DUAL NATURE OF MATTER AND RADIATION part 2

INSTRUCTIONS

1 This is part 2 of a short and interesting chapter which consists of the following topics as per CBSE syllabus

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Matter waves-wave nature of particles, de-Broglie relation, Davisson-Germer experiment (experimental details should be omitted; only conclusion should be explained)

This section covers

Particle nature of light Matter waves-wave nature of particles, de-Broglie relation, Davisson-Germer experiment (experimental details should be omitted; only conclusion should be explained)

2 It has small weightage of about 3-4 marks (for whole chapter) in the CBSE examination.

3 To fully prepare this chapter , you can practice previous year question papers of CBSE given along here.

Main points of the chapter

PARTICLE NATURE OF LIGHT: THE PHOTON

Photoelectric effect thus gave evidence to the strange fact that light in interaction with matter behaved as if it was made of quanta or packets of energy, each of energy hv.

Einstein arrived at the important result, that the light quantum can also be associated with momentum (h v/c). A definite value of energy as well as momentum is a strong sign that the light quantum can be associated with a particle. This particle was later named photon.

The particle-like behaviour of light was further confirmed, in 1924, by the experiment of A.H. Compton (1892-1962) on scattering of X-rays from electrons.

In 1921, Einstein was awarded the Nobel Prize in Physics for his contribution to theoretical physics and the photoelectric effect.

In 1923, Millikan was awarded the Nobel Prize in physics for his work on the elementary charge of electricity and on the photoelectric effect.

We can summarise the photon picture of electromagnetic radiation as follows:

(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 n, or wavelength l, have the same energy E =hν = hc/λ and momentum p =h/λ 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

In 1924, the French physicist Louis Victor de Broglie (pronounced as de Broy) (1892-1987) put forward the bold hypothesis that moving particles of matter should display wave-like properties under suitable conditions. ***He reasoned that nature was symmetrical and that the two basic physical entities – matter and energy, must have symmetrical character. If radiation shows dual aspects, so should matter.***

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

$\lambda = h/p$ ***where*** $p = mv$

where m is the mass of the particle and v its speed. This 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. On the left hand side of ,λ is the attribute of a wave while on the right hand side the momentum p is a typical attribute of a particle. Planck's constant h relates the two attributes.

Equation $\lambda = h/p$ *for a material particle is basically a hypothesis whose validity can be tested only by experiment. However, it is interesting to see that it is satisfied also by a photon. For a photon, as we have seen,*

$p = h\nu/c$

Therefore,

$h/p = c/\nu = \lambda$

That is, the de Broglie wavelength of a photon .

DEBROGLIE WAVELENGTH OF AN ACCELERATED ELECTRON

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=eV

K=p²/2m

So $\boldsymbol{\lambda = \frac{h}{p}}$ ***or***

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

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

solving the values of m ,e ,h this equation can be modified to

$$\lambda = \frac{1.22\ nm}{\sqrt{V}}$$

Where nm is nano meter and 1 nm= $\boldsymbol{10^{-9}m}$

$$\lambda = \frac{12.27\ A}{\sqrt{V}}$$

$$1\ \dot{A} = 10^{-10}m$$

Where Ȧ is Angstorm

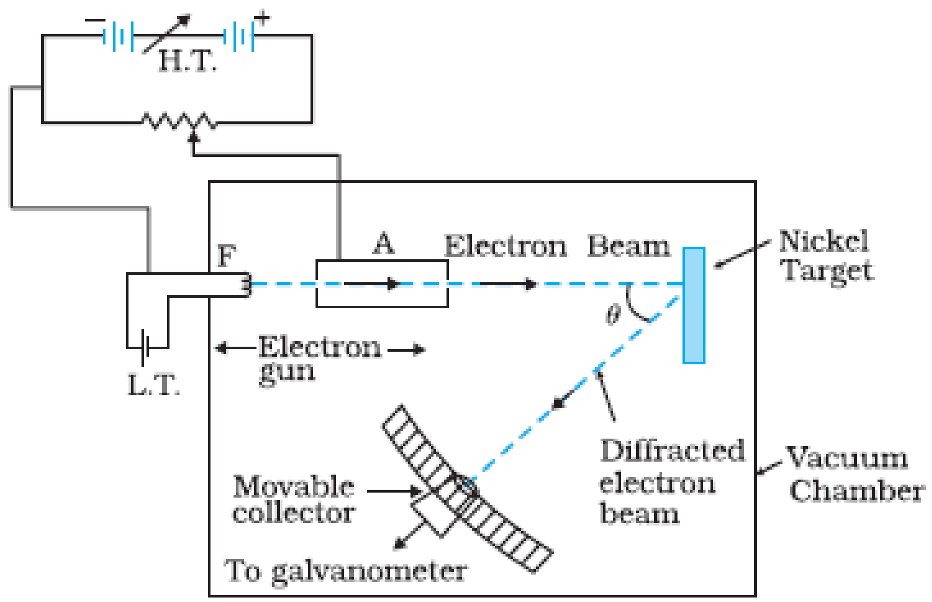
where *V* is the magnitude of accelerating potential in volts. For a 120 V accelerating potential, gives wavelength = 0.112 nm. This wavelength is of the same order as the spacing between the atomic planes in crystals.

This suggests that matter waves associated with an electron could be verified by crystal diffraction experiments analogous to X-ray diffraction.

In 1929, de Broglie was awarded the Nobel Prize in Physics for his discovery of the wave nature of electrons.

DAVISSON AND GERMER EXPERIMENT (experimental details not in syllabus, only broad idea of the topic to be read)

Wave nature of electrons was first experimentally verified by C.J.Davisson and L.H .Germer.



The experimental setup consists of an electron gun, which comprises of a tungsten filament coated with barium oxide and heated by a low-tension battery.

Electrons emitted by this filament are accelerated to a desired velocity by potential of High-Tension battery. They are collimated to a fine beam by allowing them to pass through a cylinder with fine holes along its axis.

The fine collimated beam is made to fall on the surface of a nickel crystal.

An electron detector (collector) measures the intensity of the electron beam, scattered in a given direction. The detector can be rotated on a *circular scale and is connected to a sensitive galvanometer for recording current.*

Deflection of galvanometer is proportional to the intensity of the electron beam entering the collector.

By rotating the detector in various directions, intensity of scattered beam is measured for different values of angle of scattering θ, which is the angle between incident and scattered directions of beam.

The variation of angle of scattering θ was obtained for different accelerating voltages.

Graphs show when accelerating voltage ranged from 44V to 68V, there is a sharp peak corresponding to a sharp diffraction maximum in the electron distribution at an accelerating voltage of 54V and scattering angle $\theta=50°$.

The appearance of the peak in a particular direction is due to constructive interference of electrons scattered from different layers the regularly spaced atoms of the crystals. From electron diffraction measurements, the wavelength of matter waves was found to be 0.165nm.

The de Broglie wavelength associated with electron for V=54V is
$\lambda=h/p$

Or $\lambda=1.227nm/\ 54\ V$ *==0.166nm which gives a close matching between the theoretically and experimentally obtained values. Davisson Germer experiment thus strikingly confirms the wave nature of electrons and the de Broglie relation.*

Video links

https://www.youtube.com/watch?v=Ho7K27B_Uu8

https://www.youtube.com/watch?v=caVIh3RZOA4

ASSIGNMENT (questions from previous year CBSE papers)

1What is the de Broglie wavelength of a 3 kg object moving with a speed of 2m/s?

2A photon and an electron have energy 200 eV each. Which one of these has greater deBroglie wavelength?

3 Find the ratio of deBroglie wavelengths associated with two electrons 'A' and 'B' which are accelerated through 8V and 64 volts respectively.

4 Xrays of wave length λ fall on a photo sensitive surface emitting electrons. Assuming that the work function of the surface can be neglected, find an expression for deBroglie wavelength of electrons emitted

5 A particle of mass M at rest decays into two particles of masses m_1 and m_2 having velocities V_1 and V_2 respectively. Find the ratio of debroglie Wavelengths of the two particles.

6 A proton is accelerated through a potential difference V. Find the percentage increase or decrease in its deBroglie wavelength if potential difference is increased by 21%

7 The de-broglie wave length of a photon is same as the wave length of electron. Show that K.E. of a photon is $2mc\lambda/h$ times K.E. of electron. Where 'm' is mass of electron,c is velocity of light.

8 An electron and alpha particle and proton have same kinetic energy , which have shortest De-broglie wavelength?

9 If the potential difference used to accelerate electron is doubled , by what factor the Debroglie wave length of the electron beam changed.

10 The De-broglie wave length associated with an electron accelerated through the potential difference "V" is λ. What will be its wave length , when accelerating potential is increased to 4v?

11 A nucleus of mass M initially at rest splits in two fragments of masses M/3 & 2M/3. Find the ratio of de-Broglie's wavelength of two fragments.

12 An a-particle and proton are accelerated from rest through same PD 'V'.Find the ratio of de-Broglie wavelength associated with them.

13 Calculate the (i) momentum and (ii) de- Broglie wavelength of electron accelerated through a potential difference of 56 V.