defined as wave function of the particle and is denoted by the letter ψ_n

4. What is compton wavelength? Give its value

The shift in wavelength corresponding to the scattering 90° called compton wavelength

we know compton shift

$$\Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$$

$$\Delta\lambda = \frac{6.625 \times 10^{-34}}{3 \times 10^{8} \times 9.11 \times 10^{-31}}(1-0)$$

$$\Delta\lambda = 0.024 \text{ Å}$$

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