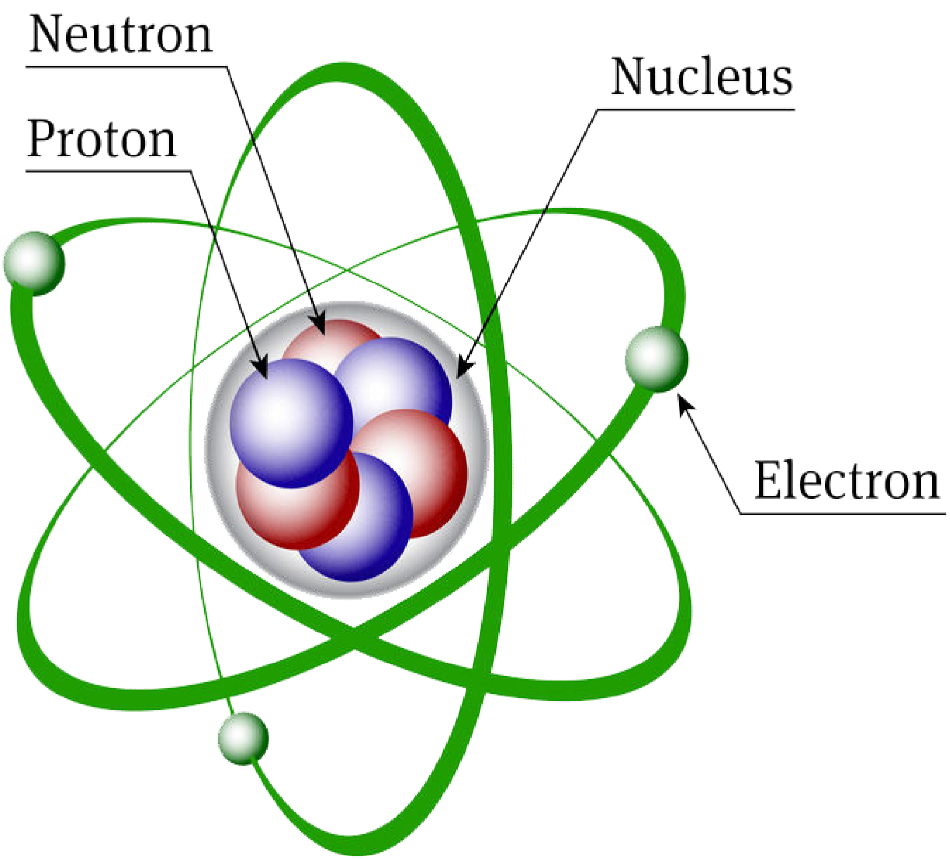
Structure Of Atom



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De Broglie Concept of matter waves

- **Einstein in 1905** gave dual behaviour of **light**
- Particle: black body radiation, photoelectric effect
- Wave: reflection , refraction, dispersion, interference.
- De Broglie in 1924 contradicted Bohr statement. He suggested that just as light all microscopic particles also exhibit dual behavior.

Acc. to De Broglie

$$\lambda = h/mv \text{ or } \lambda = h/p$$

Acc to Plancks

$$E = h\upsilon \ldots\ldots\ldots\ldots \text{(i)}$$

Acc to Einstein

$$E = mc^2 \ldots\ldots\ldots \text{(ii)}$$

From eq. (i) and (ii)

$$h\upsilon = mc^2 \ldots\ldots\ldots\ldots \text{(iii)}$$

But $\upsilon = c/\lambda$

Substituting the value of ν in equation….(iii),

$$hc/\lambda = mc^2$$

$$\lambda = h/mc \text{ or } \lambda = h/p$$

Justification of Dual Nature

1. **Particle nature:** Electrons exhibit characteristics of particle i.e. they have mass, momentum , energy and charge.

2. **Wave nature** was experimentally verified by Germer and Davidson in1927 and George Thomas in 1928

WAVE NATURE OF ELECTRON AND QUANTISATION OF ANGULAR MOMENTUM :

- de Broglie was able to explain correctly the concept of angular momentum given by Bohr.

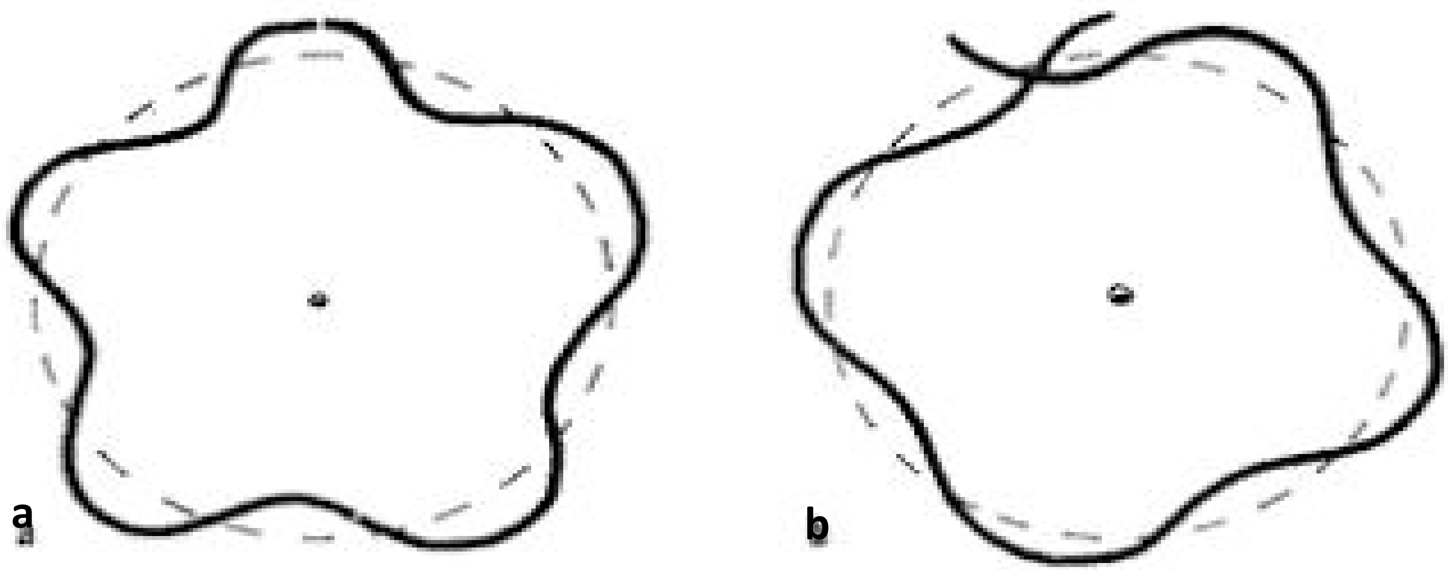
- Acc.to Bohr, the angular momentum of an electron in a particular orbital is quantized and is an integral multiple of $(nh/2\pi)$

- Acc. to de Broglie, electron has both wave and particle like character.

- The electron moves around the nucleus in the form of wave in a circular orbit of radius ‘r’

❖ The movement of electrons in the form of wave can be of two types:

i. In phase : **stationary or standing wave**
ii. Out of phase: **non-stationary wave**



a) In phase **b) out of phase**

- For a wave to be completely in phase, the circumference of the orbit must be an integral multiple of the wavelength ‘λ’

$$\text{Circumference} = n\lambda$$

$$2\pi r = n\lambda \ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

$$\lambda = h/mv \text{ (de Broglie)}$$

Substituting the value of λ in equation (i),

$$2\pi r = nh/mv$$

$$mvr = nh/2\pi$$

where mvr = angular momentum

Significance of de Broglie relationship :

- Dual nature of matter is significant only for microscopic objects.

- For larger bodies wavelength associated is small and cannot be measured.

- The wavelength of an electron can be calculated by

$$\lambda = h/mv$$

$$= \frac{6.63 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{9.11 \times 10^{-31} \text{ kg} \times (10^6 \text{ ms}^{-1})}$$

$$= 7.28 \times 10^{-10} \text{ m (same as x-ray)}$$

- The wavelength associated with ball(10g) can be calculated by the similar way

$$\lambda = h/mv$$

$$= \frac{6.63 \text{ x } 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{10 \text{ x } 10^{-3} \text{ kg } \mathbf{x} \text{ } (10^6 \text{ ms}^{-1})}$$

$$= 6.63 \mathbf{\ x\ } 10^{-38}\text{m}$$

- This wavelength is shorter than any known wavelength and cannot be measured.

Q1. Calculate de Broglie wavelength of an electron of mass (9.11×10^{-31} kg) moving at 1% of speed of light (h= 6.63×10^{-34} kg m^2 s^{-1}

Ans:

$\lambda = h/mv$

h = 6.63×10^{-34} kg m^2 s^{-1}

m = 9.11×10^{-31} kg

v= 1% speed of light = $1 \times 3 \times 10^8/100$ ms^{-1}= 3×10^6 ms^{-1}

$$= \frac{6.63 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{9.11 \times 10^{-31} \text{ kg} \times (3 \times 10^6 \text{ ms}^{-1})} = 2.43 \times 10^{-10} \text{ m (243 pm)}$$

Calculate de Broglie wavelength of an electron that has been accelerated from rest through a potential difference of 1kV.

Ans:

$e = 1.6 \times 10^{-19}$ C, $V = 10^{3}$V, $m = 9.11 \times 10^{-31}$ kg

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

$$\frac{1}{2} \times 9.11 \times 10^{-31} \text{ kg} \times v^2 = 1.6 \times 10^{-19} \text{ C} \times 10^{3} \text{ V}$$

$$v = 0.188 \times 10^{8} \text{ ms}^{-1}$$

$$\lambda = h/mv$$

$$= \frac{6.63 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{9.11 \times 10^{-31} \text{ kg} \times (0.188 \times 10^{8} \text{ ms}^{-1})} = 3.85 \times 10^{-11} \text{ m}$$

HEISENBERG'S UNCERTAINTY PRINCIPLE:

It is not possible to define both position and velocity (or momentum) of a microscopic particle with absolute accuracy or certainty.

Mathematically, **Δx x $\Delta p \geq h/4\pi$**

where **Δx** is uncertainty in position ; **Δp** is uncertainty in momentum of a particle.

CASES

i) Δx = *is small, i.e., position of the particle is measured accurately*

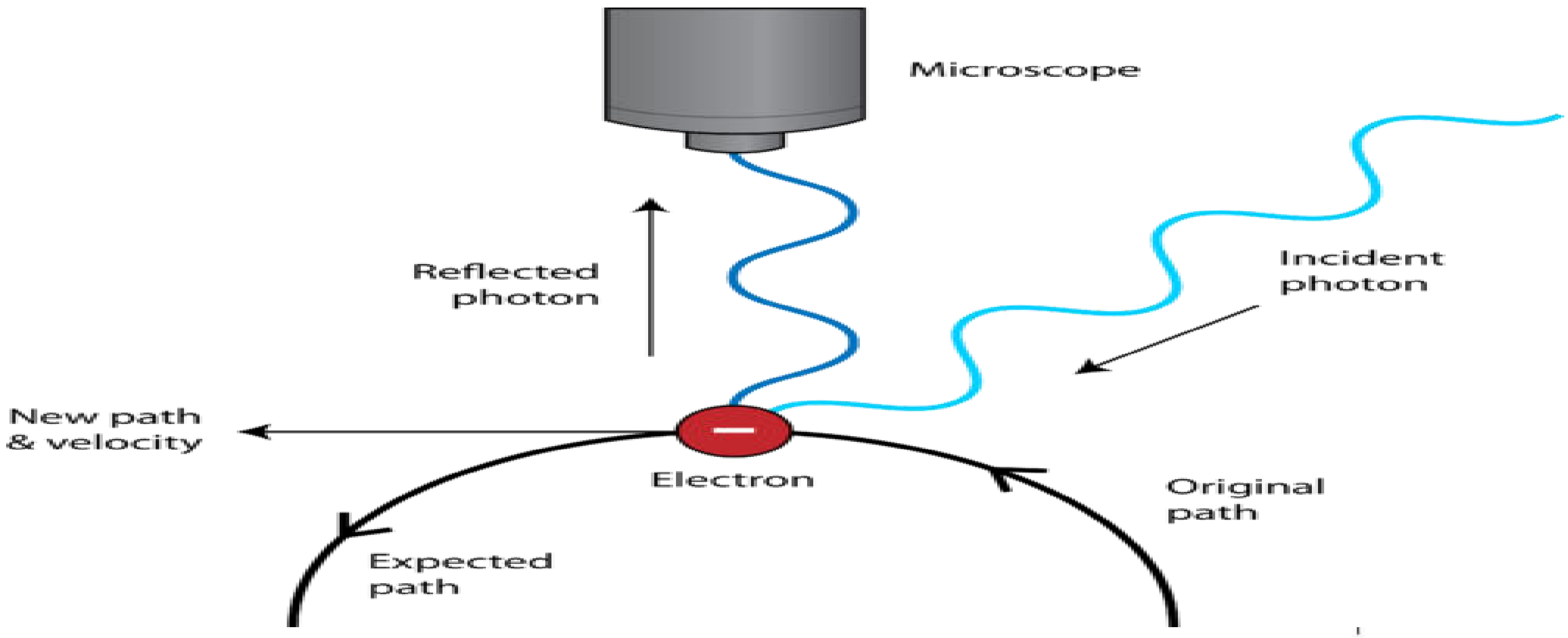
Δp would be large i.e., there would be large uncertainty in the momentum.

ii) Δp = is small, i.e., momentum od particle is measured accurately

Δx would be large i.e., there would be large uncertainty in the position .

Physical concept of uncertainty

- In order to determine the position of an object, we have to see the object.
- When beam of light falls on the object photon of incident light are scattered and the reflected light enter our eye.



- To locate an electron, you might strike it with a photon.
- The electron has such a small mass that striking it with a photon affects its motion in a way that cannot be predicted accurately.
- The very act of measuring the position of the electron changes its momentum, making its momentum uncertain.

Why electron cannot remain inside nucleus?

Atomic radii of nucleus is 10^{-15} m

$$\Delta x = 10^{-15} \text{ m}$$

Now, according to uncertainity principle,

$$\Delta x \times \Delta p = \frac{h}{4\pi}$$

$$\Delta x \times m\Delta V = \frac{h}{4\pi} \qquad 1$$

$$\Delta V = \frac{h}{4\pi m \Delta x}$$

Mass of electron,

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

$$\Delta x = 1 \times 10^{-15} \text{ m}$$

$$\therefore \quad \Delta V = \frac{6{\cdot}6 \times 10^{-34}}{4 \times 3{\cdot}14 \times 9{\cdot}1 \times 10^{-31} \times 1 \times 10^{-15}}$$

$$= 5.77 \times 10^{10} \text{ ms}^{-1} \qquad 1$$

The value of uncertainity in velocity, ΔV is much higher than the velocity of light (3.0×10^{8} ms^{-1}) and hence an electron cannot be found within the atomic nucleus. 1

The mass of an electron is 9.11×10^{-31} kg. Calculate the uncertainty in its velocity if the uncertainty in its position is of the order of $\pm$10pm

Ans:

$\Delta x = 10pm = 10 \times 10^{-12} = 10^{-11}$ m

$m = 9.11 \times 10^{-31}$ kg

$\Delta P = ?$

$\Delta x \times \Delta p \geq h/4\pi$

$\Delta x \times \Delta mv \geq h/4\pi$

$$\Delta v = \frac{6.6 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{4 \times 3.14 \times 9.11 \times 10^{-31} \text{ kg} \times 10^{-11} \text{ m}}$$

$= 5.76 \times 10^{6}$ ms^{-1}

Calculate the uncertainty in the position of an electron if uncertainty in its velocity is

(i) .001% (ii) zero (the velocity of e= 300m/s)

Ans: $\Delta v = .001\% = 0.001 \times 300/100 = 3 \times 10^{-3}$ m/s

(i) $\Delta x \times \Delta p \geq h/4\pi$

$$\Delta x = \frac{6.6 \times 10^{-34}\ kg\ m^2\ s^{-1}}{4 \times 3.14 \times 9.11 \times 10^{-31}\ kg \times 3 \times 10^{-3}\ m} = 1.92 \times 10^{-2}\ m/s$$

(ii) $\Delta x \times \Delta p \geq h/4\pi$

$\Delta v = 0$

$\Delta x \times \Delta mv \geq h/4\pi$, $\Delta x \times \geq h/4\pi m\Delta v$

= as denominator becomes zero and the uncertainty in position is infinity.