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Dual Nature of Radiation and Matter

TOPIC 1
Photoelectric Effect

01 Light of frequency 1.5 times the threshold frequency is incident on a photosensitive material. What will be the photoelectric current if the frequency is halved and intensity is doubled? **[NEET (Sep.) 2020]**

(a) Four times (b) One-fourth
(c) Zero (d) Doubled

Ans. *(c)*

Initially, frequency of light, $\nu = 1.5\nu_0$

But when the frequency of incident light is halved, then $\nu' = \frac{\nu}{2} = 0.75\nu_0$. Thus, it becomes less than the threshold frequency. In that case, no photoelectric effect takes place. Hence, photoelectric current becomes zero.

Hence, correct option is (c).

02 The work function of a photosensitive material is 4.0 eV. This longest wavelength of light that can cause photon emission from the substance is (approximately) **[NEET (Odisha) 2019]**

(a) 3100 nm (b) 966 nm
(c) 31 nm (d) 310 nm

Ans. *(d)*

The work function of material is given by

$$\phi = h\nu$$

$$\phi = \frac{hc}{\lambda} \quad \text{...(i)} \left[\because \nu = \frac{c}{\lambda}\right]$$

where, h = Planck's constant

$= 6.63 \times 10^{-34}$ J-s

c = speed of length $= 3 \times 10^8$ ms^{-1}

and λ = wavelength of light

Here, $\phi = 4$ eV $= 4 \times 1.6 \times 10^{-19}$ J

Substituting the given values in Eq. (i), we get

$$\Rightarrow 4 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

or $$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4 \times 1.6 \times 10^{-19}}$$

$$= 3.108 \times 10^{-7} \text{ m} \simeq 310 \text{ nm}$$

03 When the light of frequency $2\nu_0$ (where, ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2. The ratio of v_1 to v_2 is **[NEET 2018]**

(a) 4 : 1 (b) 1 : 4
(c) 1 : 2 (d) 2 : 1

Ans. *(c)*

According to the Einstein's photoelectric equation,

$$K_{max} = \frac{1}{2}mv_{max}^2 = hv - \phi_0$$

$$= hv - hv_0 \quad \text{...(i)}$$

where, K_{max} is the maximum kinetic energy of photoelectrons having maximum velocity v_{max}.

When incident frequency of light, $v = 2v_0$

Substituting the value of ν in Eq. (i), we get

$$\frac{1}{2}mv_1^2 = h(2v_0) - hv_0$$

$$= 2hv_0 - hv_0 = hv_0 \quad \text{...(ii)}$$

If incident frequency of radiation,

$$\nu = 5\nu_0$$

Substituting the value of ν in Eq. (i), we get

$$\frac{1}{2}mv_2^2 = h(5v_0) - hv_0$$

$$= 5hv_0 - hv_0 = 4hv_0 \quad \text{...(iii)}$$

On dividing Eq. (ii) by Eq (iii), we get

$$\frac{\frac{1}{2}mv_1^2}{\frac{1}{2}mv_2^2} = \frac{hv_0}{4hv_0}$$

$$\Rightarrow \quad \frac{v_1^2}{v_2^2} = \frac{1}{4} \text{ or } \frac{v_1}{v_2} = \frac{1}{2}$$

$$\therefore \quad v_1 : v_2 = 1 : 2$$

04 The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2536×10^{-10} m is (Given, $h = 4.14 \times 10^{-15}$ eVs and $c = 3 \times 10^8$ ms^{-1}) **[NEET 2017]**

(a) $\approx 6 \times 10^5$ ms^{-1} (b) $\approx 0.6 \times 10^6$ ms^{-1}
(c) $\approx 61 \times 10^3$ ms^{-1} (d) $\approx 0.3 \times 10^6$ ms^{-1}

Ans. *(a, b)*

Thinking Process Applying Einstein's photoelectric equation, kinetic energy of emitted electron can be given by

$$K = \frac{1}{2}mv^2 = h\nu - h\nu_0 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

Given threshold wavelength,

$$\lambda_0 = 3250 \times 10^{-10} \text{ m}$$

Wavelength of ultraviolet light,

$$\lambda = 2536 \times 10^{-10} \text{ m}$$

Let, velocity of ejected electron be v.
Now, applying Einstein's photoelectric equation, we have

$$E = K + \phi_0$$
$$\Rightarrow \quad h\nu = \frac{1}{2} m_e v^2 + h\nu_0$$
$$\Rightarrow \frac{1}{2} m_e v^2 = h\nu - h\nu_0$$
$$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

$\Rightarrow$ Velocity of electron

$$v = \sqrt{\frac{2hc}{m_e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)}$$
$$= \sqrt{\frac{2 \times 4.14 \times 10^{-15} \times 1.6 \times 10^{-19} \times 3 \times 10^8}{9.1 \times 10^{-31}} \left(\frac{3250 - 2536}{3250 \times 2536}\right)}$$
$$= 0.6 \times 10^6 \text{ ms} = 6 \times 10^5 \text{ ms}^{-1}$$

05 When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$. The threshold wavelength for the metallic surface is **[NEET 2016]**

(a) 5λ (b) $\frac{5}{2}\lambda$
(c) 3λ (d) 4λ

Ans. *(c)*

In Ist case, when a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V.
So, photoelectric equation can be written as

$$eV = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \quad \text{...(i)}$$

In IInd case, when the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$. So, photoelectric equation can be written as

$$\frac{eV}{4} = \frac{hc}{2\lambda} - \frac{hc}{\lambda_0}$$
$$\Rightarrow \quad eV = \frac{4hc}{2\lambda} - \frac{4hc}{\lambda_0} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$\Rightarrow \quad \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{4hc}{2\lambda} - \frac{4hc}{\lambda_0}$$
$$\Rightarrow \quad \frac{1}{\lambda} - \frac{1}{\lambda_0} = \frac{2}{\lambda} - \frac{4}{\lambda_0}$$
$$\Rightarrow \quad \lambda_0 = 3\lambda$$

06 Photons with energy 5 eV are incident on a cathode C in a photoelectric cell. The maximum energy of emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A, if the stopping potential of A relative to C is **[NEET 2016]**

(a) + 3 V (b) + 4 V (c) − 1 V (d) − 3 V

Ans. *(d)*

Key Idea Use Einstein's photoelectric equation.

We know that, $E = (\text{KE})_{\text{max}}$ + Work function (ϕ)

where, $\phi = h\nu_0$, $E = h\nu$

$$(\text{KE})_{\text{max}} = \frac{1}{2} m v_0^2$$
$$\Rightarrow \quad (\text{KE})_{\text{max}} = h\nu - \phi$$
$$\Rightarrow \quad 2\text{eV} = 5\text{eV} - \phi \quad \text{(given)}$$
$$\Rightarrow \quad \phi = 3\text{eV}$$

Thus, $V_{\text{cathode}} - V_{\text{anode}} = 3\text{V}$

$$\Rightarrow \quad V_{\text{anode}} - V_{\text{cathode}} = -3\text{V}$$

07 A certain metallic surface is illuminated with monochromatic light of wavelength λ. The stopping potential for photoelectric current for this light is $3V_0$. If the same surface is illuminated with light of wavelength 2λ, the stopping potential is V_0. The threshold wavelength for this surface for photoelectric effect is **[CBSE AIPMT 2015]**

(a) 6λ (b) 4λ (c) $\frac{\lambda}{4}$ (d) $\frac{\lambda}{6}$

Ans. *(b)*

From photoelectric equation

$h\nu = W + eV_0$

(where, W = work function)

$$\text{So} \quad \frac{hc}{\lambda} = W + 3eV_0 \quad \text{...(i)}$$
$$\text{Also,} \quad \frac{hc}{2\lambda} = W + eV_0$$
$$\Rightarrow \quad \frac{hc}{\lambda} = 2W + 2eV_0 \quad \text{...(ii)}$$

Subtracting Eq. (i) from Eq. (ii), we get

$0 = W - eV_0 \Rightarrow W = eV_0$

From Eq. (i),

$$\frac{hc}{\lambda} = eV_0 + 3eV_0 = 4eV_0$$

The threshold wavelength is given by

$$\lambda_{\text{th}} = \frac{hc}{W} = \frac{4eV_0\lambda}{eV_0} = 4\lambda$$

08 A photoelectric surface is illuminated successively by monochromatic light of wavelength λ and $\frac{\lambda}{2}$. If the maximum kinetic energy of the emitted photoelectrons in the second case is 3 times that in the first case, the work function of the surface of the material is **[CBSE AIPMT 2015]**

(h = Planck's constant, c = speed of light)

(a) $\frac{hc}{2\lambda}$ (b) $\frac{hc}{\lambda}$ (c) $\frac{2hc}{\lambda}$ (d) $\frac{hc}{3\lambda}$

Ans. *(a)*

According to Einstein's photoelectric equation,

$$E = K_{\text{max}} + \phi$$

where, K_{max} is maximum kinetic energy of emitted electron and ϕ is work function of an electron.

$$K_{\text{max}} = E - \phi = h\nu - \phi$$
$$K_{\text{max}} = \frac{hc}{\lambda} - \phi \quad \text{...(i)}$$

Similarly, in second case, maximum kinetic energy of emitted electron is 3 times that in first case, we get

$$3K_{\text{max}} = \frac{hc}{\frac{\lambda}{2}} - \phi \quad \text{...(ii)}$$

Solving Eqs. (i) and (ii), we get work function of an emitted electron from a metal surface.

$$\phi = \frac{hc}{2\lambda}$$

09 Light of wavelength 500 nm is incident on a metal with work function 2.28 eV. The de-Broglie wavelength of the emitted electron is **[CBSE AIPMT 2015]**

(a) $< 2.8 \times 10^{-10}$ m (b) $< 2.8 \times 10^{-9}$ m
(c) $\geq 2.8 \times 10^{-9}$ m (d) $\leq 2.8 \times 10^{-12}$ m

Ans. *(c)*

As, energy of photon, $E = h\nu \Rightarrow E = \frac{hc}{\lambda}$

$$\Rightarrow E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}$$
$$\Rightarrow E = \frac{0.0397 \times 10^{-34} \times 10^8}{10^{-9}}$$
$$= 0.0397 \times 10^{-21} \text{ J}$$
$$= \frac{0.0397 \times 10^{-21}}{1.6 \times 10^{-19}} = 0.0248 \times 10^2 \text{ eV}$$
$$= 2.48 \text{ eV}$$

According to Einstein's photoelectric emission, we have

$$KE_{max} = E - W = 2.48 - 2.28 = 0.2 \text{ eV}$$

For de-Broglie wavelength of the emitted electron,

$$\lambda_{e\,min} = \frac{12.27\ \text{Å}}{\sqrt{KE_{max}(\text{eV})}} = \frac{12.27}{\sqrt{0.2}}$$

$$= 27.436\ \text{Å} = 27.436 \times 10^{-10}\ \text{m}$$

Thus, minimum wavelength of the emitted electron is

$$\lambda_{min} = 2.7436 \times 10^{-9}\ \text{m}$$

i.e. $\lambda \geq \lambda_{min}$

10 When the energy of the incident radiation is increased by 20%, the kinetic energy of the photoelectrons emitted from a metal surface increased from 0.5 eV to 0.8 eV. The work function of the metal is **[CBSE AIPMT 2014]**

(a) 0.65 eV (b) 1.0 eV
(c) 1.3 eV (d) 1.5 eV

Ans. ***(b)***

For photo electric equation,
Einstein's equation can be written as

$$(KE)_{max} = h\nu - \phi_0$$

For the first condition,

$$0.5 = E - \phi_0 \quad \text{...(i)}$$

For the second condition,

$$0.8 = 1.2E - \phi_0 \quad \text{...(ii)}$$

From Eqs. (i) and (ii)

$$-0.3 = -0.2E$$

$$E = \frac{0.3}{0.2} = 1.5 \text{ eV}$$

From Eq. (i) $0.5 = 1.5 - \phi_0$

$$\phi_0 = 0.5 - 0.5 = 1 \text{ eV}$$

11 For photoelectric emission from certain metal, the cut-off frequency is ν. If radiation of frequency 2ν impinges on the metal plate, the maximum possible velocity of the emitted electron will be (m is the electron mass) **[NEET 2013]**

(a) $\sqrt{\frac{h\nu}{(2m)}}$ (b) $\sqrt{\frac{h\nu}{m}}$
(c) $\sqrt{\frac{2h\nu}{m}}$ (d) $2\sqrt{\frac{h\nu}{m}}$

Ans. ***(c)***

As we know that,

$$\frac{1}{2}m(v_{max})^2 = h\nu$$

So, $$v_{max} = \sqrt{\frac{2h\nu}{m}}$$

12 Light of two different frequencies whose photons have energies 1 eV and 2.5 eV respectively illuminate a metallic surface whose work function is 0.5 eV successively. Ratio of maximum speeds of emitted electrons will be **[CBSE AIPMT 2011]**

(a) 1 : 2 (b) 1 : 1 (c) 1 : 5 (d) 1 : 4

Ans. ***(a)***

Kinetic energy in photoelectric effect can also be written as

$$KE = \phi - \phi_0 \quad \begin{bmatrix} \phi = \text{incident energy} \\ \phi_0 = \text{work function} \end{bmatrix}$$

Given, $KE_1 = 1 - 0.5 = 0.5$ eV

$KE_2 = 2.5 - 0.5 = 2$ eV

So, $$\frac{KE_1}{KE_2} = \frac{0.5}{2} = \frac{1}{4}$$

or $$\frac{v_1^2}{v_2^2} = \frac{1}{4} \quad \left[\because KE = \frac{1}{2}mv^2\right]$$

or $$\frac{v_1}{v_2} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

13 Photoelectric emission occurs only when the incident light has more than a certain minimum **[CBSE AIPMT 2011]**

(a) wavelength (b) intensity
(c) frequency (d) power

Ans. ***(c)***

According to the concept of threshold minimum frequency needed for photoelectric emission i.e.

$$KE = h\nu - \phi_0$$

or $$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

So, $$\nu \geq \nu_0$$

14 In photoelectric emission process from a metal of work function 1.8 eV, the kinetic energy of most energetic electrons is 0.5 eV. The corresponding stopping potential is **[CBSE AIPMT 2011]**

(a) 1.3 V (b) 0.5 V
(c) 2.3 V (d) 1.8 V

Ans. ***(b)***

As we know that stopping potential gives the maximum KE of ejected electrons, so

$$KE_{max} = eV_0$$

So, $$1.6 \times 10^{-19} \times V_0 = 0.5 \times 1.6 \times 10^{-19}$$

$$\Rightarrow V_0 = 0.5 \text{ V}$$

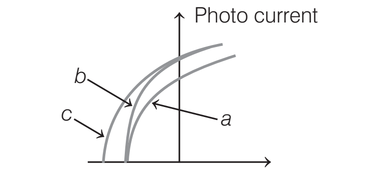
15 The number of photoelectrons emitted for light of a frequency ν (higher than the threshold frequency ν_0) is proportional to

(a) $\nu - \nu_0$ **[CBSE AIPMT 2009]**
(b) threshold frequency (ν_0)
(c) intensity of light
(d) frequency of light (ν)

Ans. ***(c)***

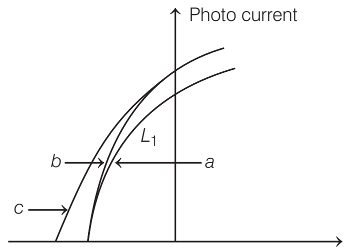
Independent of frequency (ν) of light, it only depends on the intensity of incident light. If intensity increases, number of photo electrons increases.

16 The figure shows a plot of photocurrent *versus* anode potential for a photo sensitive surface for three different radiations. Which one of the following is a correct statement ? **[CBSE AIPMT 2009]**



(a) Curves *a* and *b* represent incident radiations of different frequencies and different intensities
(b) Curves *a* and *b* represent incident radiations of same frequency but of different intensities
(c) Curves *b* and *c* represent incident radiations of different frequencies and different intensities
(d) Curves *b* and *c* represent incident radiations of same frequency having same intensity

Ans. ***(b)***



Since in the graph retarding potential is same in graph (a) and (b) and photo current is different so, for curves they have same frequency but different intensity of light.

17 In the phenomenon of electric discharge through gases at low pressure, the coloured glow in the tube appears as a result of

[CBSE AIPMT 2008]

(a) excitation of electrons in the atoms
(b) collision between the atoms of the gas
(c) collisions between the charged particles emitted from the cathode and the atoms of the gas
(d) collision between different electrons of the atoms of the gas

Ans. *(c)*

In the phenomenon of electric discharge through gases at low pressure, as the charged particles emitted from the cathode collides with the atoms of the gas, coloured glow appears in the tube.

18 The work function of a surface of a photosensitive material is 6.2 eV. The wavelength of the incident radiation for which the stopping potential is 5 V lies in the

[CBSE AIPMT 2008]

(a) ultraviolet region
(b) visible region
(c) infrared region
(d) X-ray region

Ans. *(d)*

According to Einstein's photoelectric equation, kinetic energy of photoelectron

$$KE = h\nu - W_0 \quad \text{or} \quad h\nu = KE + W_0$$

As maximum KE of ejected electrons is given by

$$KE = eV_0$$

where, V_0 is stopping potential.

$$h\nu = 5\,eV + 6.2\,eV \quad [\because eV_0 = 5\,eV]$$
$$= 11.2\,eV \quad \text{(lies in X-ray region)}$$

19 A 5 W source emits monochromatic light of wavelength 5000 Å. When placed 0.5 m away, it liberates photoelectrons from a photosensitive metallic surface. When the source is moved to a distance of 1.0 m, the number of photoelectrons liberated will be reduced by a factor of

[CBSE AIPMT 2007]

(a) 4 (b) 8
(c) 16 (d) 2

Ans. *(a)*

Intensity of light is inversely proportional to square of distance of source

i.e. $$I \propto \frac{1}{d^2}$$

For two different situations, $\frac{I_2}{I_1} = \frac{(d_1)^2}{(d_2)^2}$

Given, $d_1 = 0.5\text{ m}$, $d_2 = 1.0\text{ m}$

Therefore, $\frac{I_2}{I_1} = \frac{(0.5)^2}{(1)^2} = \frac{1}{4}$

Since, number of photoelectrons emitted per second is directly proportional to intensity, so number of electrons emitted would decrease by factor of 4.

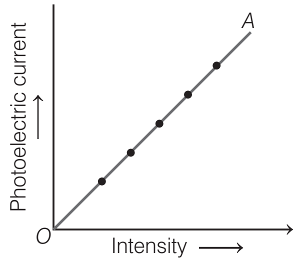
20 A photocell employs photoelectric effect to convert

[CBSE AIPMT 2006]

(a) change in the frequency of light into a change in electric voltage
(b) change in the intensity of illumination into a change in photoelectric current
(c) change in the intensity of illumination into a change in the work function of the photocathode
(d) change in the frequency of light into a change in the electric current

Ans. *(b)*

In a photoelectric effect, when monochromatic radiations of suitable frequency fall on the photosensitive plate called cathode, the photoelectrons are emitted which get accelerated towards anode. These electrons flow in the outer circuit resulting in the photoelectric current.



Using the incident radiations of a fixed frequency, it is found that the photoelectric current increases linearly with the intensity of incident light as shown in figure. Hence, a photocell employs photoelectric effect to convert change in the intensity of illumination into a change in photoelectric current.

21 A photosensitive metallic surface has work function, $h\nu_0$. If photons of energy $2h\nu_0$ fall on this surface, the electrons come out with a maximum velocity of 4×10^6 m/s. When the photon energy is increased to $5h\nu_0$, then maximum velocity of photoelectrons will be

[CBSE AIPMT 2005]

(a) 2×10^6 m/s (b) 2×10^7 m/s
(c) 8×10^5 m/s (d) 8×10^6 m/s

Ans. *(d)*

Einstein's photoelectric equation can be written as

$$KE = \frac{1}{2}mv^2 = h\nu - W_0$$

where, [W_0 = work function]

When photon of energy $2h\nu_0$ falls then

$$\Rightarrow \frac{1}{2}m \times (4 \times 10^6)^2 = 2h\nu_0 - h\nu_0 \quad \text{...(i)}$$

When photon of energy $5h\nu_0$ falls then

$$\frac{1}{2}m \times v^2 = 5h\nu_0 - h\nu_0 \quad \text{...(ii)}$$

Dividing Eq. (i) by (ii), we get

$$\frac{v^2}{(4 \times 10^6)^2} = \frac{4h\nu_0}{h\nu_0}$$

or $v^2 = 4 \times 16 \times 10^{12}$

or $v^2 = 64 \times 10^{12}$

$\therefore$ $v = 8 \times 10^6$ m/s

22 The work functions for metals A, B and C are respectively 1.92 eV, 2.0 eV and 5 eV. According to Einstein's equation, the metals which will emit photoelectrons for a radiation of wavelength 4100 Å is/are

[CBSE AIPMT 2005]

(a) None of these
(b) A only
(c) A and B only
(d) All the three metals

Ans. *(c)*

Work function for wavelength of 4100 Å is given by

$$W_0 = \frac{hc}{\lambda}$$
$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{4100 \times 10^{-10}}$$
$$= 4.8 \times 10^{-19}\text{ J}$$

Energy in eV is given by

$$= \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}}\text{ eV} = 3\text{ eV}$$

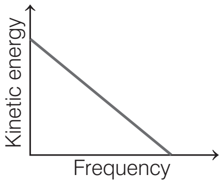
Now, we have

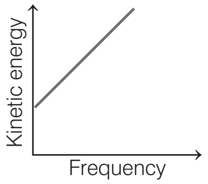
$$W_A = 1.92\text{ eV},$$
$$W_B = 2.0\text{ eV},$$
$$W_C = 5\text{ eV}$$

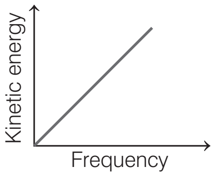
Since, $W_A < W$

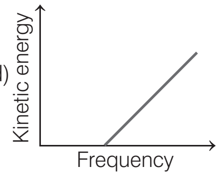
and $W_B < W$, hence, A and B will emit photoelectrons.

23 According to Einstein's photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is **[CBSE AIPMT 2004]**

(a)


(b)


(c)


(d)


Ans. *(d)*

Einstein's photoelectric equation is

$$\mathrm{KE} = h\nu - W_0 \quad \text{...(i)}$$

where, W_0 = work function of metal, $(= h\nu_0)$

Comparing above Eq. (i) with equation of a straight line $y = mx + c$

we get, $m = h$, $c = -W_0$

Therefore, if we draw a graph between kinetic energy and frequency, then a straight line cutting the frequency axis at ν_0 and giving an intercept of $(-W_0)$ on the kinetic energy axis, is obtained.

NOTE

As we know that for emission of electrons, there is a certain threshold frequency after which emission starts. Considering this fact graph (*d*) is correct.

24 A photoelectric cell is illuminated by a point source of light 1 m away. When the source is shifted to 2 m, then **[CBSE AIPMT 2003]**

(a) each emitted electron carries half the initial energy
(b) number of electrons emitted is a quarter of the initial number
(c) each emitted electron carries one quarter of the initial energy
(d) number of electrons emitted is half the initial number

Ans. *(b)*

Intensity of light source is inversely proportional to the distance (*d*)

i.e. $I \propto \frac{1}{d^2}$

When distance is doubled, intensity becomes one-fourth. As number of photoelectrons ∝ intensity, so number of photoelectrons is quarter of the initial number.

25 When ultraviolet rays are incident on metal plate, the photoelectric effect does not occur. It occurs by incidence of **[CBSE AIPMT 2002]**

(a) infrared rays (b) X-rays
(c) radiowaves (d) light waves

Ans. *(b)*

For photoelectric emission from given metal plate, the incident wavelength must be less than that of ultraviolet rays assuming the wavelength of ultraviolet rays as the threshold value. Out of the given radiations, X-rays have wavelength less than that of ultraviolet rays. Thus, X-rays can cause photoelectric emission.

26 Which of the following is not the property of cathode rays? **[CBSE AIPMT 2002]**

(a) It produces heating effect
(b) It does not deflect in electric field
(c) Its casts shadow
(d) It produces fluorescence

Ans. *(b)*

Cathode rays are negatively charged particles called as electrons

(a) Cathode rays possess very high kinetic energy due to their high velocity. When these highly energetic rays fall on platinum (a metal), their kinetic energy is converted to heat energy.
(b) Outside the discharge tube, if an electric field is applied, the cathode rays bend towards the positive plate.
(c) Cathode rays travel in straight lines. This can be proved by an arrangement which shows that cathode rays cast shadow of the object placed in straight line path of cathode rays.
(d) In certain substances like barium platinocyanides, zinc sulphate, diamond etc, they produce fluorescence.

Thus, (b) is right option.

27 A light source is at a distance *d* from a photoelectric cell, then the number of photoelectrons emitted from the cell is *n*. If the distance of light source and cell is reduced to half, then the number of photoelectrons emitted will become **[CBSE AIPMT 2001]**

(a) $\frac{n}{2}$ (b) $2n$ (c) $4n$ (d) n

Ans. *(c)*

Intensity of light source is given by

$$I \propto \frac{1}{d^2}$$

where, *d* is the distance of light source from the cell.

So, for two different situations for intensities,

or $\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$

or $I_2 = 4I_1$

As number of photoelectrons emitted is directly proportional to intensity, so number of photoelectrons emitted will become 4 times, i.e. 4 *n*.

28 Einstein's work on photoelectric effect gives support to **[CBSE AIPMT 2000]**

(a) $E = mc^2$ (b) $E = h\nu$
(c) $h\nu = \frac{1}{2}mv^2$ (d) $E = \frac{h}{\lambda}$

Ans. *(b)*

In 1905, Einstein realized that the photoelectric effect could be understood if the energy in light is not spread out over wavefronts but is concentrated in small packets, or photons. Each photon of light of frequency ν has the energy $h\nu$. Thus, Einstein's work on photoelectric effect gives support to $E = h\nu$.

29 When intensity of incident light increases **[CBSE AIPMT 1999]**

(a) photocurrent increases
(b) photocurrent decreases
(c) kinetic energy of emitted photoelectrons increases
(d) kinetic energy of emitted photoelectrons decreases

Ans. *(a)*

According to Einstein's theory of photoelectric effect, a single incident photon ejects a single electron. Therefore, when intensity increases, the number of incident photons increases, so number of ejected electrons increases, hence, photocurrent increases.

Now, maximum energy of electron $= \frac{1}{2} mv_{max}^2$ and $\frac{1}{2} mv_{max}^2 = eV_0$, where V_0 is stopping potential.

Thus, the maximum kinetic energy of the electrons does not depend upon the intensity of the incident rays, because the stopping potential is not affected by the increase of the intensity of rays. Hence, options (c) and (d) are wrong.

30 The photoelectric work function for a metal surface is 4.125 eV. The cut-off wavelength for this surface is **[CBSE AIPMT 1999]**

(a) 4125 Å (b) 3000 Å
(c) 6000 Å (d) 2062.5 Å

Ans. *(b)*

The minimum wavelength below which no photoelectron can emit from metal surface is called cut-off wavelength or threshold wavelength and is given by

$$\text{Work function} = \frac{hc}{\text{cut - off wavelength}}$$

or $$\text{cut-off wavelength} = \frac{hc}{\text{work function}}$$

$$\therefore \quad \lambda_0 = \frac{hc}{W_0} \quad \text{...(i)}$$

Given, $h = 6.6 \times 10^{-34}$ J-s

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

$W_0 = 4.125$ eV

$= 4.125 \times 1.6 \times 10^{-19}$ J

Substituting the given values in Eq. (i), we get

$$\lambda_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.125 \times 1.6 \times 10^{-19}} \text{ Å}$$

$$= 3 \times 10^{-7} \text{ m} = 3000 \text{ Å}$$

31 In a photoemissive cell, with exciting wavelength λ, the fastest electron has speed v. If the exciting wavelength is changed to $3\lambda/4$, the speed of the fastest emitted electron will be **[CBSE AIPMT 1998]**

(a) $v\left(\frac{3}{4}\right)^{1/2}$

(b) $v\left(\frac{4}{3}\right)^{1/2}$

(c) less than $v\left(\frac{4}{3}\right)^{1/2}$

(d) greater than $v\left(\frac{4}{3}\right)^{1/2}$

Ans. *(d)*

Einstein's photoelectric equation is given by

$$\text{KE} = E - W_0$$

As we know that

$$\text{KE} = \frac{1}{2} mv^2$$

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

$$\therefore \quad \frac{1}{2} mv^2 = \frac{hc}{\lambda} - W_0 \quad \text{...(i)}$$

Suppose v' be the new speed, when λ is changed to $\frac{3\lambda}{4}$.

The new equation can be written as

$$\frac{1}{2} mv'^2 = \frac{hc}{(3\lambda/4)} - W_0$$

or $$\frac{1}{2} mv'^2 = \frac{4}{3}\frac{hc}{\lambda} - W_0 \quad \text{...(ii)}$$

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{v'^2}{v^2} = \frac{\frac{4}{3}\frac{hc}{\lambda} - W_0}{\frac{hc}{\lambda} - W_0}$$

$$= \frac{\frac{4}{3}\frac{hc}{\lambda} - \frac{4}{3}W_0 + \frac{1}{3}W_0}{\frac{hc}{\lambda} - W_0}$$

$$= \frac{4}{3} + \frac{W_0}{3\left(\frac{hc}{\lambda} - W_0\right)} > \frac{4}{3}$$

$$\therefore \quad \frac{v'}{v} > \sqrt{\frac{4}{3}} \quad \text{or} \quad v' > \sqrt{\frac{4}{3}}\, v$$

32 Light of wavelength 5000 Å falls on a sensitive plate with photoelectric work function of 1.9 eV. The kinetic energy of the photoelectron emitted will be **[CBSE AIPMT 1998]**

(a) 0.58 eV (b) 2.48 eV
(c) 1.24 eV (d) 1.16 eV

Ans. *(a)*

Energy of photon is given by

$$E = \frac{hc}{\lambda} = \frac{12375}{\lambda(\text{Å})} \text{ eV}$$

$$[\because hc = 12375 \text{ eV- Å}]$$

$$\therefore \quad E = \frac{12375}{5000} = 2.48 \text{ eV}$$

According to Einstein's photoelectric equation

$$\text{KE} = E - W_0 = 2.48 \text{eV} - 1.9 \text{eV}$$

$$= 0.58 \text{ eV}$$

33 Which of the following is true ? **[CBSE AIPMT 1997]**

(a) The stopping potential increases with increasing intensity of incident light
(b) The photocurrent increases with increasing intensity of light
(c) The current in photocell increases with increasing frequency of light
(d) The photocurrent is proportional to applied voltage

Ans. *(b)*

(a) Stopping potential is the negative potential applied to stop the photoelectrons from the metal. Stopping potential is given by
$$eV_0 = K_{max}$$
Since, maximum kinetic energy of photo- electrons does not depend on intensity of light, so stopping potential does not vary with intensity of light. Thus, choice (a) is not correct.

(b) If intensity of incident light is increased, we can say that the number of photons incident per unit area per unit time will be increased. Therefore, more electrons will be emitted per second. Hence, photo-current increases. Thus, choice (b) is correct.

(c) The photo-current does not depend on frequency of light. Thus, choice (c) is not correct.

(d) The photo-current does not depend on applied voltage. Thus, choice (d) is not correct.

34 If the threshold wavelength for a certain metal is 2000 Å, then the work function of the metal is **[CBSE AIPMT 1995]**

(a) 6.2 J (b) 6.2 eV
(c) 6.2 MeV (d) 6.2 keV

Ans. *(b)*

The minimum energy required to remove an electron from the surface of metal without giving any kinetic energy is called work function.

$$W_0 = h\nu_0 = \frac{hc}{\lambda_0}$$

Given wavelength,

$$\lambda_0 = 2000 \text{ Å} = 2000 \times 10^{-10} \text{ m}$$

$$\therefore \quad W_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2000 \times 10^{-10}}$$

$$= 9.9 \times 10^{-19} \text{ J} = \frac{9.9 \times 10^{-19}}{1.6 \times 10^{-19}}$$

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

$$= 6.2 \text{ eV}$$

35 In photoelectric effect, the work function of a metal is 3.5 eV. The emitted electrons can be stopped by applying a potential of – 1.2 V. Then, **[CBSE AIPMT 1994]**

(a) the energy of the incident photons is 4.7 eV
(b) the energy of the incident photons is 2.3 eV
(c) if higher frequency photons be used, the photoelectric current will rise
(d) when the energy of photons is 3.5 eV, the photoelectric current will be maximum

Ans. *(a)*

When a photon of light of frequency ν is incident on a photosensitive metal surface. Then, according to Einstein's photoelectric equation

$$h\nu = W_0 + \frac{1}{2}mv^2$$

where, W_0 is work function of the metal and $\frac{1}{2}mv^2$ is KE of the photoelectron.

Given, $W_0 = 3.5\,\text{eV}$, KE $= 1.2\,\text{eV}$

$\therefore h\nu = 3.5 + 1.2 = 4.7$ eV

Note

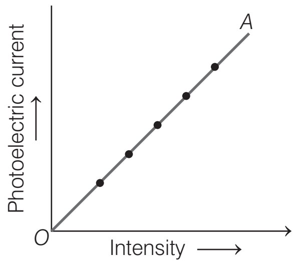
Stopping potential always gives maximum kinetic energy of ejected electrons.

36 Number of ejected photoelectron increases with increase **[CBSE AIPMT 1993]**

(a) in intensity of light
(b) in wavelength of light
(c) in frequency of light
(d) Never

Ans. *(a)*

It is found that the photoelectric current increases linearly with the intensity of incident light.



It means number of photoelectrons emitted per second from photosensitive plate is directly proportional to the intensity of the incident radiation.

37 The cathode of a photoelectric cell is changed such that the work function changes from W_1 to W_2 ($W_2 > W_1$). If the current before and after changes are I_1 and I_2, all other conditions remaining unchanged, then (assuming $h\nu > W_2$) **[CBSE AIPMT 1992]**

(a) $I_1 = I_2$ (b) $I_1 < I_2$
(c) $I_1 > I_2$ (d) $I_1 < I_2 < 2I_1$

Ans. *(a)*

By work function of a metal, it means that the minimum energy required for the electron in the highest level of conduction band to get out of the metal. The work function has no effect on photoelectric current as long as $h\nu > W_0$. The photoelectric current is proportional to the intensity of incident light. Since, there is no change in the intensity of light, hence $I_1 = I_2$

38 Photoelectric work function of a metal is 1 eV, light of wavelength $\lambda = 3000\,\text{Å}$ falls on it. The photoelectrons come out with velocity **[CBSE AIPMT 1991]**

(a) 10 m/s (b) 10^2 m/s
(c) 10^4 m/s (d) 10^6 m/s

Ans. *(d)*

According to Einstein's photoelectric equation, KE of the photoelectron

$$\frac{1}{2}mv^2 = \frac{hc}{\lambda} - W_0$$

$$\begin{bmatrix} \text{where, } W_0 = \text{work function} \\ \frac{1}{2}mv^2 = \text{KE of ejected electrons} \\ \frac{hc}{l} = \text{threshold energy} \end{bmatrix}$$

Given, $\lambda = 3000\,\text{Å} = 3000 \times 10^{-10}$ m

$W_0 = 1\text{ eV} = 1.6 \times 10^{-19}$ J

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

$$\therefore \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{3000 \times 10^{-10}} - 1.6 \times 10^{-19}$$

$\Rightarrow v = 10^6$ m/s

39 Ultraviolet radiation of 6.2 eV falls on an aluminium surface. KE of fastest electron emitted is (work function = 4.2 eV) **[CBSE AIPMT 1989]**

(a) 3.2×10^{-21} J (b) 3.2×10^{-19} J
(c) 7×10^{-25} J (d) 9×10^{-32} J

Ans. *(b)*

According to Einstein photoelectric equation

$$\text{KE} = E - W_0 \quad \begin{bmatrix} E = \text{energy incidented} \\ W_0 = \text{work function} \end{bmatrix}$$

Here, $E = 6.2\,\text{eV}$

$W_0 = 4.2\,\text{eV}$

$\therefore$ KE $= 6.2 - 4.2 = 2.0$ eV

$= 2 \times 1.6 \times 10^{-19}$

$= 3.2 \times 10^{-19}$ J

40 The threshold frequency for photoelectric effect on sodium corresponds to a wavelength of 5000 Å. Its work function is **[CBSE AIPMT 1988]**

(a) 4×10^{-19} J
(b) 1 J
(c) 2×10^{-19} J
(d) 3×10^{-19} J

Ans. *(a)*

When a photon of light of frequency ν incident on a photosensitive metal surface, the energy of the photon ($h\nu$) is spent in two ways. A part of energy of photon is used in liberating the electron from the metal surface which is equal to the work function W_0 of the metal.

$W_0 = h\nu_0$

(where, ν_0 is threshold frequency)

or $W_0 = \frac{hc}{\lambda_0}$

Here, $\lambda_0 = 5000\,\text{Å}$

$= 5000 \times 10^{-10}$ m

$$\therefore W_0 = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{5000 \times 10^{-10}}$$

$= 4 \times 10^{-19}$ J

Threshold frequency (ν_0) → It is the minimum frequency given to metallic surface so that emission of electrons start.

41 Which of the following are thermions ? **[CBSE AIPMT 1988]**

(a) Protons (b) Electrons
(c) Photons (d) Positrons

Ans. *(b)*

Thermionic emission is the phenomenon of emission of electrons from the metal surface when heated suitably. Here, the energy required for the emission of electrons from metal surface is being supplied by thermal energy. The emitted electrons are called thermal electrons or thermions.

TOPIC 2
Particle Nature of Light-The Photon

42 The number of photons per second on an average emitted by the source of monochromatic light of wavelength 600 nm, when it delivers the power of 3.3×10^{-3} W will be ($h = 6.6 \times 10^{-34}$ J-s)
[NEET 2021]

(a) 10^{18} (b) 10^{17} (c) 10^{16} (d) 10^{15}

Ans. *(c)*

Given, the monochromatic light of the wavelength, $\lambda = 600$ nm

The power of the source,

$P = 3.3 \times 10^{-3}$ W

We know that, $P = \frac{nhc}{\lambda}$

Here, P is the power of the source,

n is the number of photons per second,

h is the Planck's constant,

c is the speed of the light in vacuum,

λ is the wavelength of the monochromatic light.

Substituting the values in the above equation, we get

$$3.3 \times 10^{-3} = \frac{n \times 6.6 \times 10^{-34} \times 3 \times 10^{8}}{600 \times 10^{-9}}$$

$$\Rightarrow \quad n = 10^{16}$$

43 A 200 W sodium street lamp emits yellow light of wavelength 0.6 μm. Assuming it to be 25% efficient in converting electrical energy to light, the number of photons of yellow light it emits per second is
[CBSE AIPMT 2012]

(a) 1.5×10^{20}

(b) 6×10^{18}

(c) 62×10^{20}

(d) 3×10^{19}

Ans. *(a)*

Efficient power (P) is given by

$$P = \frac{N}{t} \times \frac{hc}{\lambda}$$

(N = total number of photons)

$$\frac{N}{t} = \frac{P \times \lambda}{hc} = \frac{50 \times 0.6 \times 10^{-6}}{6.6 \times 10^{-34} \times 3 \times 10^{8}}$$

$[\because = 25\% \text{ of } 200\text{W} = 50\text{W}]$

$$= 1.5 \times 10^{20}$$

44 A source S_1 is producing, 10^{15} photons/s of wavelength 5000 Å. Another source S_2 is producing 1.02×10^{15} photons per second of wavelength 5100 Å. Then, (power of S_2)/ (power of S_1) is equal to
[CBSE AIPMT 2010]

(a) 1.00 (b) 1.02

(c) 1.04 (d) 0.98

Ans. *(a)*

Number of photons emitted per second is given by

$$n = \frac{P}{\left(\frac{hc}{\lambda}\right)} \qquad \left[\begin{array}{l} P = \text{Power} \\ \frac{hc}{\lambda} = \text{Energy} \end{array}\right]$$

So, $P = \frac{nhc}{\lambda}$

So, for two different situations,

$$\Rightarrow \frac{P_2}{P_1} = \frac{n_2 \lambda_1}{n_1 \lambda_2} = \frac{1.02 \times 10^{15} \times 5000}{10^{15} \times 5100} = 1$$

45 Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is
[CBSE AIPMT 2009]

(a) 9×10^{17} (b) 3×10^{16}

(c) 9×10^{15} (d) 3×10^{19}

Ans. *(b)*

Here, $\lambda = 667 \times 10^{-9}$ m, $P = 9 \times 10^{-3}$ W

$$\text{Power} = \frac{\text{energy}(E)}{\text{time}(t)} = \frac{nhc}{\lambda t} = \frac{Nhc}{\lambda}$$

$$\left[\begin{array}{l} E = \frac{hc}{\lambda}, n = \text{Total number of photons} \\ N = \text{Number of photons emitted per second} = \frac{n}{t} \end{array}\right]$$

So, $N = \frac{P \times \lambda}{hc} = \frac{9 \times 10^{-3} \times 667 \times 10^{-9}}{6.6 \times 10^{-34} \times 3 \times 10^{8}}$

$= 3 \times 10^{16}$ m /s

46 Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2×10^{-3} W. The number of photons emitted, on the average, by the source per second is
[CBSE AIPMT 2007]

(a) 5×10^{15} (b) 5×10^{16}

(c) 5×10^{17} (d) 5×10^{14}

Ans. *(a)*

Power emitted, $P = 2 \times 10^{-3}$ W

Energy of photon,

$$E = h\nu = 6.6 \times 10^{-34} \times 6 \times 10^{14} \text{ J}$$

Here, h being Planck's constant.

Number of photons emitted per second is given by

$$n = \frac{\text{Power}(P)}{\text{Energy}(E)} = \frac{2 \times 10^{-3}}{6.6 \times 10^{-34} \times 6 \times 10^{14}} = 5 \times 10^{15}$$

47 The momentum of a photon of energy 1 MeV in kg m/s, will be
[CBSE AIPMT 2006]

(a) 0.33×10^{6} (b) 7×10^{-24}

(c) 10^{-22} (d) 5×10^{-22}

Ans. *(d)*

Energy of photon is given by

$$E = \frac{hc}{\lambda} \quad \text{...(i)}$$

where h is Planck's constant, c the velocity of light and λ its wavelength.

de-Broglie wavelength is given by

$$\lambda = \frac{h}{p} \quad \text{...(ii)}$$

p being momentum of photon.

From Eqs. (i) and (ii), we have

$$E = \frac{hc}{h/p} = pc \text{ or } p = \frac{E}{c}$$

Given, $E = 1\text{MeV} = 1 \times 10^{6} \times 1.6 \times 10^{-19}$ J,

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

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

Hence, after putting numerical values, we obtain

$$p = \frac{1 \times 10^{6} \times 1.6 \times 10^{-19}}{3 \times 10^{8}} \text{ kg-m/s}$$

$$= 5 \times 10^{-22} \text{ kg-m/s}$$

48 The 21 cm radiowave emitted by hydrogen in interstelar space is due to the interaction called the hyperfine interaction in atomic hydrogen. The energy of the emitted wave is nearly
[CBSE AIPMT 1998]

(a) 10^{-17} J (b) 1 J

(c) 7×10^{-6} J (d) 10^{-24} J

Ans. *(d)*

The energy of emitted photon is given by

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

Given, wavelength, $\lambda = 21\text{cm} = 0.21\text{ m}$

So, $E = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{0.21} = 10^{-24}$ J

49 The nature of ions knocked out from hot surfaces is **[CBSE AIPMT 1995]**

(a) protons (b) electrons
(c) neutrons (d) nuclei

Ans. *(b)*

In thermionic emission and other types of emission, ions emitted are atoms that has lost or gained electrons having negative or positive charge respectively. Thus, the nature of ions knocked out from hot surfaces, are electrons.

50 Momentum of a photon of wavelength λ is **[CBSE AIPMT 1993]**

(a) $\frac{h}{\lambda}$ (b) zero (c) $\frac{h\lambda}{c^2}$ (d) $\frac{h\lambda}{c}$

Ans. *(a)*

As a photon moves with the velocity of light

i.e. $v = c$

$\therefore$ The momentum of the photon

$$= mc = \frac{h\nu}{c} = \frac{h}{\lambda} \quad \left[\lambda = \frac{c}{\nu}\right]$$

51 The wavelength of a 1 keV photon is 1.24×10^{-9} m. What is the frequency of 1 MeV photon? **[CBSE AIPMT 1991]**

(a) 1.24×10^{15} Hz (b) 2.4×10^{20} Hz
(c) 1.24×10^{18} Hz (d) 2.4×10^{23} Hz

Ans. *(b)*

Energy of photon is $E = h\nu = \frac{hc}{\lambda}$

As, $\frac{hc}{\lambda} = 10^3$ eV

$\therefore \quad h = \frac{10^3 \lambda}{c}$ ...(i)

And for 2nd case as given in question

$h\nu = 10^6$ eV ...(ii)

Putting value of h in Eq. (ii),

$$\frac{10^3 \lambda}{c} \nu = 10^6$$

$$\therefore \quad \nu = \frac{10^3 c}{\lambda} = \frac{10^3 \times 3 \times 10^8}{1.24 \times 10^{-9}} \quad [\because \lambda = 1.24 \times 10^{-9} \text{ m}]$$

$= 2.4 \times 10^{20}$ Hz

52 The momentum of a photon of an electro- magnetic radiation is 3.3×10^{-29} kg-ms^{-1}. What is the frequency of the associated waves? **[CBSE AIPMT 1990]**

($h = 6.6 \times 10^{-34}$ J-s, $c = 3 \times 10^8$ ms^{-1})

(a) 1.5×10^{13} Hz (b) 7.5×10^{12} Hz
(c) 6.0×10^{13} Hz (d) 3.0×10^3 Hz

Ans. *(a)*

The energy of a photon of a radiation of frequency ν and wavelength λ is

$$E = h\nu = \frac{hc}{\lambda} \quad \text{...(i)}$$

If photon is considered to be a particle of mass m, the energy associated with it, according to Einstein mass energy relation, is given by

$$E = mc^2 \quad \text{...(ii)}$$

From Eqs. (i) and (ii),

$h\nu = mc^2$

or $m = \frac{h\nu}{c^2} \Rightarrow \frac{h\nu}{c} = mc$

As $mc = p$

(p = momentum of photon)

So, $\nu = \frac{cp}{h} = \frac{3 \times 10^8 \times 3.3 \times 10^{-29}}{6.6 \times 10^{-34}}$

$= 1.5 \times 10^{13}$ Hz

53 A radio transmitter operates at a frequency 880 kHz and a power of 10 kW. The number of photons emitted per second is **[CBSE AIPMT 1990]**

(a) 1.72×10^{31} (b) 1.327×10^{25}
(c) 1.327×10^{37} (d) 1.327×10^{45}

Ans. *(a)*

Power of radio transmitter = 10 kW

= 10000 W

Operating frequency of transmitter

= 880 kHz = 880×10^3 Hz

Number of photons emitted per second

$$n = \frac{P}{E} = \frac{P}{h\nu} = \frac{10^4}{6.63 \times 10^{-34} \times 880 \times 10^3} \quad [h = 6.63 \times 10^{-34} \text{ J-s}]$$

$= 1.72 \times 10^{31}$

54 The energy of a photon of wavelength λ is **[CBSE AIPMT 1988]**

(a) $hc\lambda$ (b) $\frac{hc}{\lambda}$ (c) $\frac{\lambda}{hc}$ (d) $\frac{\lambda h}{c}$

Ans. *(b)*

According to Planck's quantum theory, a source of radiation emits energy in the form of photons, which travel in straight line. The energy of a photon is given by

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

where, h = Planck's constant

$= 6.62 \times 10^{-34}$ J-s

ν_1 and λ = frequency and wavelength of photon, respectively

and c = speed of light

$= 3 \times 10^8$ m/s

TOPIC 3
Wave Nature of Light

55 The de-Broglie wavelength of an electron moving with kinetic energy of 144 eV is nearly **[NEET (Oct.) 2020]**

(a) 102×10^{-3} nm (b) 102×10^{-4} nm
(c) 102×10^{-5} nm (d) 102×10^{-2} nm

Ans. *(d)*

Kinetic energy of electron,

$K = 144 \text{ eV} \Rightarrow eV = 144 \text{ eV}$

$\Rightarrow V = 144$ V

$\therefore$ de-Broglie wavelength

$$\lambda = \frac{1.227}{\sqrt{V}} \text{Å} = \frac{1.227}{\sqrt{144}} \text{Å} = \frac{1.227}{12} \text{Å}$$

$= 0.102 \text{Å} = 1.02$ nm

$= 102 \times 10^{-2}$ nm

56 The wave nature of electrons was experimentally verified by **[NEET (Oct.) 2020]**

(a) de-Broglie
(b) Hertz
(c) Einstein
(d) Davisson and Germer

Ans. *(a)*

The wave nature of electrons was experimentally verified by de-Broglie.

57 An electron is accelerated from rest through a potential difference of V volt. If the de-Broglie wavelength of the electron is 1.227×10^{-2} nm, the potential difference is **[NEET (Sep.) 2020]**

(a) 10^2 V (b) 10^3 V (c) 10^4 V (d) 10 V

Ans. *(c)*

Given, $\lambda = 1.227 \times 10^{-2}$ nm $= 1.227 \times 10^{-11}$ m

Potential difference, V = ?

Relation for de-Broglie wavelength for moving electron is

$$\lambda = \frac{12.27}{\sqrt{V}} \text{Å}$$

$$\Rightarrow \quad \sqrt{V} = \frac{12.27}{\lambda} \times 10^{-10} = \frac{12.27 \times 10^{-10}}{1.227 \times 10^{-11}} = 10^2$$

$\Rightarrow \quad V = 10^4$ V

Hence, correct option is (c).

58 A proton and an α-particle are accelerated from rest to the same energy. The de-Broglie wavelengths λ_p and λ_α are in the ratio **[NEET (Odisha) 2019]**

(a) 2 : 1 (b) 1 : 1 (c) $\sqrt{2}:1$ (d) 4 : 1

Ans. *(a)*

The de-Broglie wavelength associated with a charged particle is given by

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

where, h = planck's constant and p = momentum $= \sqrt{2mKE}$ (here, KE is the kinetic energy of the charged particle)

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2mKE}}$$

For proton and α-particle, the wavelengths are respectively given as,

$$\lambda_p = \frac{h}{\sqrt{2m_p KE_p}}$$

and

$$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha KE_\alpha}}$$

$$\therefore \quad \frac{\lambda_p}{\lambda_\alpha} = \frac{\sqrt{2m_\alpha KE_\alpha}}{\sqrt{2m_p KE_P}} \quad \text{...(i)}$$

Here, $KE_\alpha = KE_P$ and $m_\alpha = 4m_p$

Substituting these above mentioned relations in Eq. (i), we get

$$\Rightarrow \quad \frac{\lambda_P}{\lambda_\alpha} = \sqrt{\frac{4m_P}{m_p}} = \frac{2}{1}$$

or $\lambda_P : \lambda_\alpha = 2:1$

59 An electron is accelerated through a potential difference of 10,000 V. Its de-Broglie wavelength is, (nearly) : ($m_e = 9\times10^{-31}$ kg) **[NEET (National) 2019]**

(a) 12.2×10^{-12} m (b) 12.2×10^{-14} m

(c) 12.2 nm (d) 12.2×10^{-13} m

Ans. *(a)*

Given, potential difference, $V = 10000$ V

If electron is accelerated through a potential of V volt, then the wavelength associated with it is given by

$$\lambda = \frac{h}{\sqrt{2eVm_e}} \quad \text{... (i)}$$

where, h = Planck's constant $= 6.63\times10^{-34}$ J-s,

e = electronic charge $= 1.6\times10^{-19}$ C

and m_e = mass of electron $= 9\times10^{-31}$ kg

Substituting these values in Eq. (i), we get

$$\lambda = \frac{12.27}{\sqrt{V}}\,\text{Å} = \frac{12.27}{\sqrt{10000}}\times10^{-10}$$

$$= \frac{12.27\times10^{-10}}{100} = 12.27\times10^{-12}\ \text{m}$$

60 An electron of mass m with a velocity $\mathbf{v} = v_0\hat{\mathbf{i}}$ ($v_0 > 0$) enters an electric field $\mathbf{E} = -E_0\hat{\mathbf{i}}$ (E_0 = constant > 0) at $t = 0$. If λ_0 is its de-Broglie wavelength initially, then its de-Broglie wavelength at time t is **[NEET 2018]**

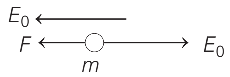
(a) $\lambda_0 t$ (b) $\lambda_0\left(1+\frac{eE_0}{mv_0}t\right)$

(c) $\frac{\lambda_0}{\left(1+\frac{eE_0}{mv_0}t\right)}$ (d) λ_0

Ans. *(c)*

According to the question,

$\mathbf{v} = v_0\hat{\mathbf{i}}$, $\mathbf{E} = -E_0\hat{\mathbf{i}}$



Thus, magnitude of force on the electron due to the electric field, $|\mathbf{F}| = q|\mathbf{E}|$

$\Rightarrow F = eE_0$

From Newton's second law of motion,

$$F = ma$$

$$\therefore \quad F = ma = eE_0$$

$$\Rightarrow \quad a = \frac{eE_0}{m} \quad \text{...(i)}$$

$$\text{or} \quad \mathbf{a} = \frac{(-e)(-E_0\hat{\mathbf{i}})}{m} = \frac{eE_0}{m}\hat{\mathbf{i}}$$

From first equation of motion,

$$v = u + at$$

Here, u (initial velocity) $= v_0$

$$\Rightarrow \quad v = v_0 + \frac{eE_0}{m}t \quad \text{...(ii) (from Eq. (i))}$$

Initial de-Broglie wavelength of the electron is given as

$$\lambda_0 = \frac{h}{mv_0} \Rightarrow h = \lambda m v_0 \quad \text{...(iii)}$$

After time t, de-Broglie wavelength is given as

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

Substituting the value of v from Eq. (ii), we get

$$\lambda = \frac{h}{m\left(v_0 + \frac{eE_0}{m}t\right)}$$

$$= \frac{h}{mv_0\left[1+\frac{eE_0}{mv_0}t\right]}$$

$$= \frac{\lambda\, mv_0}{mv_0\left[1+\frac{eE_0}{mv_0}t\right]} \quad \text{[from Eq. (iii)]}$$

$$= \frac{\lambda_0}{\left[1+\frac{eE_0}{mv_0}t\right]}$$

$$\therefore \quad \lambda = \frac{\lambda_0}{1+\frac{eE_0}{mv_0}t}$$

61 The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (Kelvin) and mass m, is **[NEET 2017]**

(a) $\frac{h}{\sqrt{mkT}}$ (b) $\frac{h}{\sqrt{3mkT}}$

(c) $\frac{2h}{\sqrt{3mkT}}$ (d) $\frac{2h}{\sqrt{mkT}}$

Ans. *(b)*

Thinking Process de-Broglie wavelength associated with a moving particle can be given as

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m(\text{KE})}}$$

At thermal equilibrium, temperature of neutron and heavy water will be same.

This common temperature is given as, T.

Also, we know that, kinetic energy of a particle

$$\text{KE} = \frac{p^2}{2m}$$

where, p = momentum of the particle

m = mass of the particle

Kinetic energy of the neutron is

$$\text{KE} = \frac{3}{2}kT$$

$\therefore$ de-Broglie wavelength of the neutron

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m(\text{KE})}}$$

$$= \frac{h}{\sqrt{2m\times\frac{3}{2}kT}} = \frac{h}{\sqrt{3mkT}}$$

62 An electron of mass m and a photon have same energy E. The ratio of de-Broglie wavelengths associated with them is **[NEET 2016]**

(a) $\left(\frac{E}{2m}\right)^{\frac{1}{2}}$ (b) $c(2mE)^{\frac{1}{2}}$

(c) $\frac{1}{c}\left(\frac{2m}{E}\right)^{\frac{1}{2}}$ (d) $\frac{1}{c}\left(\frac{E}{2m}\right)^{\frac{1}{2}}$

(c being velocity of light)

Ans. *(d)*

Since, it is given that electron has mass m. de-Broglie's wavelength for an electron will be given as

$$\lambda_e = \frac{h}{P} \quad ...(i)$$

where, h = Planck's constant

P = Linear momentum of electron

As kinetic energy of electron

$$E = \frac{P^2}{2m} \Rightarrow P = \sqrt{2mE} \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\lambda_e = \frac{h}{\sqrt{2mE}} \quad ...(iii)$$

Energy of a photon can be given as

$$E = h\nu$$

$$\Rightarrow \quad E = \frac{hc}{\lambda_p}$$

$$\Rightarrow \quad \lambda_p = \frac{hc}{E} \quad ...(iv)$$

Hence, λ_p = de-Broglie's wavelength of photon.

Now, divide Eq. (iii) by Eq. (iv), we get

$$\frac{\lambda_e}{\lambda_p} = \frac{h}{\sqrt{2mE}} \cdot \frac{E}{hc}$$

$$\Rightarrow \quad \frac{\lambda_c}{\lambda_p} = \frac{1}{c} \cdot \sqrt{\frac{E}{2m}}$$

63 Electrons of mass m with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength (λ_0) of the emitted X-ray is **[NEET 2016]**

(a) $\lambda_0 = \frac{2mc\lambda^2}{h}$

(b) $\lambda_0 = \frac{2h}{mc}$

(c) $\lambda_0 = \frac{2m^2c^2\lambda^3}{h^2}$

(d) $\lambda_0 = \lambda$

Ans. *(a)*

Key Idea Cut-off wavelength occurs when incoming electron looses its complete energy in collision. This energy appears in the form of X-rays.

Given, mass of electrons = m

de-Broglie wavelength = λ

So, kinetic energy of electron = $\frac{p^2}{2m}$

$$= \frac{\left(\frac{h}{\lambda}\right)^2}{2m} = \frac{h^2}{2m\lambda^2}$$

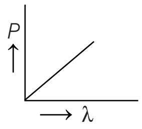
Now, maximum energy of photon can be given by

$$E = \frac{hc}{\lambda_0} = \frac{h^2}{2m\lambda^2}$$

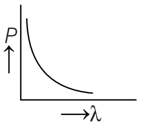
$$\Rightarrow \quad \lambda_0 = \frac{hc \times 2\lambda^2 \cdot m}{h^2} = \frac{2mc\lambda^2}{h}$$

64 Which of the following figures represent the variation of particle momentum and the associated de-Broglie wavelength? **[CBSE AIPMT 2015]**

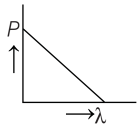
(a)



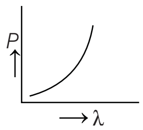
(b)



(c)



(d)



Ans. *(b)*

The de-Broglie wavelength is given by

$$\lambda = \frac{h}{P} \Rightarrow P\lambda = h$$

This equation is in the form of $yx = c$, which is the equation of a rectangular hyperbola. Hence, the graph given in option (b) is the correct one.

65 If the kinetic energy of the particle is increased to 16 times its previous value, the percentage change in the de-Broglie wavelength of the particle is **[CBSE AIPMT 2014]**

(a) 25 (b) 75

(c) 60 (d) 50

Ans. *(b)*

For de-Broglie wavelength,

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

For 1st case,

$$\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$$

For 2nd case,

$$\lambda_2 = \frac{h}{\sqrt{2m16K}} = \frac{h}{4\sqrt{2mK}} = \frac{\lambda_1}{4}$$

$$\lambda_2 = 25\% \text{ of } \lambda_1$$

So, 75% change in the wavelength takes place.

66 The wavelength λ_e of an electron and λ_p of a photon of same energy E are related by **[NEET 2013]**

(a) $\lambda_p \propto \lambda_e^2$ (b) $\lambda_p \propto \lambda_e$

(c) $\lambda_p \propto \sqrt{\lambda_e}$ (d) $\lambda_p \propto \frac{1}{\sqrt{\lambda_e}}$

Ans. *(a)*

Wavelength of electron is given by

$$\lambda_e = \frac{h}{p_e} = \frac{h}{\sqrt{2mE}} \quad [\because p_e = \sqrt{2mE}]$$

and for photon,

$$\lambda_p = \frac{hc}{E} \Rightarrow \lambda_e^2 = \frac{h^2}{2mE} \text{ or } E = \frac{hc}{\lambda_P}$$

$$\therefore \lambda_e^2 = \frac{h^2}{2m \cdot \frac{hc}{\lambda_p}} \Rightarrow \lambda_e^2 = \frac{h^2}{2mhc}\lambda_P$$

$$\Rightarrow \lambda_e^2 \propto \lambda_P$$

67 A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of 3×10^6 ms^{-1}. The velocity of the particle is (mass of electron $= 9.1 \times 10^{-31}$ kg) **[CBSE AIPMT 2008]**

(a) 2.7×10^{-18} ms^{-1} (b) 9×10^{-2} ms^{-1}

(c) 3×10^{-31} ms^{-1} (d) 2.7×10^{-21} ms^{-1}

Ans. *(a)*

According to de-Broglie relation, wavelength of a particle is given by

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

where, h is Planck's constant and wavelength of an electron is given by

$$\lambda_e = \frac{h}{p_e}$$

but $\lambda = \lambda_e$, so $p = p_e$

or $m_e v_e = mv$ or $v = \frac{m_e v_e}{m}$

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

$v_e = 3 \times 10^6$ ms^{-1}

and $m = 1$ mg

$= 1 \times 10^{-6}$ kg

$$\therefore \quad v = \frac{9.1 \times 10^{-31} \times 3 \times 10^6}{1 \times 10^{-6}}$$

$$= 2.7 \times 10^{-18} \text{ m/s}$$

68 The following particles are moving with the same velocity, then maximum de-Broglie wavelength will be for **[CBSE AIPMT 2002]**

(a) proton (b) α-particle

(c) neutron (d) β-particle

Ans. *(d)*

de-Broglie wavelength is given by

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

For same velocity, $\lambda \propto \frac{1}{m}$

Out of the given particles, the mass of β-particle which is a fast moving electron, is minimum. Thus, de-Broglie wavelength is maximum for β-particle.

69 The energy of a photon of light is 3 eV. Then the wavelength of photon must be **[CBSE AIPMT 2000]**

(a) 4125 nm

(b) 412.5 nm

(c) 41250 nm

(d) 4 nm

Ans. *(b)*

If energy E is expressed in (eV) and wavelength λ (in Å), then energy of photon,

$$E = \frac{hc}{\lambda} = \frac{12375}{\lambda\,(\text{Å})}\,\text{eV}$$

$$\therefore\ \lambda = \frac{12375}{E\,(\text{eV})}\,\text{Å} \qquad [\because hc = 12375\,\text{eV-Å}]$$

$$= \frac{12375}{3\,(\text{eV})}\,\text{Å} = 4125\,\text{Å} = 412.5\,\text{nm}$$

Note

Energy of photon is $E = \frac{hc}{\lambda\,(\text{Å})} = \frac{12375}{\lambda\,(\text{Å})} eV$

Here, hc = 12375 eV-Å comes from the following procedure

hc = (Planck's constant) (velocity of light)

$$= \frac{(6.6 \times 10^{-34}\ J\text{-}s)\ (3 \times 10^{8}\ m/s)}{(1.6 \times 10^{-19}\ J/eV)}$$

$= 12.375 \times 10^{-7}$ eV-m

= 12375 eV-Å

70 The wavelength associated with an electron, accelerated through a potential difference of 100 V, is of the order of **[CBSE AIPMT 1996]**

(a) 1000 Å (b) 100 Å

(c) 10.5 Å (d) 1.2 Å

Ans. *(d)*

When electrons are accelerated through V volt, the gain in KE of the electron is given by

$$\frac{1}{2}mv^2 = \text{eV} \quad \text{or} \quad v^2 = \frac{2\text{eV}}{m}$$

Given, $V = 100$ V

So, $v = \sqrt{\frac{2e(100)}{m}}$ ...(i)

According to de-Broglie theory, wavelength

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

$$\therefore \quad \lambda = \frac{h}{m\sqrt{\frac{2\,e(100)}{m}}} = \frac{h}{\sqrt{2me(100)}}$$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 100}}$$

$$= 1.2 \times 10^{-10}$$

$$\Rightarrow \quad = 1.2\ \text{Å}$$

71 The de-Broglie wave corresponding to a particle of mass m and velocity v has a wavelength associated with it **[CBSE AIPMT 1989]**

(a) $\frac{h}{mv}$ (b) hmv

(c) $\frac{mh}{v}$ (d) $\frac{m}{hv}$

Ans. *(a)*

According to de-Broglie, a moving particle sometimes acts as a wave and sometimes as a particle. The wave associated with moving particle is called matter wave or de-Broglie wave whose wavelength is called de-Broglie wavelength and it is given by

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

where, m and v are the mass and velocity of the particle and h is Planck's constant.