ATOMIC PHYSICS

4.C0MPTON EFFECT NAD MATTEER WAVES

POINTS TO REMEMBER

1. **Compton Effect (A.H.Compton)**
   a. This provides a supports the quantum nature of light.
   b. The change in the wavelength or frequency of X-rays when scattered by a free electron is called Compton Effect.When X-rays of certain frequency are incident on substances like carbon or paraffin a change in the frequency or wavelength occurs.
   c. In the scattered X-rays there are two components.The component which has no change in its wavelength. This is called coherent component. The component which has more wavelength than that of incident X-rays. This is called incoherent component.
   d. The increase in the wavelength or Compton shift is given by

   $\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 C}(1-\cos\theta)$ Where θ = scattering angle and m_0 = rest mass of electron.
   e. Compton shift is independent of the material that scatters the photons
   f. The compton shift depends only on the scattering angle but not on the original wavelength of X-rays.
   g. The value of $\frac{h}{m_0 c}$ = 0.0243Å is called Compton wavelength.
   h. The collision of X-rays with the free e^-s is an elastic collision.
2. **Matter Waves (or) deBroglie Waves**
   a. deBroglie suggested that the matter should possess dual nature as electromagnetic waves.The waves associated with particles (electrons protons, neutrons etc) are called matter waves or de Broglie waves. $\lambda = \frac{h}{mc}$ Where h = Planck's constant.
   b. The ratio between the planck's constant and the momentum of the particle is called de Broglie wavelength. $\lambda = \frac{h}{p} = \frac{h}{mv}$ Where v = velocity of the particle.
   c. de Broglie wavelength $\lambda = \frac{h}{\sqrt{2eVm}}$ or $\lambda = \frac{h}{\sqrt{2mE}}$ where E is energy of the particle.

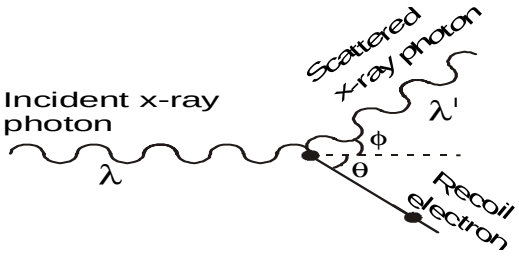
SHORT ANSWER QUESTIONS

1. What is Compton Effect? Explain.

A: The change in the wavelength or frequency of X-rays when scattered by a free electron is called Compton Effect. When X-rays of certain frequency are incident on

substances like carbon or paraffin a change in the frequency or wavelength occurs. In the scattered X-rays there are two components. The component which has no change in its wavelength. This is called coherent component. This is called coherent scattering or Thomson scattering. The component which has more wavelength than that of incident X-rays. This is called incoherent component. This is called incoherent scattering. The increase in the wavelength or Compton shift is given by

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 C}(1-\cos\theta)$$



Or $\Delta\lambda = 0.0243(1-\cos\theta)$ (in Å)

$= 2.43 \times 10^{-12}(1 - \cos\theta)$ (in m)

$\Delta\lambda = 0.0486 \sin^2(\theta/2)$

Where θ = scattering angle

Compton shift is independent of the material that scatters the photons The compton shift depends only on the scattering angle but not on the original wavelength of X-rays. The value of $\frac{h}{m_0 c}$ = 0.0243Å is called Compton wavelength. The collision of X-rays with the free electrons is an elastic collision.

2. Write briefly the de-Broglie's hypothesis.

A: deBroglie suggested that the matter should possess dual nature as electromagnetic waves. The waves associated with particles (electrons protons, neutrons etc) are called matter waves or de Broglie waves. Energy of a photon is given by

$$E = h\nu = \frac{hc}{\lambda}$$

Consider the photon as a particle of mass m moving with a velocity c, the energy associated with it is given by

$E = mc^2$

$\therefore mc^2 = \frac{hc}{\lambda} \quad \Rightarrow mc = \frac{h}{\lambda} \quad \Rightarrow \lambda = \frac{h}{mc}$ Where h = Planck's constant.

The ratio between the planck's constant and the momentum of the particle is called de Broglie wavelength.

$\lambda = \frac{h}{p} = \frac{h}{mv}$ Where v = velocity of the particle.

1. de-Broglie wavelength is inversely proportional to mass of the particle. So for lighter bodies λ is more and for heavier bodies λ is very less.

2. de-Broglie wavelength is inversely proportional to velocity of the body, when $\upsilon = 0$ then $\lambda = \infty$. So matter waves are produced due to motion of the body.

3. These matter waves are not electromagnetic waves.

VERY SHORT ANSWER QUESTIONS

1. What is Compton effect?

Sol: When X-rays are scattered by substances containing free electrons, then scattered X-rays suffer a change in their wave length.

Compton shift $\Delta\lambda = \frac{h}{m.c}(1-\cos\phi)$ where ϕ is known as angle of scattering. This effect is known as Compton effect. $\Delta\lambda$ is called Compton shift.

2. If a proton and an electron have same de-Broglie wave length which has more momentum and kinetic energy.

A: From de-Broglie's principle $\lambda = \frac{h}{m\upsilon}$. When wavelength λ is same the both proton and electron will have same momentum. But $K.E = \frac{p^2}{2m}$. So electron will have more kinetic energy $\because K.E.\alpha\frac{1}{m}$

3. Is photon a wave or a particle? What is its rest mass?

A: Photon is a particle of energy. Photons will have mass only when they are in motion. So rest of mass photon is zero.

4. What are de-Broglie's waves?

A: From de-Broglie's hypothesis, every moving particle will have some wave associated with it. They are called matter waves or De-Broglie's waves.

De-Broglie's wave length, $\lambda = \frac{h}{m\upsilon} or \lambda = \frac{h}{p}$

5. What is the equation of wave length associated with a moving particle?

A: Wavelength $\lambda = \frac{h}{m\upsilon} = \frac{h}{p}$

SOLVED PROBLEMS

1. Calculate the wavelength of the incident radiation when it undergoes Compton scattering at an angle of 60^0 by graphite and the wavelength of the scattered radiation is $2.54\times10^{-11}\,m$.

Sol: $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\Phi)$

But $\frac{h}{m_0 c} = 0.0244\ \overset{0}{A},\ \Phi = 60^0$

$\therefore \Delta\lambda = 0.0244\,\overset{0}{A}\left(\frac{1}{2}\right) = 0.012\,\overset{0}{A}$

But $\lambda = \lambda' - \Delta\lambda$. Here $\lambda' = 2.54\times10^{-11}\ m = 0.254\,A^0$

$\lambda = 0.254 - 0.012\ = 0.242\,A^0 = 2.42\times10^{-11}\,m$.

2. Electrons are accelerated through a potential difference of 150V. Calculate the de Broglie wavelength.(($h = 6.62\times10^{-34}\ Js$, $m = 9.1\times10^{-31} kg$, $e = 1.6\times10^{-17} C$)

Sol: V = 150V; $h = 6.62\times10^{-34}\ Js$, $m = 9.1\times10^{-31}\,kg$, $e = 1.6\times10^{-19} C$

$$\therefore \lambda = \frac{h}{\sqrt{2Vem}} = \frac{6.62\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times150}} = 1A^0$$

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{2500\times10^{-10}} = 3$$

3. A radiation of wavelength $2500A^0$ is incident on a metal plate whose work function is 3.5 eV. Calculate the potential required to stop the fastest photo electrons emitted by the surface ($h = 6.63\times10^{-34}\ Js$, $c = 3\times10^{8}\ ms^{-1}$)

Sol: $\lambda = 2500A^0 = 2500\times10^{-10}\,m$, $h = 6.63\times10^{-34}\ Js$, $c = 3\times10^{8}\ ms^{-1}$.

The energy of the incident radiation $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{2500\times10^{-10}} = 8\times10^{-19}$ J

Work function $(W_0) = 3.5eV = 3.5\times1.6\times10^{-19}\ J = 3.5\times10^{-19} J$.

K_{max} of the photo electrons = $h\nu - W_0 = 8.0\times10^{-19} - 5.6\times10^{-19}\ J$

If V_0 is the stopping potential then

$$eV_0 = K_{max} \qquad \Rightarrow \quad \therefore V_0 = \frac{K_{max}}{e} = \frac{2.4\times10^{-19}}{1.6\times10^{-19}} = 1.50V$$

UNSOLVED PROBLEMS

1. A photon collides with an electron and gets scattered through an angle of 90^0. The electron recoils and moves in another direction. Calculate the Compton shift. ($h = 6.62\times10^{-34}\ Js$).

Sol: $\theta = 90^0$; $h = 6.62\times10^{-34} Js$

Compton Shift $\Delta\lambda = \frac{h}{m_0 c}(1-\cos\phi) = \frac{h}{m_0 c}(\therefore \theta = 90^0)$

m_0 = rest mass of electron $= 9.11\times10^{-31} kg$

$\therefore \Delta\lambda = \frac{6.62\times10^{-34}}{9.11\times10^{-31}\times3\times10^{8}} = 0.243\times10^{-11} m$

2. Find the momentum of an electron having wavelength. $2A^0 (h = 6.62\times10^{-34} Js)$

Sol: Wavelength of electron = $\lambda = 2A^0 = 2\times10^{-10} m$

Momentum of electron = P = $\frac{h}{\lambda} = \frac{6.62\times10^{-34}}{2\times10^{-10}} = 3.31\times10^{-24} Kgms^{-1}$

3. Calculate the wavelength of de-Broglie waves associated with a beam of protons of kinetic energy $5\times10^2 eV$ **.(Mass of each proton=** $= 1.67\times10^{-27} kg$**),(** $h = 6.64\times10^{-34} Js$**).**

Sol: K.E. of proton $= 5\times10^2 eV = 500\times1.6\times10^{-19} J$

$m_p = 1.67\times10^{-27} kg$; $h = 6.64kt10^{-34} J - \sec$

De-Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_p.K.E}}$

$\lambda = \frac{6.64\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times500\times1.6\times10^{-19}}} = 1.28\times10^{-11}\ m$

4. Find the de-Broglie wavelength of an electron moving with a velocity of 0.8c where c is velocity of light in vacuum. $(c = 3\times10^8 ms^{-1}, h = 6.63\times10^{-34} Js)$

Sol: Mass of the electron $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ Where m_0 is the rest mass of the electron

$m_0 = 9.1\times10^{-31} kg$; $v = 0.8c$; $c = 3\times10^8 m/s$

$m = \frac{9.1\times10^{-31}}{\sqrt{1-\left(\frac{0.8c}{c}\right)^2}} = \frac{9.1\times10^{-31}}{\sqrt{1-0.64}} = \frac{91}{6}\times10^{-31} kg$

Then de Broglie wave length of the electron is given by

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}}{\frac{91}{6}\times10^{-31}\times0.8\times3\times10^{8}}$$

$$\therefore \lambda = 1.821\times10^{-12}\ m$$

ASSESS YOURSELF

1. Compton effect is observable with X-rays and γ-rays where as it is not observed with the ultraviolet light, visible light etc. why?

A. Compton effect is observed only with high energetic X-rays and γ-rays.

2. Is the de-Broglie wavelength of a photon of an electromagnetic radiation equal to the wavelength of the radiation?

A. Yes.

3. Why is the wave nature of matter not apparent in our daily observation?

A. Since wave length is very small compared with the size of the particle , the wave nature of matter is not apparent.