23. *In which of the following system will the radius of the first orbit* ($n = 1$) *be minimum* ?

(A) *hydrogen atom* (B) *deuterium atom*
(C) *singly ionized helium* (D) *doubly ionized lithium*

24. *In which of the following system will the wavelength corresponding to* $n = 2$ *to* $n = 1$ *be minimum* ?

(A) *hydrogen atom* (B) *deuterium atom*
(C) *singly ionized helium* (D) *doubly ionized lithium*

25. *The energy of an atom (or ion) in its ground state is* 54.4 *eV*. *It may be* :

(A) *hydrogen* (B) *deuterium* (C) He^+ (D) Li^{++}

26. *A hydrogen atom in ground state absorbs* 10.2 *eV of energy. The orbital angular momentum of the electron is increased by*:

(A) 1.05×10^{-34} *J-s* (B) 2.11×10^{-34} *J-s* (C) 3.16×10^{-34} *J-s* (D) 4.22×10^{-34} *J-s*

27. *A photon was absorbed by a hydrogen atom in its ground state and the electron was promoted to the fifth arbit. When the excited atom returned to its ground state, visible and other quanta were emitted. Other quanta are* :

(A) $2 \rightarrow 1$ (B) $5 \rightarrow 2$ (C) $3 \rightarrow 1$ (D) $4 \rightarrow 1$

28. *Of the following, radiation with maximum wavelength is* :

(A) *UV* (B) *Radio wave* (C) *X-ray* (D) *IR*

29. *Zeeman effect explain splitting of lines in* :

(A) *Magnetic field* (B) *Electron field* (C) *Both* (D) *None of these*

WAVE NATURE OF PARTICLES SECTION - 5

We have studied that light shows dual nature i.e. wave nature (*Electromagnetic Radiation*) and particle nature (*photons*). In the following article we will see that not only light but *matter also shows dual nature*.

In 1923, de Broglie suggested that, since light is dualistic in nature: behaving in some aspects as waves and in others like particles, the same might be true of matter. According to him, every form of matter (electron or proton or any other particle) behaves like waves in some circumstances. These were called as *matter waves* or *de Broglie waves*. de Broglie postulated that a particle of mass *m* moving with a velocity v should have a wavelength λ given by :

$$\lambda = \frac{h}{p} = \frac{h}{mv} \qquad (p = \text{linear momentum} = mv)$$

Now we can think of a model of atom where moving electrons (obviously around the nucleus) should behave like waves. The wave hypothesis of de Broglie was later developed by Heisenberg, Schrödinger, Fermi and many others in modern atomic theory and is known as *wave mechanics* or *quantum mechanics*.

In new theory, electrons in an atom are visualised as diffused clouds surrounding the nucleus. The idea that the electrons in an atom move in definite orbits (*Bohr's model*) is now abandoned. The new theory assigns definite energy states to an atom but discards a definite path for movement of an electron.

Due to wave nature of electron in an atom, it is now highly impossible to ascertain the exact whereabouts of an electron. This idea is defined by Heisenberg's Uncertainty Principle as :

" It is impossible to specify at any given instant, both the momentum and the position of a sub-atomic particle like electron."

Whenever there is an attempt to specify the position of electron precisely, an uncertainty is introduced in its momentum and vice-versa. If Δx is the uncertainty in position and Δp be the uncertainty in its momentum, then according to Heisenberg, these quantities are related as follows : $\Delta x \,.\, \Delta p \geq \dfrac{h}{4\pi}$

In other words, it can be defined as :

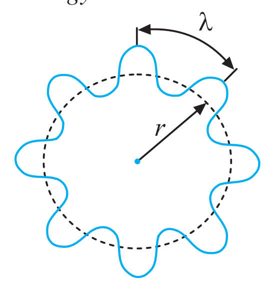
An expression of limits set by the wave nature of matter (electron) on finding the position and the state of motion of moving body (momentum) such that the product of uncertainties in simultaneous measurements of the position and momentum of a sub-atomic particle cannot be less than $h/4\pi$.

Hence, in new atomic theory, an electron can not be regarded as having a fixed (definite) path around the nucleus, called orbits. It is a matter of probability that an electron is more likely to be found in one place or the other. So we can now visualise a region in space (diffused cloud) surrounding the nucleus, where the probability of finding the electron is maximum. Such a region is called as an orbital. It can be defined as :

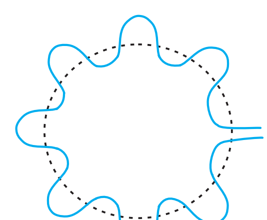
" The electron distribution described by a wave function and associated with a particular energy."

- The new theory still defines a definite energy to an orbital in an atom (*a remarkable and accepted feature of Bohr's model*). The new theory abandons the concept of sharply defined paths.

- If we consider an electron moving in a circular orbit around the nucleus, then the wave train associated with the electron is shown in the figure.



Electron wave in phase



Electron wave out of phase

If the two ends of the electron wave meet to give a regular series of crests and troughs, the electron wave is said to be *in phase*.

$$n'\lambda = 2\pi r$$

where n' is the number of waves made by an electron in that Bohr orbit

$\Rightarrow$ The number of waves made by the electron $= \dfrac{\text{circumference of the orbit}}{\text{wavelength}}$

Thus, $n' = \dfrac{2\pi r}{\lambda} = \dfrac{2\pi r}{h/mv}$ $\left[\because \lambda = \dfrac{h}{mv}\right]$

$= \dfrac{2\pi}{h}(mvr) = \dfrac{2\pi}{h}\left(\dfrac{nh}{2\pi}\right) = n$ $\left[\because mvr = \dfrac{nh}{2\pi}\right]$

Hence the number of waves (n') made by an electron in an orbit is equal to principal quantum number (n)

Illustrating the concept :

Find out the number of waves made by a Bohr electron in one complete revolution in its 3rd orbit.

Using the above result, the number of waves made by the electron in 3rd Bohr orbit is 3 (i.e. $n' = 3$).

Illustration - 13 *An electron is accelerated through a potential difference of V volts. Find the de Broglie wavelength associated with the electron.*

SOLUTION :

When the electron is accelerated through a potential difference of V volts, it acquires a kinetic energy given by E = qV, where q is the charge on the electron. Also, if *m* be its mass and v be the velocity then, $E = \frac{1}{2}mv^2$

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

And de Broglie wavelength $(\lambda) = \frac{h}{mv} = \frac{h}{\sqrt{2Em}}$

Note : The above result can be used directly, whenever required.

In the given case, $E = qV \quad \Rightarrow \quad \lambda = \frac{h}{\sqrt{2(qV)m}}$

Illustration - 14 *Calculate the uncertainty in position assuming uncertainty in momentum within* 0.1 % *for :*

(a) *a tennis ball weighing* 0.2 *kg and moving with a velocity of* 10 *m/s.*

(b) *a electron moving in an atom with a velocity of* 2×10^6 *m/s.*

SOLUTION :

Using Uncertainty Principle,

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

(a) $p = mv = 0.2 \times 10 = 2.0$ Kg m/s

$\Delta p = 0.1\%$ of $p = 2 \times 10^{-3}$

$$\Rightarrow \quad \Delta x = \frac{h}{4\pi\Delta p} = \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 2 \times 10^{-3}}$$

$$= 2.63 \times 10^{-32} \text{ m.}$$

(b) For an electron, p = m v

$$p = 9.1 \times 10^{-31} \times (2 \times 10^6)$$

$$= 1.82 \quad 10^{-24} \text{ Kg m/s}$$

$$\Delta p = 0.1 \text{ \% of } p = 1.82 \times 10^{-27} \text{ Kg m/s}$$

$$\Delta x = \frac{h}{4\pi\Delta p} = \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 1.82 \times 10^{-27}}$$

$$\Rightarrow \quad \Delta x = 2.89 \times 10^{-8} \text{ m}$$

Note : This shows that for sub-atomic (microscopic) particles, Heisenberg's Principle is highly meaningful, as Δx is greater than their atomic radius.