Studybeesofficial

Where Minds Pollinate

Class 12
Physics

Chapter 21

Exercise Solution

Q1. Prove that energy and momentum of photon are directly proportional to each other.

The energy of a photon is given by E = hf

and its momentum is P= hf / c

By dividing both equations, E = pc

This shows that the energy of a photon is directly proportional to its momentum, as both depend on frequency **v**.

Hence, **E ∝ P.**

Q2. Convert 800 MeV into joules.

$$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$$

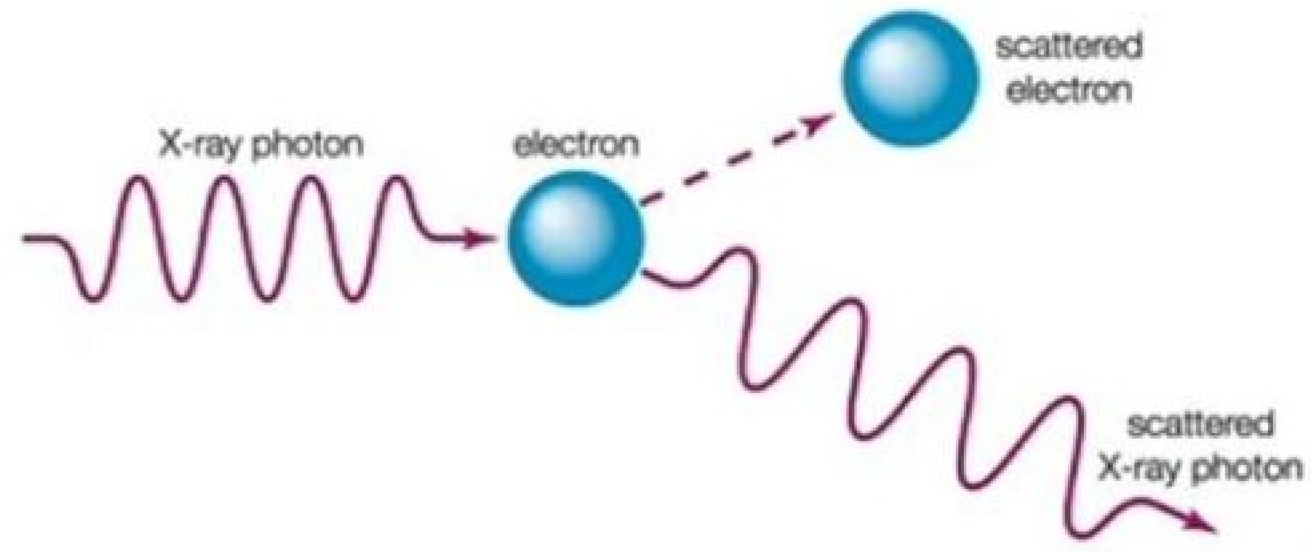
So,

$$800\ \text{MeV} = 800 \times 10^{6} \times 1.6 \times 10^{-19}\ \text{J}$$

$$E = 1.28 \times 10^{-10}\ \text{J}$$

Hence, 800 MeV = **1.28×10^{-10}** J

Q3. Write the two phenomena to describe photon–electron interaction.



Two important photon–electron interaction phenomena are:

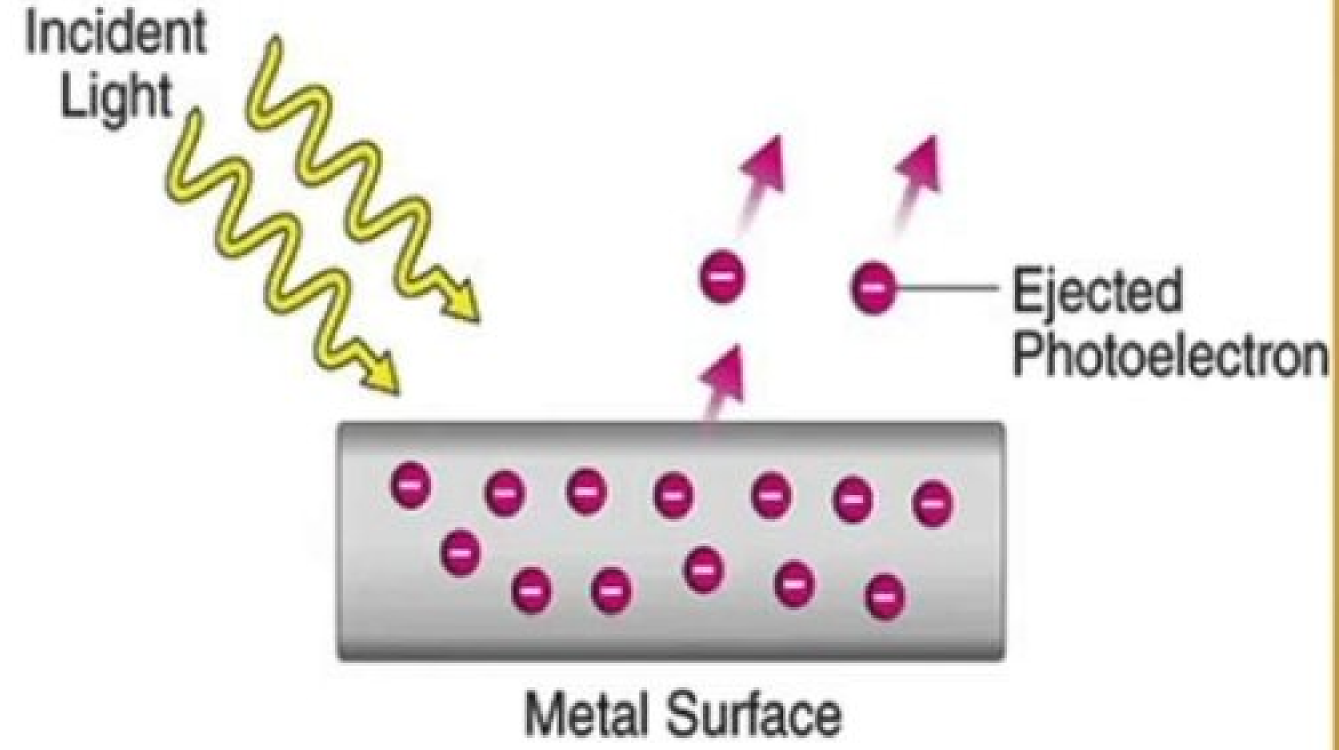
Photoelectric effect:

where photons eject electrons from a metal surface.

Compton effect:

where photons collide with electrons and scatter with reduced energy.

Both effects confirm the particle nature of light.



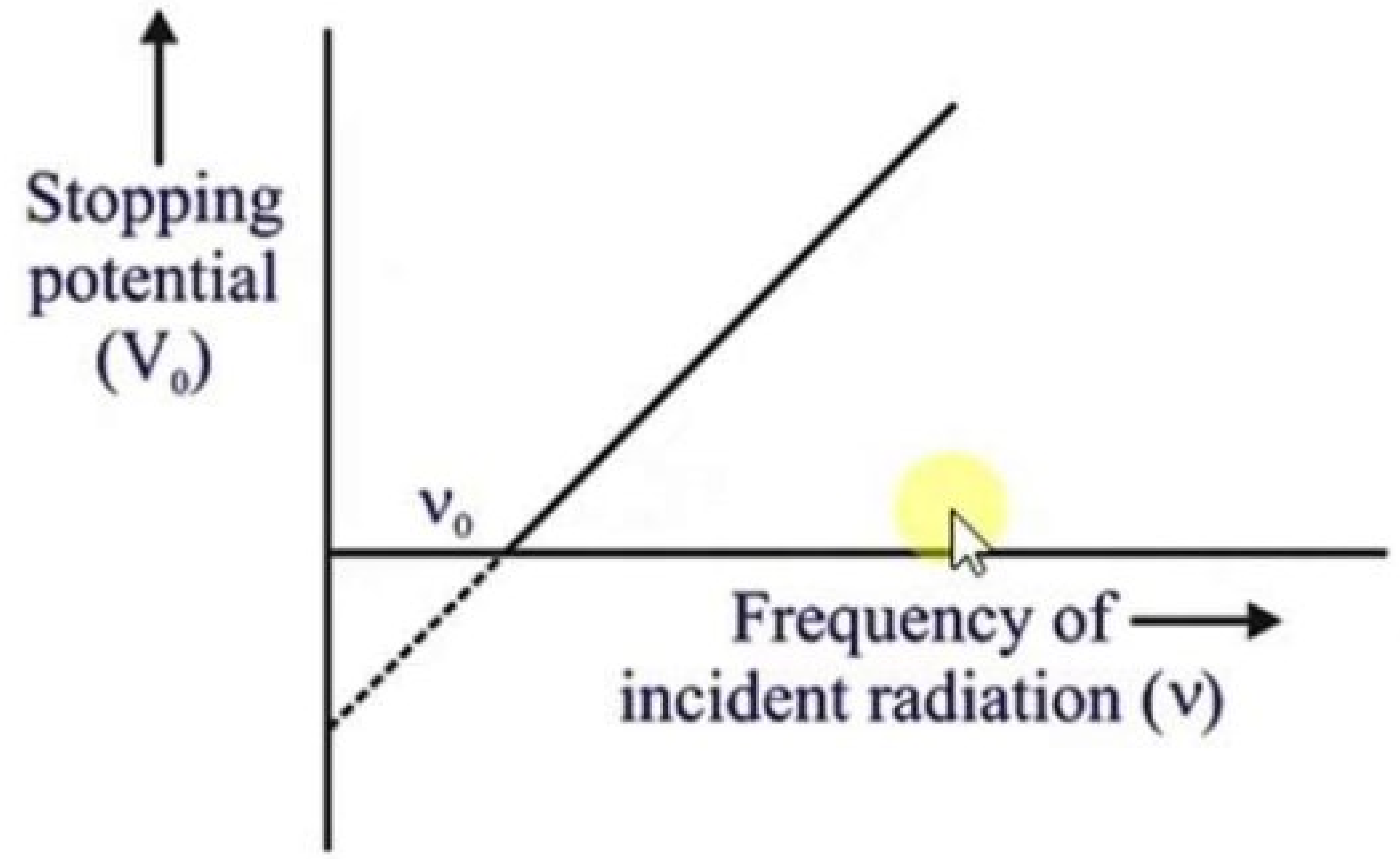
Q4. In the interpretation of the photoelectric effect, how is it known that an electron does not absorb more than one photon?

Each emitted electron has a definite kinetic energy depending only on the frequency of the incident light, not on its intensity.

If an electron absorbed multiple photons, the energy would vary continuously with intensity.

Hence, experiments show that one electron absorbs only one photon at a time.

Q5. How can you determine the work function from a plot of the stopping potential versus frequency of the incident radiation in a photoelectric effect experiment? Can you determine the value of Planck's constant from this plot?



The photoelectric equation is $eV_0 = h\nu - \phi$.

When a graph is drawn between V_0 and ν, it gives a straight line.

The **slope** of the line equals $\frac{h}{e}$, giving **Planck's constant**, and the **intercept** on the the frequency axis gives the **work function** $\phi = h\nu_0$.

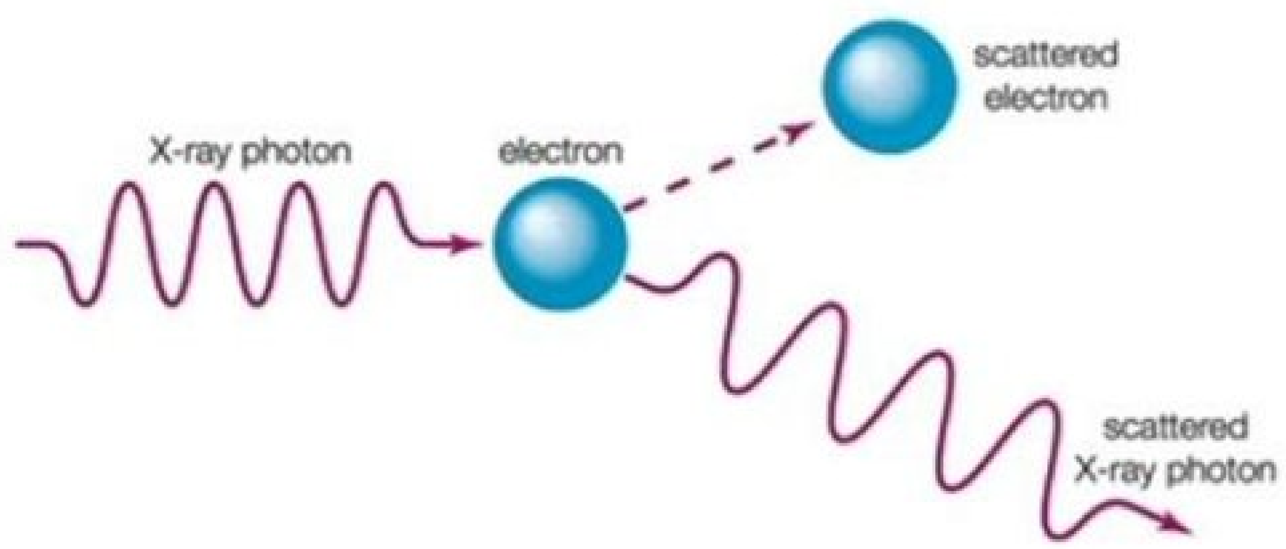
Q6. Speculate how increasing the temperature of a photoelectrode affects the outcomes of the photoelectric effect experiment.

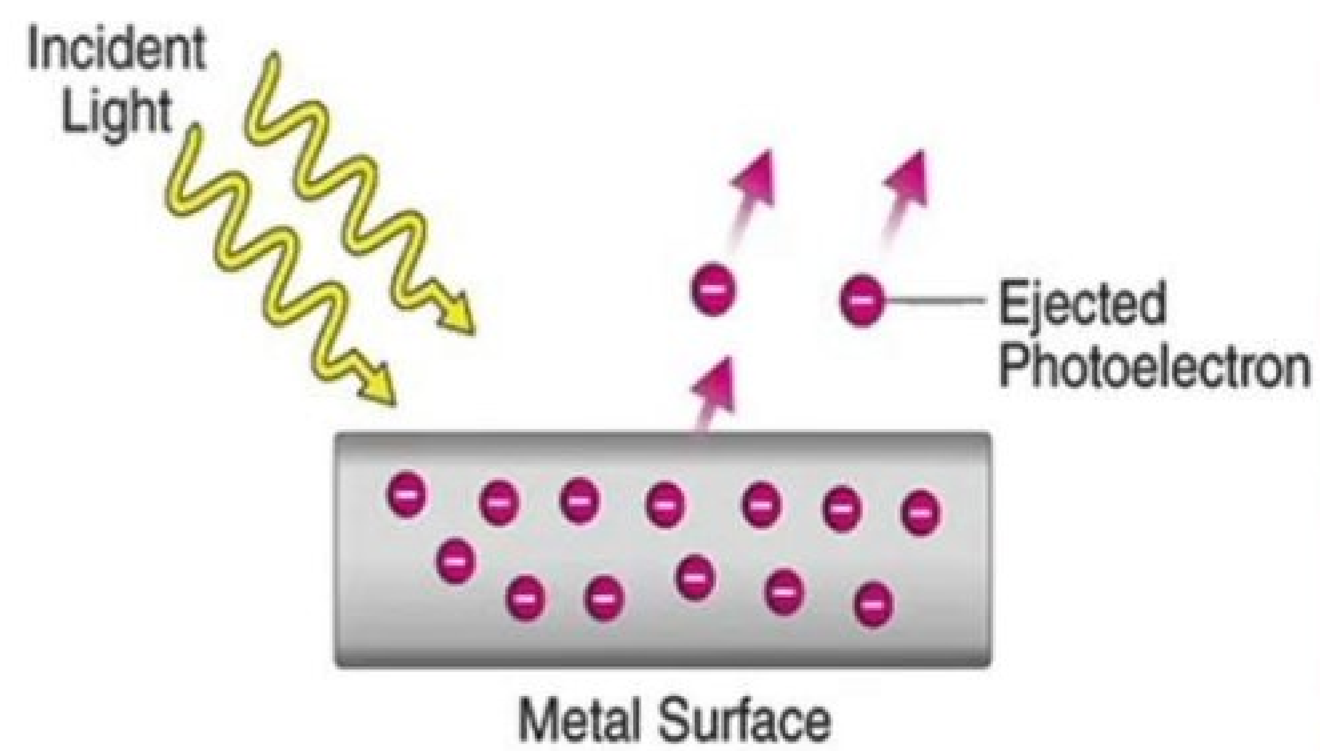
An increase in temperature gives extra thermal energy to electrons, helping some electrons escape more easily. This slightly increases the number of emitted electrons but does **not** change the maximum kinetic energy, which depends only on light frequency.

Hence, temperature affects **current**, not **stopping potential**.

Q7. Which aspects of the photoelectric effect cannot be explained by classical physics?

Classical wave theory predicted that photoelectric emission should depend on light intensity and have a time delay. However, experiments show that emission occurs instantly and depends on **frequency**, not intensity. Also, there exists a **threshold frequency** below which no electrons are emitted — unexplained by classical physics.





Q8. What is the physical significance of Compton's effect?

Compton's effect shows that light behaves as particles (photons) that carry momentum and collide with electrons. The scattering of X-rays with increased wavelength proves energy and momentum transfer like in elastic collisions.

Hence, it provides strong evidence for the **particle nature of electromagnetic radiation**.

Q9. Differentiate between Compton's shift and Compton's wavelength.

Compton's shift ($\Delta\lambda$) is the change in wavelength of a photon after scattering:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta).$$

Compton's wavelength ($\lambda_a = h / m_e c$) is the constant representing the maximum possible shift when $\theta = 180°$

Thus, Compton's wavelength is a fixed value; Compton's shift depends on the scattering angle.

Q10. How can you say that scattering angle of photon plays effective role in measurement of Compton's shift?

The Compton shift formula shows

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

As θ increases, $(1 - \cos\theta)$ increases, so **$\Delta\lambda$** increases. Maximum shift occurs at **$\theta = 180°$.**

Hence, the scattering angle directly controls how much the wavelength changes after collision.

Q11. What are the conditions required for pair production to occur?

Pair production occurs when a high-energy photon (at least 1.02 MeV) passes near a nucleus.

Its energy converts into an **electron and a positron** pair. Thus, the photon energy must be greater than or equal to $\mathbf{2m_ec^2}$, and a nucleus is required to conserve momentum.

Q12. What is meant by de Broglie wavelength?

According to de Broglie, all moving particles have wave nature associated with them.

The wavelength is given by $\lambda = \frac{h}{p}$, where p is momentum.

This concept links wave and particle behavior and forms the basis of **quantum mechanics**.

Q13. Which phenomenon provides evidence for particulate nature of electromagnetic radiation?

The **photoelectric effect** provides clear evidence for the particle nature of light.

It shows that energy is transferred in discrete packets called **photons**, each with energy $E = hv$

Only photons above a certain frequency can eject electrons, confirming that light acts as particles.

In an experiment, the work function of potassium surface is **2.1 eV**.

If the stopping potential for the emitted electron is **0.43 V**, find the **wavelength of incident radiation**.

Given data:

Work function, $\phi = 2.1\ \mathrm{eV}$

Stopping potential, $V_0 = 0.43\ \mathrm{V}$

Charge of electron, $e = 1.6 \times 10^{-19}\ \mathrm{C}$

Planck's constant, $h = 6.63 \times 10^{-34}$

Speed of light, $c = 3 \times 10^8\ \mathrm{m/s}$

$$hc = 1240\,\mathrm{eV}$$

To find:

Wavelength of light $\lambda = ?$

Formula:

From photoelectric equation,

$$\frac{hc}{\lambda} = \phi + eV_0$$

Solution:

$$\frac{hc}{\lambda} = \phi + eV_0$$

$$\lambda = \frac{hc}{\phi + eV_0}$$

$$\lambda = \frac{1240}{2.1 + 0.43}$$

$$\lambda = \frac{1240}{2.53}$$

$$\lambda = 490.1\,\mathrm{nm}$$

Light of wavelength $5000\ \text{Å}$ falls on a metal surface with work function $1.9\ \text{eV}$.

Find

(a) Energy of photon (b) Kinetic energy of emitted electrons (c) Stopping potential.

Given data:

$\lambda = 5000\ \text{Å} = 5 \times 10^{-7}\ \text{m}$

$\phi = 1.9\ \text{eV}$

$h = 6.63 \times 10^{-34}$

$c = 3 \times 10^{8}\ \text{m/s}$

$e = 1.6 \times 10^{-19}\ \text{C}$

Formula:

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

$$K.E. = E - \phi$$

$$V_0 = \frac{K.E.}{e}$$

Solution:

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5 \times 10^{-7}} = 3.978 \times 10^{-19}\ \text{J}$$

$$E = \frac{3.978 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.48\ \text{eV}$$

$$K.E. = 2.48 - 1.9 = 0.58\ \text{eV}$$

$$V_0 = 0.58\ \text{V}$$

Find photon energy for:

(i) violet light of 413 nm

(ii) X-rays of 0.1 nm

(iii) radio waves of 1 m.

Given data:

$h = 6.63 \times 10^{-34}$

$c = 3 \times 10^{8}\ \mathrm{m/s}$

Formula:

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

Solution:

(i) For violet light, $\lambda = 413 \times 10^{-9}$:

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4.13 \times 10^{-7}} = 4.81 \times 10^{-19}\ \mathrm{J}$$

$$E = 3\ \mathrm{eV}$$

(ii) For X-rays, $\lambda = 0.1 \times 10^{-9}$:

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1 \times 10^{-10}} = 1.99 \times 10^{-15}\ \mathrm{J}$$

$$E = 1.24 \times 10^{4}\ \mathrm{eV}$$

(iii) For radio waves, $\lambda = 1\ \mathrm{m}$:

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1} = 1.99 \times 10^{-25}\ \mathrm{J}$$

$$E = 1.24 \times 10^{-6}\ \mathrm{eV}$$

Calculate the **minimum energy required by a photon** to transfer **half of its energy** to an **electron at rest**.

Given Data:

$$E'_\gamma = \frac{E_\gamma}{2}$$

$$m_e c^2 = 0.511\,\mathrm{MeV}$$

$$\theta = 180^\circ$$

To Find: $E_\gamma = ?$

Formula:

From **Compton scattering equation:**

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$E = \frac{hc}{\lambda}, \quad E' = \frac{hc}{\lambda'}$$

$$\frac{1}{E'_\gamma} - \frac{1}{E_\gamma} = \frac{1 - \cos\theta}{m_e c^2}$$

Solution:

Substitute $E'_\gamma = \frac{E_\gamma}{2}$:

$$\frac{1}{E_\gamma/2} - \frac{1}{E_\gamma} = \frac{1 - \cos\theta}{m_e c^2}$$

$$\frac{2}{E_\gamma} - \frac{1}{E_\gamma} = \frac{1 - \cos\theta}{m_e c^2}$$

$$\frac{1}{E_\gamma} = \frac{1 - \cos\theta}{m_e c^2}$$

For **maximum transfer of energy,**

$\theta = 180^\circ \Rightarrow (1 - \cos\theta) = 2$

$$\frac{1}{E_\gamma} = \frac{2}{m_e c^2}$$

$$E_\gamma = \frac{m_e c^2}{2} = \frac{0.511}{2} = 0.255\,\mathrm{MeV}$$

An electron is in a box of atomic size $1\ \mathring{A}$. Find its velocity.

Given data:

$\lambda = 1 \times 10^{-10}\ \mathrm{m}$

$h = 6.63 \times 10^{-34}$

$m_e = 9.1 \times 10^{-31}\ \mathrm{kg}$

Formula:

$$p = \frac{h}{\lambda}, \quad v = \frac{p}{m}$$

Solution:

$$p = \frac{6.63 \times 10^{-34}}{1 \times 10^{-10}} = 6.63 \times 10^{-24}$$

$$v = \frac{6.63 \times 10^{-24}}{9.1 \times 10^{-31}} = 7.29 \times 10^{6}\ \mathrm{m/s}$$

A 50 keV X-ray is scattered through an angle of 90°. What is the energy of the X-ray after Compton scattering?

Given Data

- Incident X-ray energy, $E = 50\,\text{keV}$
- Scattering angle, $\theta = 90^\circ$
- Rest energy of electron, $m_e c^2 = 511\,\text{keV}$

To Find

Energy of scattered X-ray E'

Formula

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$E = \frac{hc}{\lambda}, \quad E' = \frac{hc}{\lambda'}$$

$$\frac{1}{E'} - \frac{1}{E} = \frac{1 - \cos\theta}{m_e c^2}$$

Solution:

$$\frac{1}{E'} = \frac{1}{E} + \frac{1 - \cos\theta}{m_e c^2}$$

At $\theta = 90^\circ$, $\cos 90^\circ = 0$

$$\frac{1}{E'} = \frac{1}{50} + \frac{1}{511}$$

$$\frac{1}{E'} = 0.02 + 0.001957 = 0.021957$$

$$E' = \frac{1}{0.021957} = 45.55\,\text{keV}$$