Modern Physics
(Lec-8)

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OUTLINES

- De Broglie Concept
- Condition for wave and particle behavior
- Bohr atomic model

De Broglie matter waves

" If radiation which is basically a wave can exhibit particle nature under certain circumstances, and since nature likes symmetry, then entities which exhibit particle nature ordinarily, should also exhibit wave nature under suitable circumstances."

The Considerations that led de Broglie to develop his concept of matter waves are as follows,

- Nature loves symmetry: Matter and energy, the two fundamental forms in which nature manifest itself, must be mutually symmetrical. Radiant energy possess dual nature-wave and particle, matter must also possess the same dual nature-particle and wave.
- Close parallelism between mechanics and optics as regards their fundamental laws governing motion, momentum, mass and energy.
- Bohr's theory of atomic structure: This implies, if energy (radiant) is undulatory and/or corpuscular, matter (i.e electron) must be corpuscular and/or undulatory.

De Broglie wavelength for an electron

The Wave associated with the matter particle is called Matter Wave. The Wavelength associated is called de Broglie Wavelength. The de Broglie wavelength is the wavelength, λ, associated with a massive particle (i.e., a particle with mass, as opposed to a massless particle) and is related to its momentum, p, through the Planck constant, h

A photon of light of frequency hν has the momentum

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

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

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

The wavelength of a photon is therefore specified by the relation

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

This wavelength is called de-Broglie wavelength.

de-Broglie suggested that equation (1) is completely general one that applies to material particle as well as photons.

The momentum of a particle of mass m and velocity v is given by

$$p = mv$$

and its de -Broglie wavelength is accordingly

$$\lambda = \frac{h}{mv} \qquad (2)$$

Cont…

Thus, the greater the particle's momentum, the shorter its wavelength.

We know,

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

$$v = \sqrt{\frac{2E}{m}}$$

Again, we know

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

$$\lambda = \frac{h}{m\sqrt{\frac{2E}{m}}}$$

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

This is the expression for the Broglie wavelength in terms of energy.

substituting for h, m, *and* e *we get*

$$\lambda = \frac{6.625\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.602\times10^{-19}\times V}} = \frac{1.226}{\sqrt{V}}\ nm$$

thus for $V = 100$ *Volts*

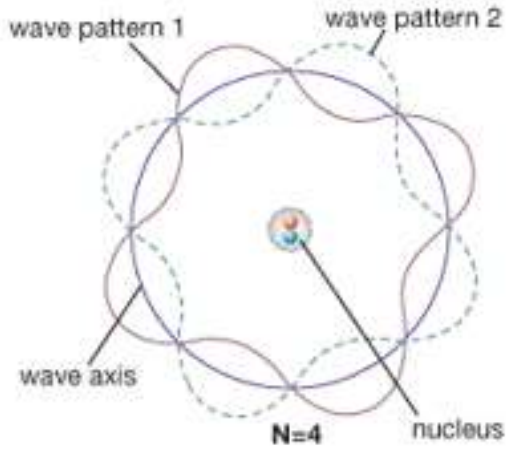
$$\lambda = \frac{1.226}{\sqrt{100}} = 0.1226\ nm$$

Wave mechanical atom model / De Broglie's Explanation of Bohr's Second Postulate:

According to the new theory of dual nature of matter, the electron in an atom does not behave as through it were a particle. The electron move around the nucleus as wave packets, which are formed in a somewhat similar manner as standing waves are formed in sound.

According to this model electrons in various orbits behave as matter wave of wavelength $\lambda = h/mv$. The energy level and orbits of Bohr atom model are retained. Bohr's quantum conditions which are assumed arbitrarily can be derived in a more natural way by considering the wave like property of the electron. For example, consider the electron in the hydrogen atom as a standing wave extending in a circle round the nucleus (fig:1). In order that this wave may just occupy the circumference of a circle, the circle must contain an integral number of wavelengths.

CONT…



If r is the radius of the circular orbit, then,

$$2\pi r = n\lambda, \text{ where n is an integer } (=1,2,3)$$

Taking the wavelength to be the de Broglie wavelength ($\lambda = h/p$), this becomes:

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

The momentum, p, is simply mv as long as we're talking about non-relativistic speeds, so this becomes:

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

Rearranging this a little gives,

$$L_n = mvr = nh/2\pi$$

But mvr is the angular momentum of the electron as a particle. Thus, the wave mechanical pictures lead naturally to Bohr's postulates that the angular momentum is equal to an integer multiple of $h/2\pi$

PAULI'S EXCLUSION PRINCIPLE

- This principle stated as, "No two electrons in a single atom can have the same set of quantum numbers (n, l, m_l, m_s)."

This principle implies that each electron in an atom must have a different set of quantum numbers n, l, m_l, m_s. If two electrons have exactly identical set of quantum numbers, then one of those electrons excluded from entering in to the constitution of this atom. Hence the name exclusion principle.

- **Bohr atomic model**

  In 1913, Bohr suggested that, *positively charged nucleus is at the centre and negatively charged electrons revolve round the nucleus in various circular orbits*. The electrons revolving round the nucleus only in certain permitted orbits are called *energy levels*. Each energy level has a certain *fixed amount of energy*. The larger the orbit (i.e. larger radius), the greater is the energy of electrons. Electrons give out energy in the form of electromagnetic radiation when it jumps from *higher to lower level*.

POSTULATES OF BOHR ATOMIC MODEL

- Bohr atomic model is based on the following postulates:

(i) An atom consists of positively charged nucleus at the center.

(ii) The negatively charged electrons move round the nucleus in various orbits known as stationary energy levels. The electrons can't emit radiations when moving in their own stationary level

(iii) The Coulombian and Newtonian forces are applicable in the domain of the atom.

(iv) The electrons revolve round the nucleus in various circular orbits and the angular momentum, $mvr=2\pi nh$

where n (= 1, 2, 3, 4,…..) is called the quantum number, and h is the Planck's constant.

(v) When an electron jumps from a higher energy level to a lower energy level, it gives out electromagnetic radiations of a particular frequency