Dual Nature

Particle Nature of Light

(i) In interaction of radiation with matter, radiation **behaves** as if it is made up of particles called **photons**.

(ii) Each photon has energy E (=hν) and momentum p (= h ν /c), and speed c, the speed of light.

(iii) All **photons** of light of a particular frequency ν , or wavelength λ, have the **same** energy E ($=h\nu = hc/\lambda$) and **momentum** p ($= h\nu /c = h/\lambda$), whatever the **intensity** of radiation may be.

By increasing the **intensity** of light of given wavelength, there is only an **increase** in the **number** of photons per second crossing a given area, with each photon having the **same** energy. Thus, photon **energy** is **independent** of **intensity** of radiation.

(iv) Photons are electrically **neutral** and are **not deflected** by **electric** and **magnetic** fields.

(v) In a **photon-particle** collision (such as photon-electron collision), the total energy and total momentum are **conserved**. However, the **number** of photons **may not** be **conserved** in a collision.

The photon may be **absorbed** or a new photon may be **created**.

Wave Nature of Matter

The dual (**wave-particle**) nature of light (electromagnetic radiation, in general) comes out clearly from what we have learnt in this and the preceding chapters. The **wave** nature of light shows up in the phenomena of **interference**, **diffraction** and **polarisation**.

On the other hand, in **photoelectric** effect and **Compton** effect which **involve energy** and **momentum** transfer , **radiation behaves** as if it is made up of a bunch of particles – the photons

De Broglie Hypotheses

De Broglie proposed that the wave length λ associated with a particle of momentum p is given as

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

where m is the mass of the particle and v its speed. Equation is known as the de Broglie relation and the wavelength λ of the matter wave is called de Broglie wavelength. The dual aspect of matter is evident in the de Broglie relation.

For a photon, as we have seen,

$$p = h\nu / c$$

Therefore,

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

That is, the de Broglie wavelength of a photon equals the wavelength of electromagnetic radiation of which the photon is a quantum of energy and momentum

Consider an electron (mass m, charge e) accelerated from rest through a potential V. The kinetic energy K of the electron equals the work done (eV) on it by the electric field:

$$K = e\,V$$

Now, $K = \frac{1}{2} m v^2 = \frac{p^2}{2m}$, so that

$$p = \sqrt{2\,m\,K} = \sqrt{2\,m\,eV}$$

The de Broglie wavelength λ of the electron is then

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,mK}} = \frac{h}{\sqrt{2\,meV}}$$

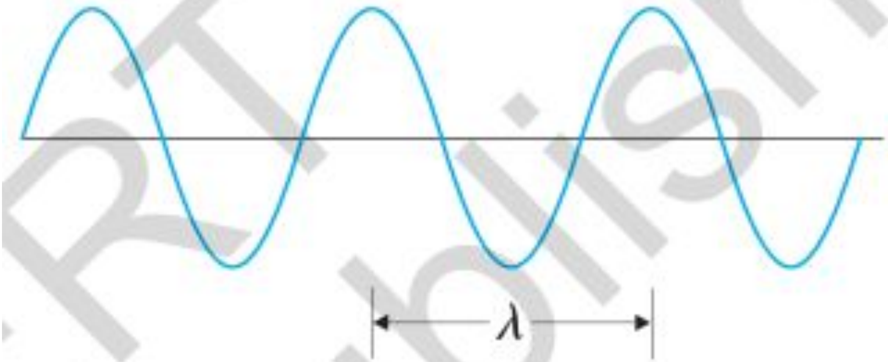
Substituting the numerical values of h, m, e, we get

$$\lambda = \frac{1.227}{\sqrt{V}}\ \text{nm}$$

The matter–wave picture elegantly incorporated the Heisenberg's uncertainty principle. According to the principle, it is not possible to measure both the position and momentum of an electron (or any other particle) at the same time exactly. There is always some uncertainty (Δx) in the specification of position and some uncertainty (Δp) in the specification of momentum. The product of Δx and Δp is of the order of ħ

$$\Delta \mathbf{x} * \Delta \mathbf{p} \approx \hbar$$

(a)

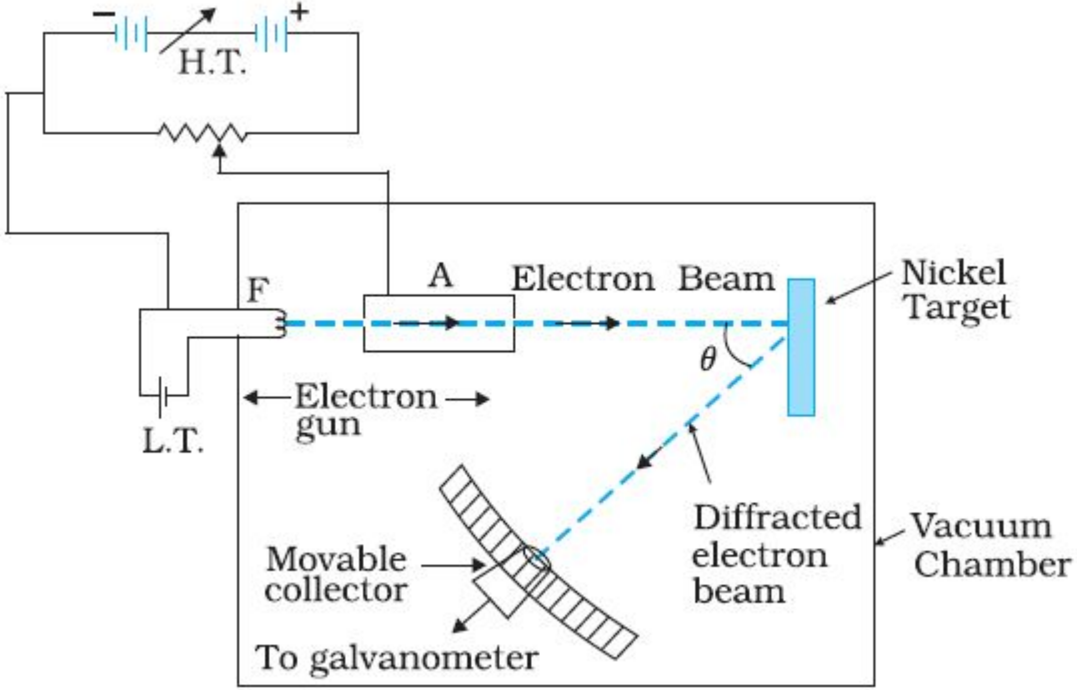


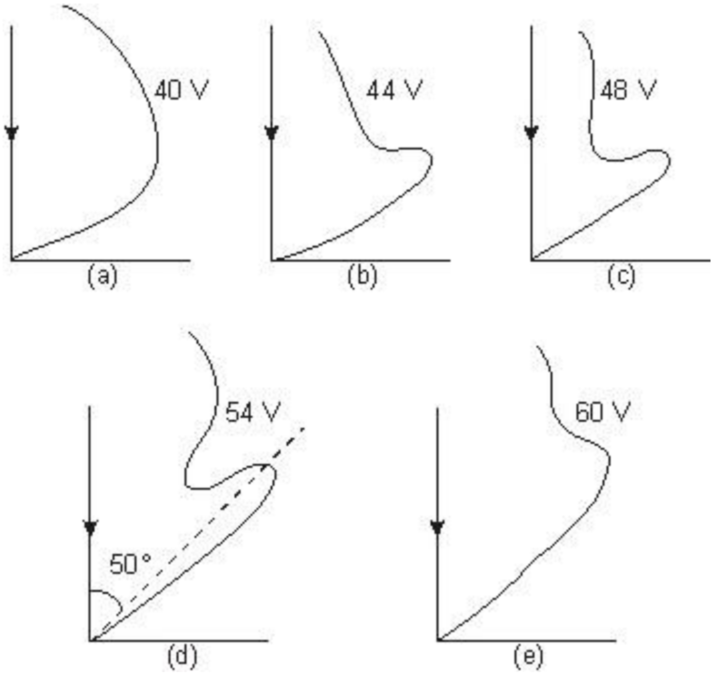
Now, if an electron has a definite momentum p, (i.e.$\Delta p = 0$), by the de Broglie relation, it has a definite wavelength λ. A wave of definite (single) wavelength extends all over space

In general, the matter wave associated with the electron is not extended all over space. It is a wave packet extending over some finite region of space. In that case Δx is not infinite but has some finite value depending on the extension of the wave packet.

Also, you must appreciate that a wave packet of finite extension does not have a single wavelength. It is built up of wavelengths spread around some central wavelength.

DAVISSON AND GERMER EXPERIMENT




40 V
44 V
48 V
(a)
(b)
(c)
54 V
60 V
50°
(d)
(e)