।। देगलूर महाविद्यालय, देगलूर ।।

ज्ञान हे उपमिजे ज्ञानेसीचि

CLASS- 4
UNIT -1
DE-BROGLIE WAVES

FOR

B. SC. T. Y. (PHYSICS)

BY

BHANUDAS NARWADE

INTRODUCTION :

1905-Theory of light quanta-

- Discovery of particle properties of waves

- Reversion to Newtons corpuscular theory

-Relation energy of corpuscles and frequency

1922 - A. H. Compton of X-ray scattering phenomena

-Further confirmation of particle properties of waves

INTRODUCTION :

For light has two contradictory theories

1) Waves

2) Corpuscles (Particle)

1924-de Broglie –Moving object have wave as well as particle characteristics

Wave-Particle duality

LOUIS VICTOR PIERRE RAYMOND DE BROGLIE (15 TH AUG 1892-19 TH MARCH 1987

Native : France

Education: First Degree in history in 1910.
science degree in 1913
military service (1914-1918)

Specialization: Theoretical Physics

Ph.D.Thesis -*Recherches sur la Théorie des Quanta*(quantum theory)

Nobe prize: 1929

DE BROGLIE WAVES:

Hypothesis: Moving body behaves in certain ways as though it has a wave nature.

Both corpuscle and wave concept at same time

Corpuscle and wave can not be independent

Parallelism between motion of corpuscles and propagation of associated wave

DE BROGLIE WAVES:

A photon of light of frequency (ν) has the momentum

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

Since c= $\nu\ \lambda$

Wavelength of a photon is specified by its momentum

Photon wavelength:

$$\lambda = \frac{h}{p} \text{ ------------(1)}$$

Eq.(1) is general one. Applies to material particles as well as photon

DE BROGLIE WAVES:

The momentum of a particle of mass (m) and velocity (ν) is

$$p = mv$$

This is **de-Broglie wavelength**

$$\lambda = \frac{h}{mv} \quad \text{------------(2)}$$

Greater particles momentum, shorter its wavelength

'm' is relativistic mass

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

NUMERICAL PROBLEM 1:

Find de Broglie wavelength of

a) A 46 g golf ball with velocity of 30m/s

b) An electron with velocity of 10^7 m/s

Given: mass of golf ball $m = 0.046$ kg

velocity of golf ball $v = 30$ m/s

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

Velocity of electron $v = 10^7$ m/s

NUMERICAL PROBLEM 1:

Solution:

a)Since velocity of golf ball $v \ll c$, $m=m_0$

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(0.046)\times 30} = 4.8 \times 10^{-34} \text{ m}$$

The wavelength of golf ball is so small compared with its dimension that we would not expect to find any wave aspect with its behaviour

NUMERICAL PROBLEM 1:

Solution:

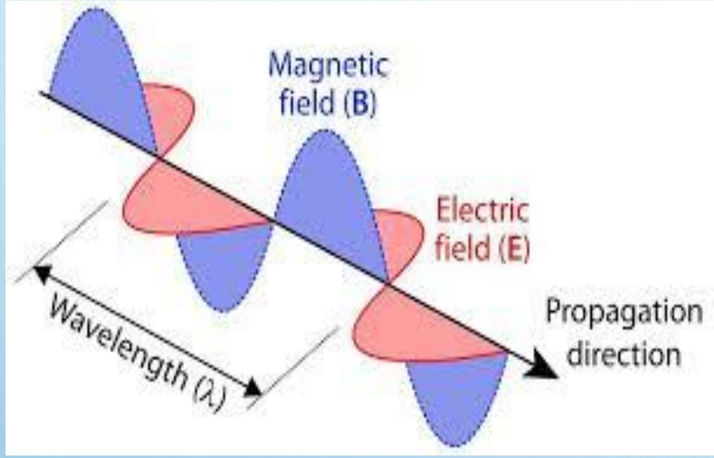
b) Since velocity of electron $v \ll c$, $m = m_0$

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(9.1 \times 10^{-31}) \times 10^{7}} = 7.3 \times 10^{-11} \text{ m}$$

The wavelength of electron is comparable with its dimension i.e. (radius of hydrogen atom 5.5×10^{-11}) we could expect the wave character of moving electron

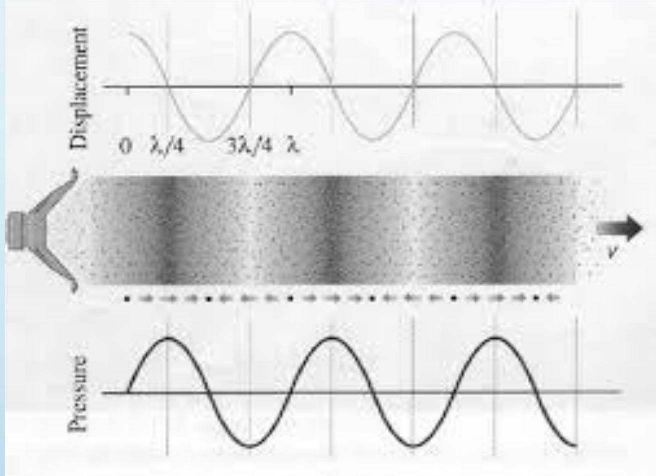
WAVE FUNCTION:

Light waves

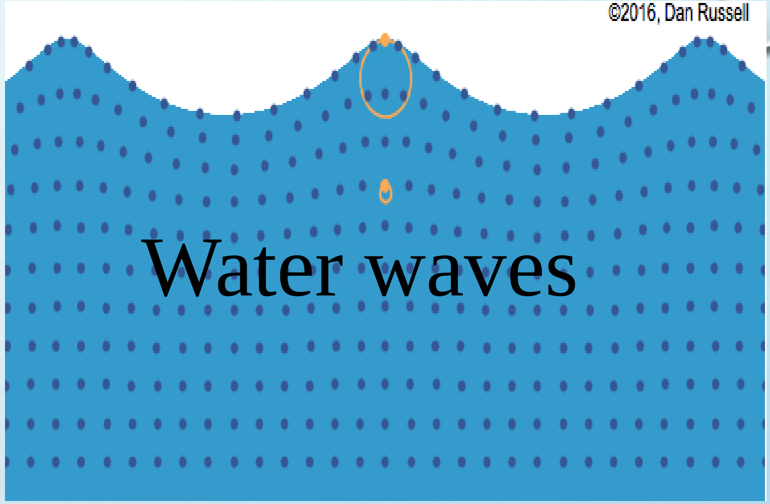


Electric and magnetic field vary

Sound waves



Pressure vary



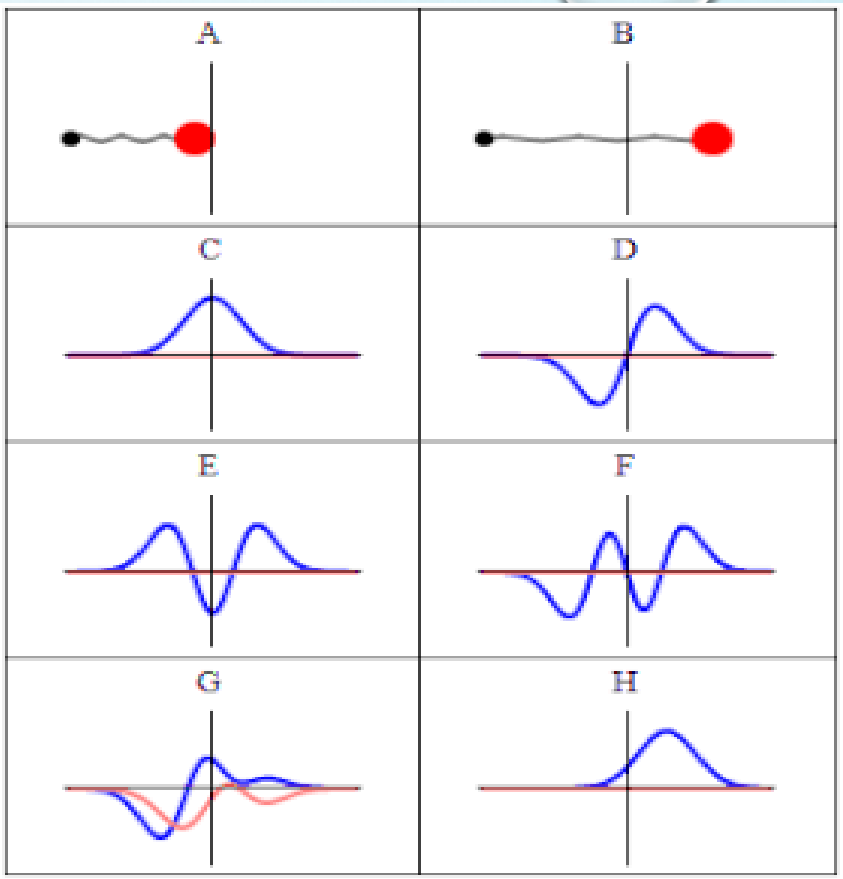
Height of water vary

What vary in matter waves?

WAVE FUNCTION:

Wave function(ψ): The quantity whose variations make up matter waves called wave function.

The value of **(ψ)** associated with a moving body at a particular point x,y, z in space and at a time t is related to likelihood finding body there at the time.



WAVE FUNCTION:

Wave function(ψ): No direct physical significance

Probability of finding object lies between 0 and 1

Intermediate say 0.3 means 30% chance

Amplitude of wave is negative

Negative probability -0.3 meaningless

Square of absolute value $|\psi^2|$ **probability density**

Large value of $|\psi^2|$ means strong probability

DE BROGLIE WAVE VELOCITY:

de Broglie wave associated with moving body, has same velocity as that of body

Let Vp is de Broglie wave velocity $V_p = \nu\lambda$

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

And $E = h\nu$

for relativistic total energy $E = mc^2$

$\therefore h\nu = mc^2$

$\nu = \frac{mc^2}{h}$

$V_p = \nu\lambda = \frac{mc^2}{h} \text{ x } \frac{h}{mv} = \frac{c^2}{v}$

CLASS- 5
UNIT -1
PHASE AND GROUP VELOCITY

FOR

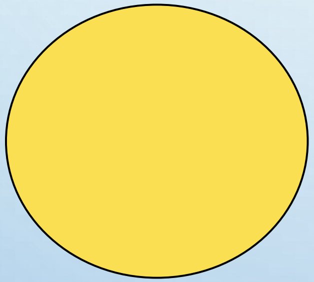
B. SC. T. Y. (PHYSICS)

BY

BHANUDAS NARWADE

PARTICLE

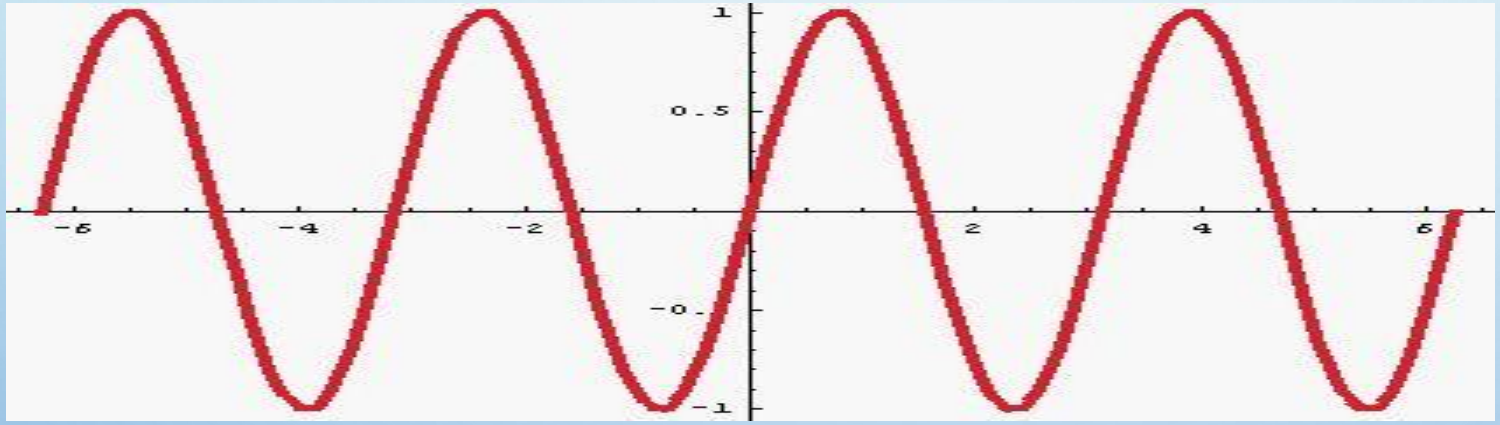
OUR TRADITIONAL UNDERSTANDING OF A PARTICLE…



"LOCALIZED" - DEFINITE POSITION, MOMENTUM, CONFINED IN SPACE

WAVE

OUR TRADITIONAL UNDERSTANDING OF A WAVE….



"DE-LOCALIZED" – SPREAD OUT IN SPACE AND TIME

WAVES

NORMAL WAVES

- ARE A DISTURBANCE IN SPACE
- CARRY ENERGY FROM ONE PLACE TO ANOTHER
- OFTEN (BUT NOT ALWAYS) WILL (APPROXIMATELY) OBEY THE CLASSICAL WAVE EQUATION

MATTER WAVES

- DISTURBANCE IS THE WAVE FUNCTION $\Psi(X, Y, Z, T)$
- PROBABILITY AMPLITUDE Ψ
- PROBABILITY DENSITY $P(X, Y, Z, T) = |\Psi|^2$

GENERAL WAVE EQUATION:

Oscillations at a particlar point

$$y = A\cos 2\pi\nu t$$

travelling waves $x = V_p\, t$

$$y = A\cos 2\pi\nu(t - x/V_p)$$

$$y = A\cos 2\pi(\nu t - \nu x/V_p)$$

$$but V_p = \nu\lambda$$

GENERAL WAVE EQUATION:

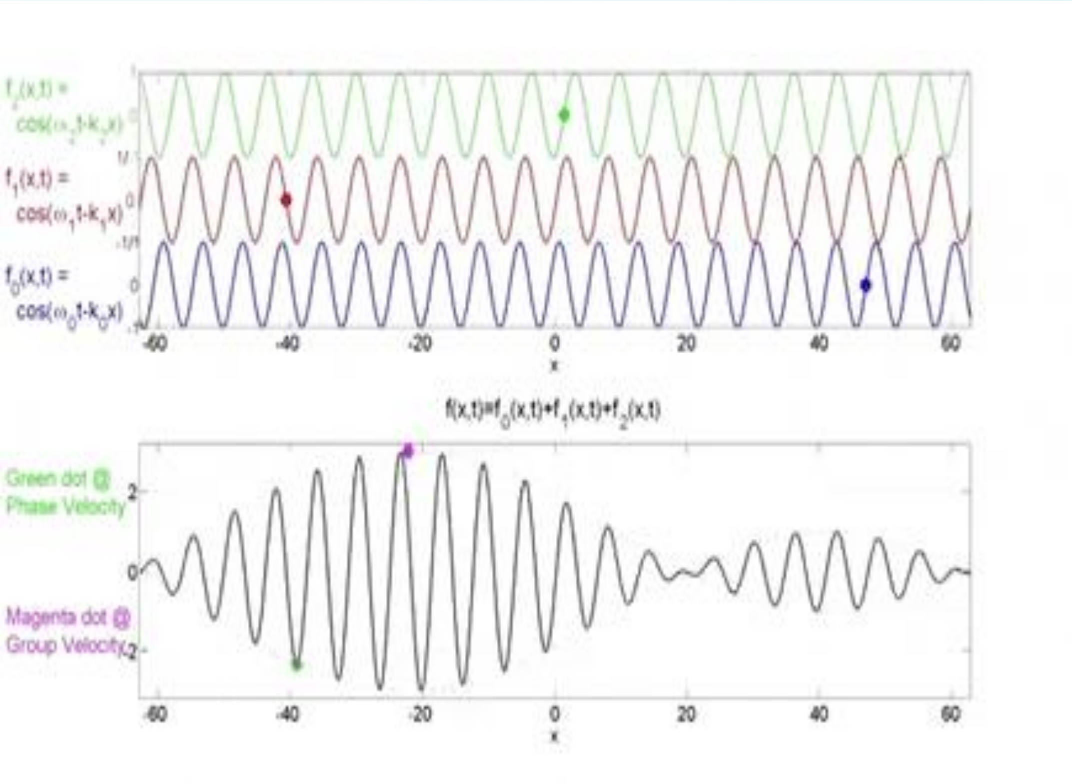
$$y = A\cos(\omega t - kx)$$

$$\omega = 2\pi\nu \ \text{(angular frequency)}$$

$$k = \frac{2\pi}{\lambda} \ \text{(wave number)}$$

WAVE PACKET, PHASE VELOCITY AND GROUP VELOCITY:

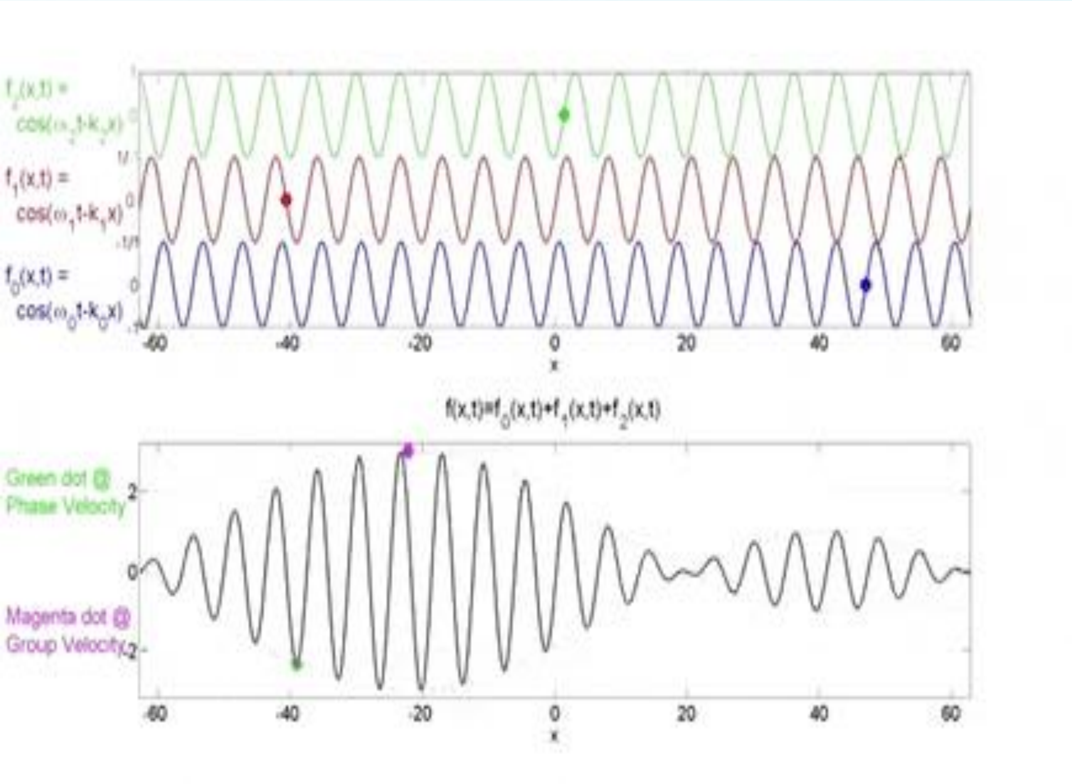
- The velocities of the individual waves which superpose to produce the wave packet representing the particle are different - the wave packet as a whole has a different velocity from the waves that comprise it



WAVE PACKET, PHASE VELOCITY AND GROUP VELOCITY:

- **Phase velocity**: The rate at which the phase of the wave propagates in space

- **Group velocity**: The rate at which the envelope of the wave packet propagates



PHASE VELOCITY:

- PHASE VELOCITY IS THE RATE AT WHICH THE PHASE OF THE WAVE PROPAGATES IN SPACE.

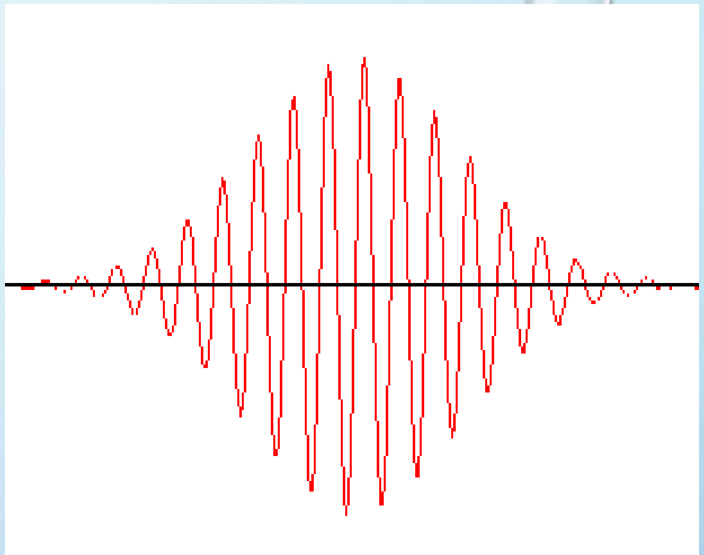
- THIS IS THE VELOCITY AT WHICH THE PHASE OF ANY ONE FREQUENCY COMPONENT OF THE WAVE WILL PROPAGATE.

- YOU COULD PICK ONE PARTICULAR PHASE OF THE WAVE AND IT WOULD APPEAR TO TRAVEL AT THE PHASE VELOCITY.

- THE PHASE VELOCITY IS GIVEN IN TERMS OF THE WAVE'S ANGULAR FREQUENCY(ω) AND WAVE VECTOR *K* BY

$$v_{\mathrm{P}} = \frac{\omega}{k}$$

GROUP VELOCITY:



Group velocity of a wave is the velocity with which the variations in the shape of the wave's amplitude (**modulation** or **envelope** of the wave) propagate through space.

The group velocity is defined by the equation

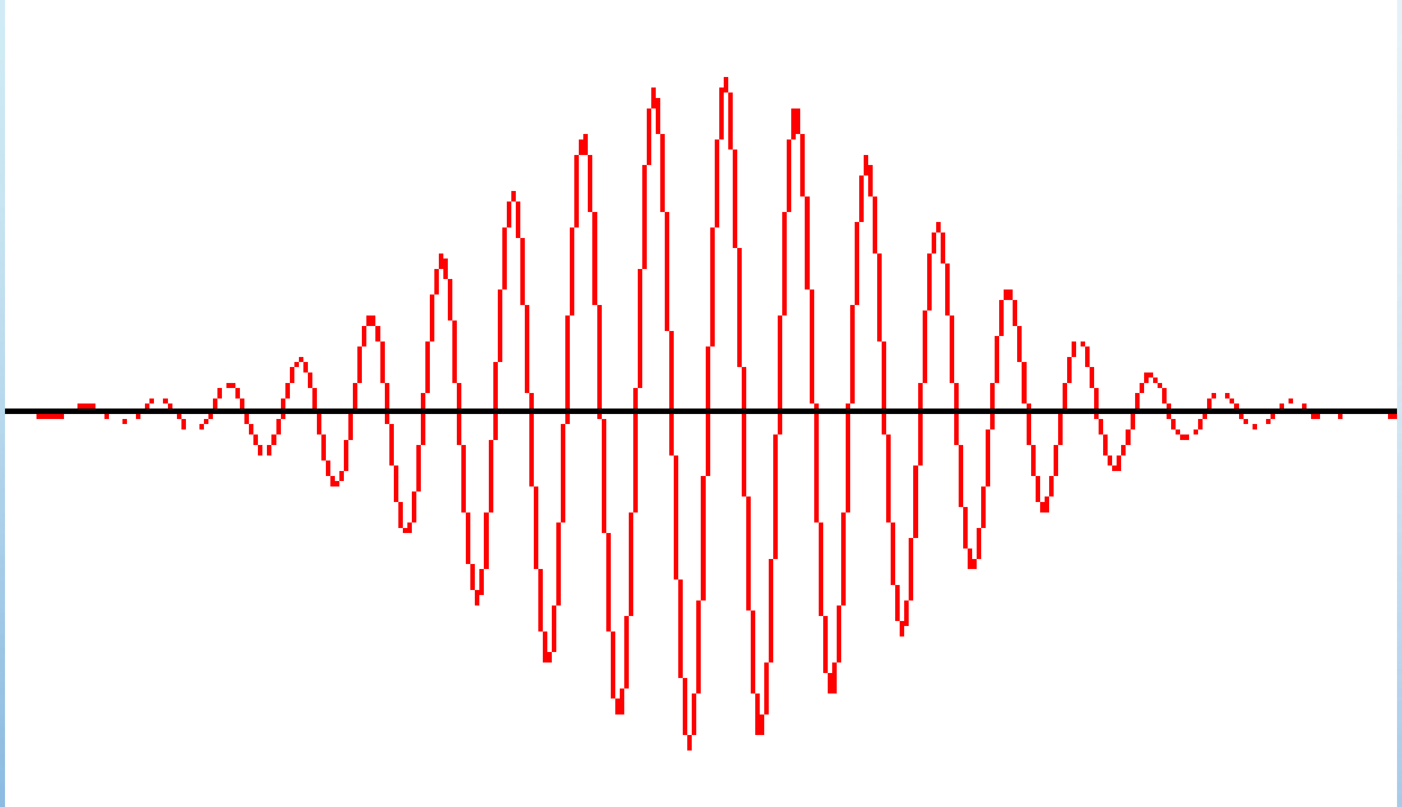
$$v_g = \frac{\delta\omega}{\delta k}$$

Where v_g is group velocity

ω is the wave's angular frequency;

k is the wave number.

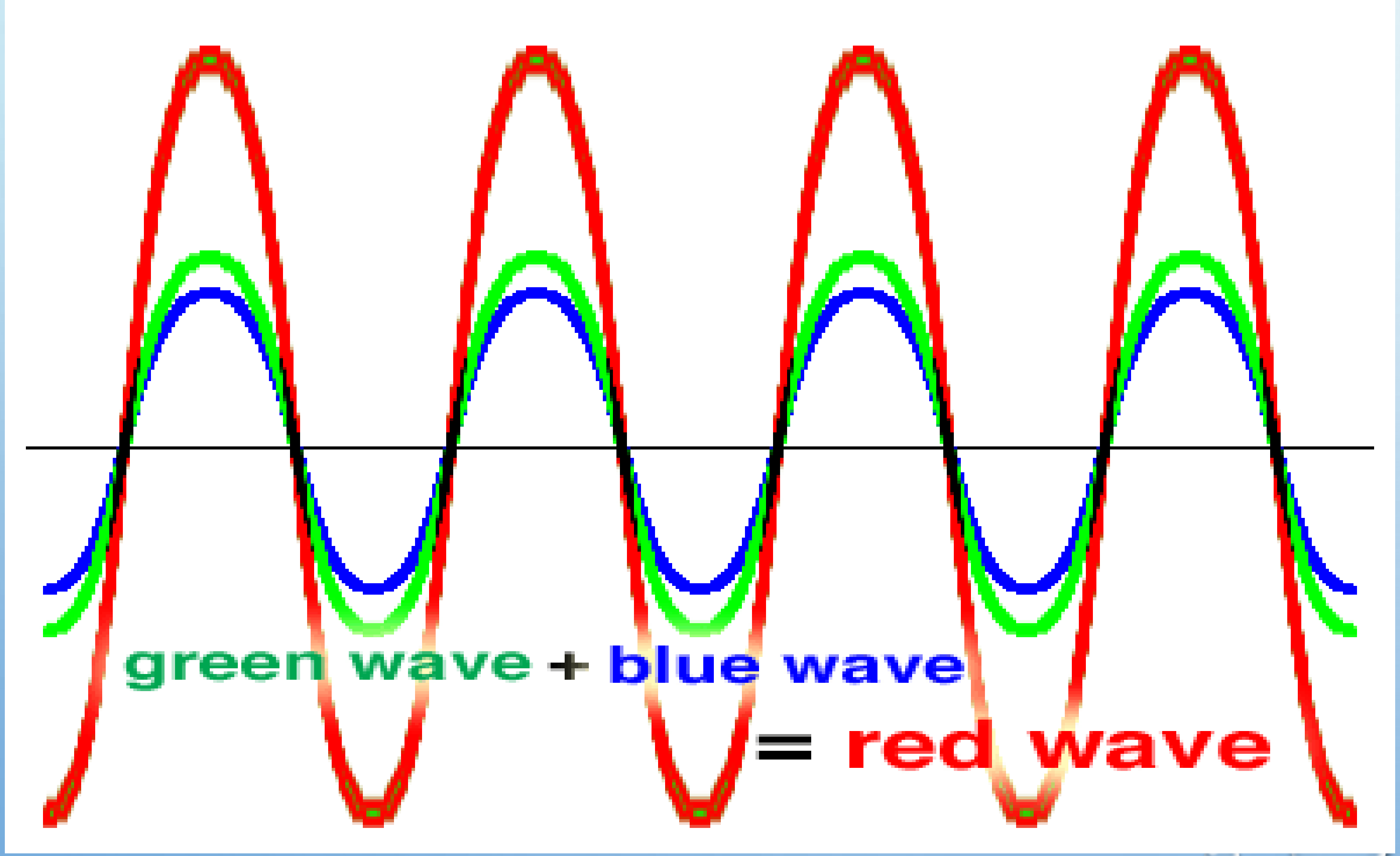
A WAVE PACKET:



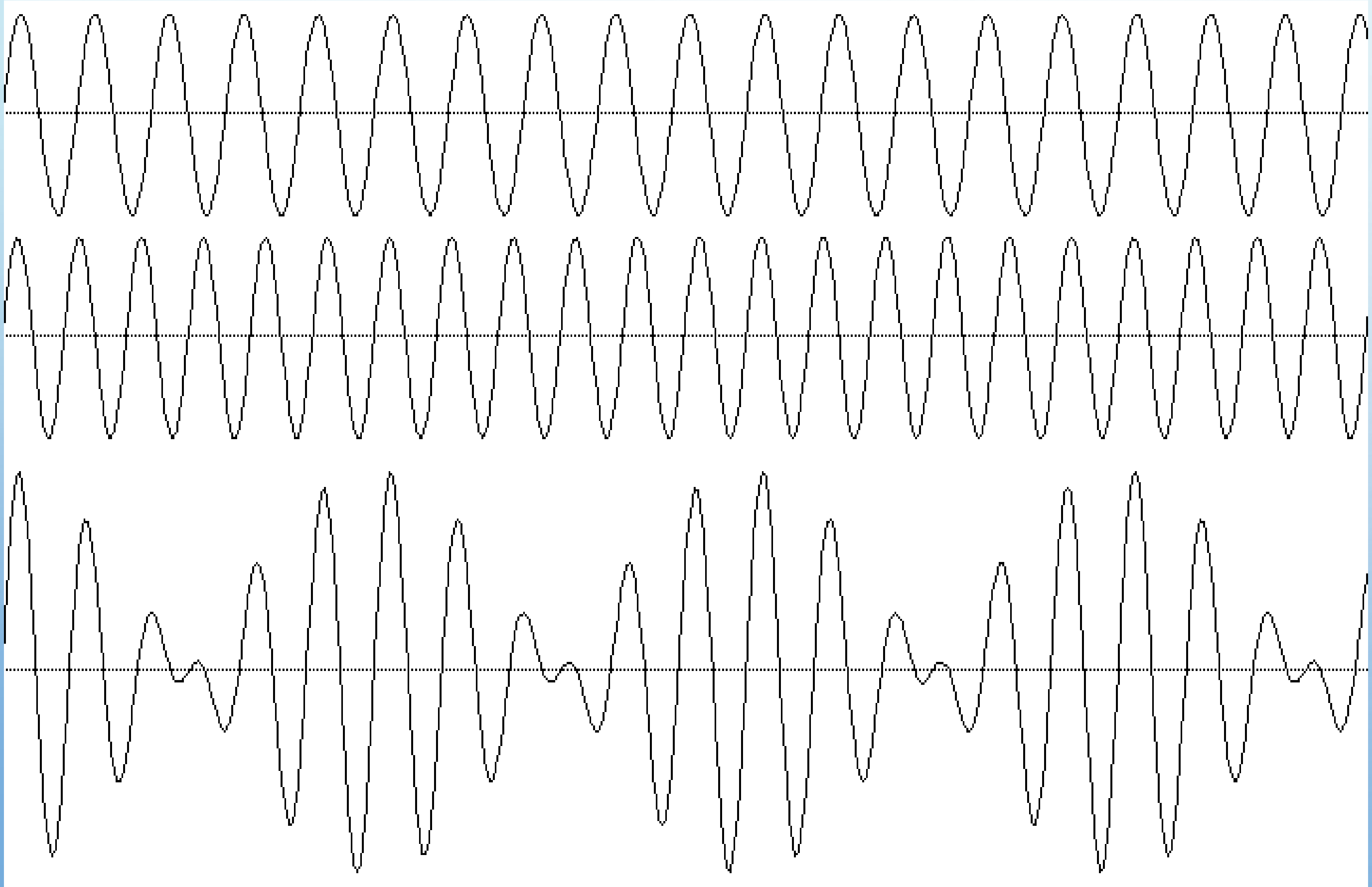
How do you construct a wave packet?

WHAT HAPPENS WHEN YOU ADD UP WAVES?

The Superposition principle



ADDING UP WAVES OF DIFFERENT FREQUENCIES....



A WAVE PACKET DESCRIBES A PARTICLE

A wave packet is a group of waves with slightly different wavelengths superposing with one another in a way that the amplitude of the group (envelope) is non-zero only in the neighbourhood of the particle

A wave packet is localized – a good representation for a particle!

DE BROGLIE WAVE VELOCITY:

de Broglie wave associated with moving body, has same velocity as that of body

Let Vp is de Broglie wave velocity $V_p = \nu\lambda$

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

And $E = h\nu$

for relativistic total energy $E = mc^2$

$\therefore h\nu = mc^2$

$$\nu = \frac{mc^2}{h}$$

$$V_p = \nu\lambda = \frac{mc^2}{h} \text{ x } \frac{h}{mv} = \frac{c^2}{v}$$

PHASE AND GROUP VELOCITY:

Wave group arises from two waves

Same Amplitude A but differ Δω and Δk

Original waves are

$$y_1 = A\cos(\omega t - kx)$$

$$y_2 = A\cos[(\omega + \Delta\omega)t - (k + \Delta k)x]$$

$$y = y_1 + y_2$$

$$y = A\cos(\omega t - kx) + A\cos[(\omega + \omega)t - (k + dk)x]$$

PHASE AND GROUP VELOCITY:

Wave group arises from two waves

Same Amplitude A but differ Δω and Δk

Original waves are

$$y_1 = A\cos(\omega t - kx)$$

$$y_2 = A\cos[(\omega + \Delta\omega)t - (k + \Delta k)x]$$

$$y = y_1 + y_2$$

$$y = A\cos(\omega t - kx) + A\cos[(\omega + \Delta\omega)t - (k + \Delta k)x]$$

PHASE AND GROUP VELOCITY:

$$y = 2A\cos\left[\frac{(2\omega + \Delta\omega)t}{2} + \frac{(2k + \Delta k)x}{2}\right]\cos\left[\frac{(\Delta\omega)t}{2} - \frac{(\Delta k)x}{2}\right]$$

$$with \quad d\omega << \omega, dk \;\; << k$$

$$y \cong 2A\cos[\omega t - kx]\cos\left[\frac{\Delta\omega}{2}t - \frac{\Delta k}{2}x\right] ------ -(1)$$

Equation1 represent a wave of angular velocity ω and wave number k which has superimposed upon it a wave (the process is called modulation) of angular velocity $\frac{\Delta\omega}{2}$ and wave number $\frac{\Delta k}{2}$

PHASE AND GROUP VELOCITY:

phase velocity= wave velocity of carrier : $v_p = \frac{\omega}{k}$

group velocity= wave velocity of envelope : $v_g = \frac{\Delta\omega}{\Delta k}$

for more than two wave contiributions: $v_g = \frac{d\omega}{dk}$

PHASE AND GROUP VELOCITY:

Angular frequency and Wave number of de-Broglie wave associated with body of rest mass m_0 moving with velocity v is

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

$$\omega = 2\pi\frac{E}{h}$$

$$\omega = 2\pi\frac{mc^2}{h}$$

Angular Frequency of de-Broglie wave

$$\omega = 2\pi\frac{m_0c^2}{h\sqrt{1-\frac{v^2}{c^2}}}$$

PHASE AND GROUP VELOCITY:

$$k = \frac{2\pi}{\lambda} = \frac{2\pi m v}{h}$$

Wave number of de-Broglie waves

$$k = \frac{2\pi m_0 v}{h\sqrt{1 - \frac{v^2}{c^2}}}$$

Both ω and k are functions of body's velocity v

Group velocity of de-Broglie wave associated with body

$$v_g = \frac{d\omega}{dk} = \frac{d\omega/dv}{dk/dv}$$

PHASE AND GROUP VELOCITY:

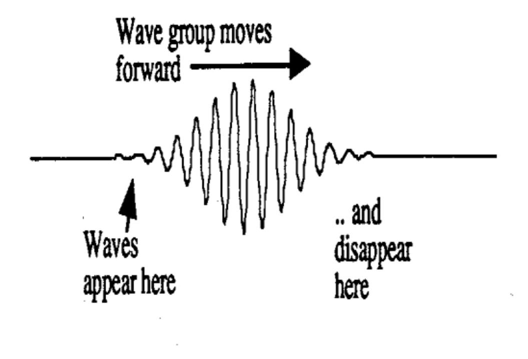
$$d\omega/dv = \frac{2\pi}{h}\frac{m_0 v}{\left(1-\frac{v^2}{c^2}\right)^{3/2}}$$

$$dk/dv = \frac{2\pi m_0}{h}\frac{1}{\left(1-\frac{v^2}{c^2}\right)^{3/2}}$$

$$\Rightarrow v_g = v$$

De-Broglie group associated with moving body travels with same velocity that of body

SCHEME:


Wave group moves forward
Waves appear here
.. and disappear here

CLASS- 6
UNIT -1
G.P. THOMSON'S EXPERIMENT

FOR

B. SC. T. Y. (PHYSICS)

BY

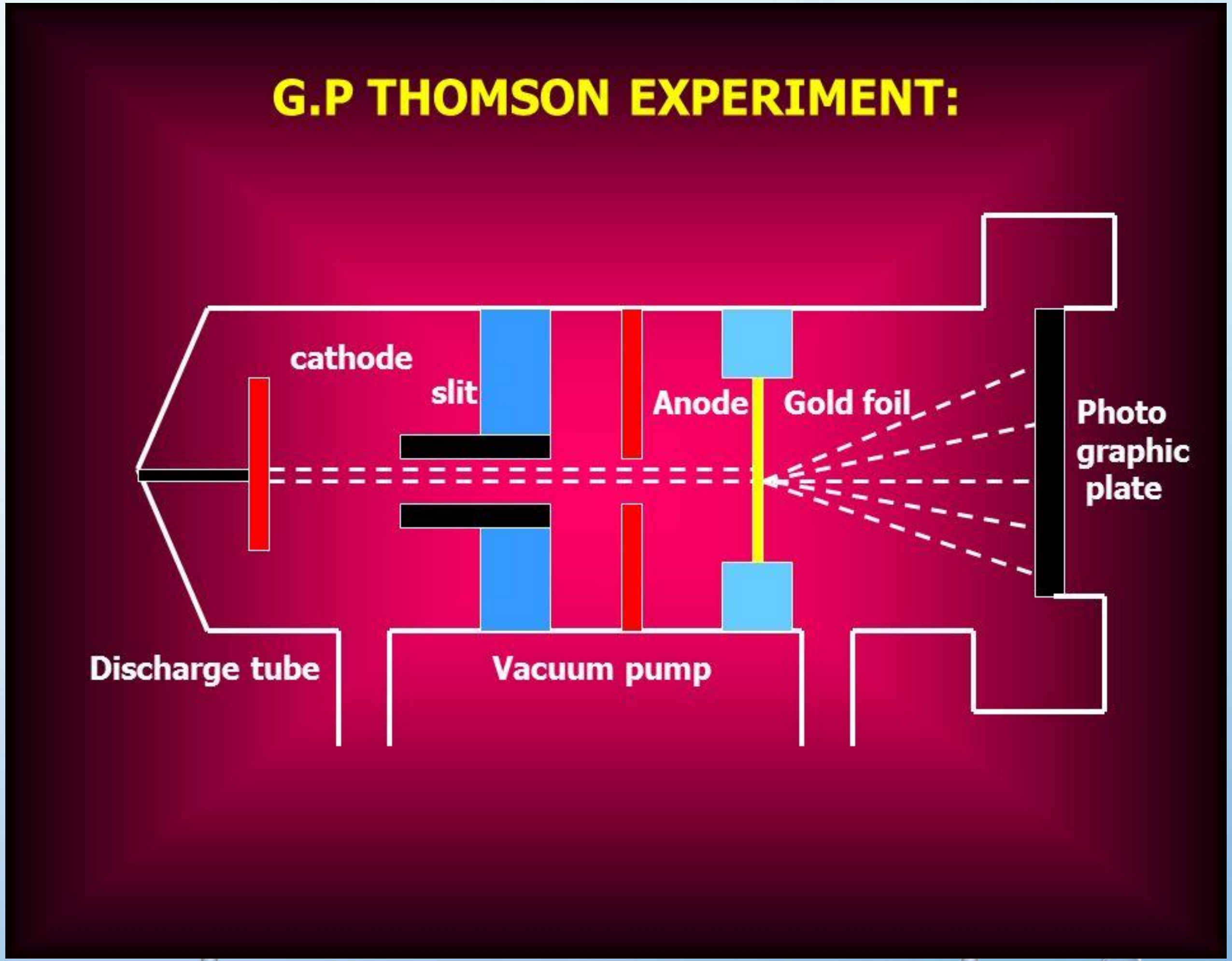
BHANUDAS NARWADE

G.P. THOMSON’S EXPERIMENT

CONFIRMATION OF MATTER WAVES

A beam of cathode ray is produced in a discharge tube by means of induction coil.

Electrons passing through a fine hole (slit) are incident on a thin gold foil

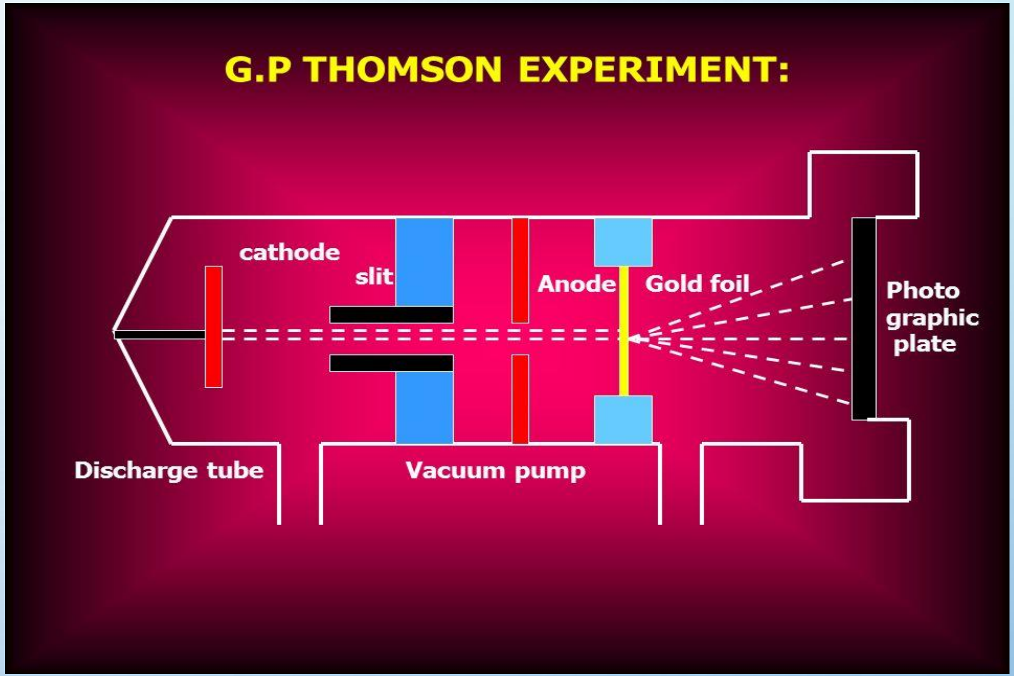


EXPERIMENTAL ARRANGEMENT:

The emergent beam of electrons is received on a photographic plate P

The visual examination of pattern is made possible by fluorescent screen

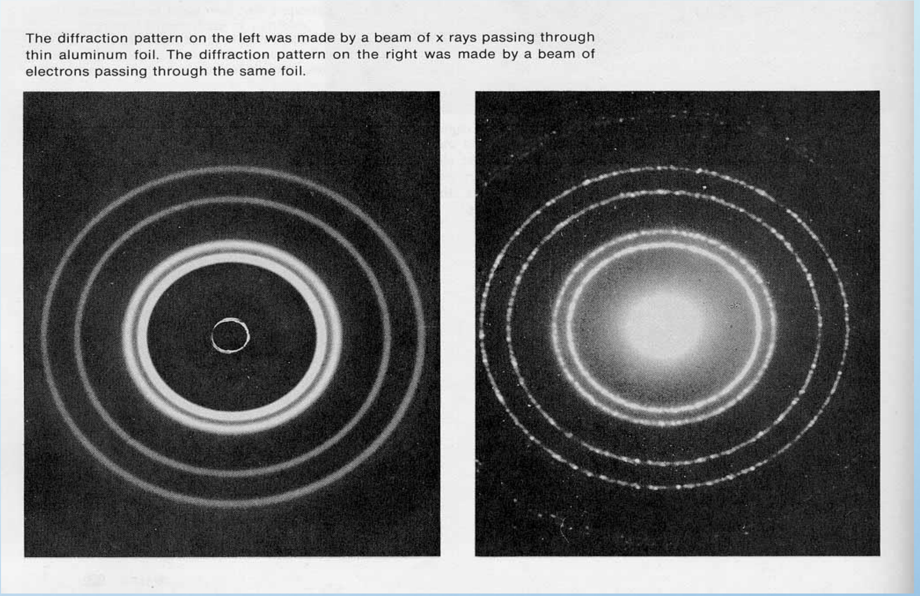
A very high vaccum is maintained in a camera part while air is allowed to leak into the discharge tube.



PROCEDURE:

A beam of electron of known velocity is made to fall on the photographic plate, after traversing the thin gold foil.

When plate is developed a symmetric pattern consisting of concentric rings about a centre spot is obtained.



PROCEDURE:

It is similar to produced by X rays in powdered crystal method.

When cathode rays are deflected by magnetic field, pattern also shift correspondingly

If foil is removed pattern disappear

DEMONSTRATION:

This experiment demonstrate that electron beam behaves as wave since diffraction pattern is produced only by waves

Formula:

$$\lambda = 12.27/\sqrt{V}$$

V is accelerating voltage

HEISENBERG'S UNCERTAINTY PRINCIPLE

Uncertainty principle states that the product of uncertainty Δx in the position of an object at same instant and uncertainty Δp in its momentum components in the x direction at the same instant is equal to or greater than h/4π or ħ /2

i.e.

$$\Delta p_x \Delta x \geq \frac{\hbar}{2}$$

WERNER HEISENBER
5 TH DEC 1901-1 ST FEB1976

Native : Germany
Education: Maximilian School Munich
Specialization: Theoretical Physics
Uncertainty Principle
founder of *quantum mechanics*,
leader of Germany's nuclear
fission research during World
War II.
Nobe prize: 1932

HEISENBERG UNCERTAINTY RELATIONS:

$$\Delta p_x \Delta x \geq \frac{\hbar}{2}$$

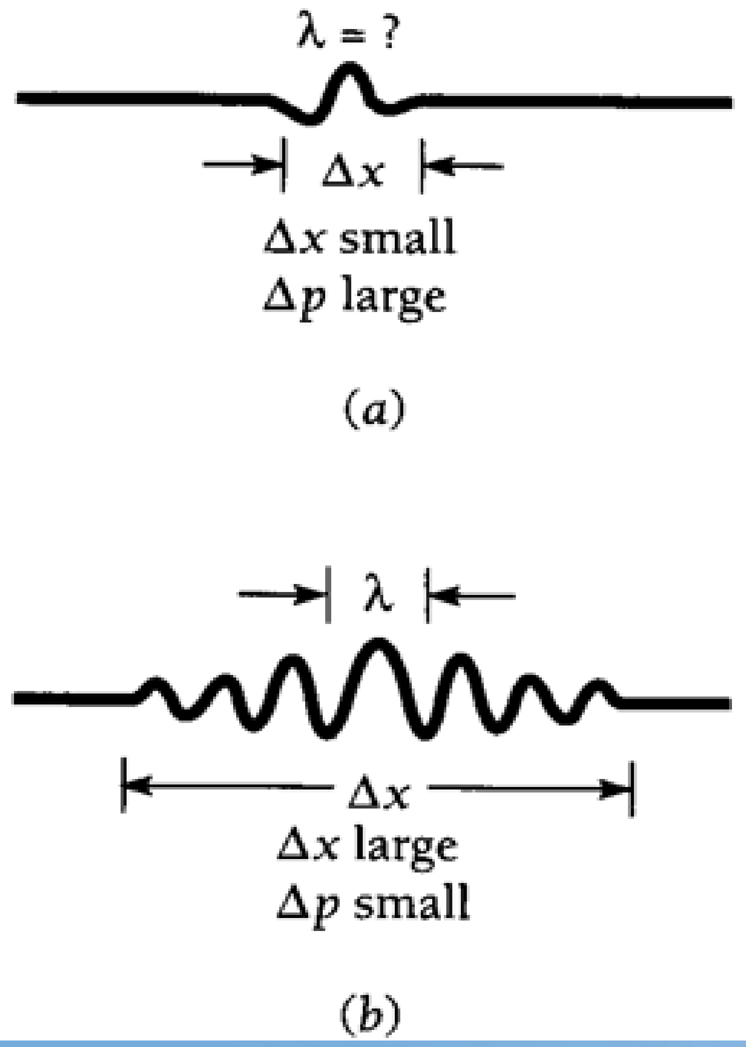


Figure 3.12 (*a*) A narrow de Broglie wave group. The position of the particle can be precisely determined, but the wavelength (and hence the particle's momentum) cannot be established because there are not enough waves to measure accurately. (*b*) A wide wave group. Now the wavelength can be precisely determined but not the position of the particle.

APPLICATIONS OF UNCERTAINTY PRINCIPLE

1) Electron does not exist in nucleus:

The nucleus radius is of the order of 10^{-14} m.

If we assume electron is confined in a nucleus the uncertainty in its position is $\Delta x = 2 \times 10^{-14}$ equal to diameter

$\hbar = 6.63 \times 10^{-34} / 6.28 = 1.05 \times 10^{-34}$ Js

Uncertainty in Δp is $\Delta p_x \Delta x \geq \frac{\hbar}{2}$

$$\Delta p = \frac{\hbar}{\Delta x} = \frac{1.54X10^{-34}}{2\,X10^{-14}}$$

$= 5.275 \times 10^{-21}$ kg m/s

ELECTRON DOES NOT EXIST IN NUCLEUS:

If this is the uncertainty in the momentum of electron.

Momentum must be at least comparable in magnitude

p=5.275 x10^{-21} kg m/s

K.E of electron of mass m maximum have

$$E = \frac{p^2}{2m} = \frac{(5.275\ \text{x}10{-}21)^2}{2\ x9.1x10-31}$$

=97 Mev

If electron is present in nucleus K.E. =97 Mev

But

Experimentally it is found that it is only 4 Mev

Electron is not in nucleus