CHAPTER 11

DUAL NATURE OF RADIATION AND MATTER

CLASS 12TH

NCERT EXERCISE AND SOLUTIONS - PHYSICS

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11.1 Find the
(a) maximum frequency, and
(b) minimum wavelength of X-rays produced by 30 kV electrons.

SOLUTION:

Given – Potential of the electrons (V) = 30 kV = 3×10^4 V

(a) Let maximum frequency of X - ray = v

The energy of the electron is given by,

$$E = hv \qquad (\because h = \text{ Planck's constant} = 6.626\times10^{-34} Js)$$

$$v = \frac{E}{h}$$

$\therefore$ Energy of the electrons E = eV = $(1.6 \times 10^{-19})(1.6 \times 10^4 \text{ V})$

$$v = \frac{(1.6\times10^{-19})\times(3\times10^4)}{(6.626\times10^{-34})}$$

$$v = 7.24\times10^{18} Hz$$

Therefore, the maximum frequency of X-rays produced is $7.24\times10^{18} Hz$.

(b) Minimum wavelength of X-rays is given by,

$$\lambda = \frac{c}{v}$$

$$\lambda = \frac{3\times10^8}{7.24\times10^{18}} = 4.14\times10^{-11}\text{m}$$

$$\lambda = 0.0414 nm$$

Therefore, the minimum wavelength of X-rays produced is $0.0414 nm$.

11.2 The work function of caesium metal is 2.14 eV. When light of frequency 6 × 10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. What is the
(a) maximum kinetic energy of the emitted electrons,
(b) Stopping potential, and
(c) maximum speed of the emitted photoelectrons?

SOLUTION:

Given – Work function (ϕ_0) = 2.14 eV, Frequency (v) = 6 × 10^{14} Hz.

(a) The maximum kinetic energy of the emitted electrons is given by,

$$K = hv - \phi_0 \qquad (\because h = \text{ Planck's constant} = 6.626\times10^{-34}\,Js)$$

$$K = \frac{(6.626\times10^{34})\times(6\times10^{14})}{1.6\times10^{-19}} - (2.14)$$

$$K = 2.485 - 2.140 = 0.345eV$$

Therefore, the maximum kinetic energy of emitted electrons is $0.345eV$.

(b) Stopping potential is given by,

$$K = eV_0$$

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

$$V_0 = \frac{0.345\times1.6\times10^{-19}}{1.6\times10^{-19}}$$

$$V_0 = 0.345\text{V}$$

Therefore, stopping potential is 0.345 V.

(c) The maximum speed of the emitted photoelectrons is given by,

$$K = \frac{1}{2}mv^2 \qquad (\because m = \text{ Mass of an electron} = 9.1\times10^{-31}\,kg)$$

$$v^2 = \frac{2K}{m}$$

$$v^2 = \frac{2\times0.345\times1.6\times10^{-19}}{9.1\times10^{-31}} = 0.1104\times10^{12}$$

$$v = 3.323\times10^5\,\text{m/s} = 332.3km/\text{s}$$

Therefore, the maximum speed of the emitted photoelectrons is 332.3 km/s.

11.3 The photoelectric cut-off voltage in a certain experiment is 1.5 V. What is the maximum kinetic energy of photoelectrons emitted?

SOLUTION:

Given – Cut-off voltage (V_0) = 1.5 V.

Need to find – Maximum kinetic energy of photoelectrons.

The maximum kinetic energy of photoelectrons is given by,

$$K_e = eV_0$$

$$K_e = 1.6\times10^{-19}\times1.5$$

$$K_e = 2.4\times10^{-19}\,\text{J}$$

Therefore, the maximum kinetic energy of photoelectrons is 2.4×10^{-19} J.

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11.4 **Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW.**

(a) Find the energy and momentum of each photon in the light beam,

(b) How many photons per second, on the average, arrive at a target irradiated by this beam? (Assume the beam to have uniform cross-section which is less than the target area), and

(c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

SOLUTION:

Given – Wavelength (λ) = 632.8 nm = 632.8×10^{-9} m, Power emitted (P) = 9.42 mW = 9.42×10^{-3} W

(a) The energy of each photon is given by,

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

Where, Planck's constant (h) = 6.626×10^{-34} Js and Speed of light (c) = 3×10^{8} m/s.

$$E = \frac{6.626\times10^{-34}\times3\times10^{8}}{632.8\times10^{-9}}$$

$$E = 3.141\times10^{-19}\,\text{J}$$

and

The momentum of each photon is given by,

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

$$p = \frac{6.626\times10^{-34}}{632.8}$$

$$p = 1.047\times10^{-27}\,kgm/s$$

Therefore, the energy and momentum of each photon is 3.141×10^{-19} J and 1.047×10^{-27} kg m/s respectively.

(b) Let number of photons arriving per second irradiated by the beam = n

Equation of power can be written as:

$$P = nE$$

$$n = \frac{P}{E}$$

$$n = \frac{9.42\times10^{-3}}{3.141\times10^{-19}} \approx 3\times10^{16}\ \text{photon / s}$$

Therefore, the number of photons arriving per second is 3×10^{16} p/s.

(c) Hydrogen atoms have the same momentum as that of the photon.

i.e., $p = 1.047\times10^{-27}\,kgms^{-1}$

We know that the momentum is given by,

$$v = \frac{p}{m}$$

$$v = \frac{1.047\times10^{-27}}{1.66\times10^{-27}}$$
$$v = 0.621\,\text{m/s}$$

Therefore, the speed of hydrogen atoms is 0.621 m/s.

11.5 In an experiment on photoelectric effect, the slope of the cut-off voltage versus frequency of incident light is found to be 4.12 × 10^{-15} V s. Calculate the value of Planck's constant.

SOLUTION:

Given – $\frac{V}{v} = 4.12\times10^{-15}\,Vs$.

Need to find – Plank's constant.

We know that,

$$E = hv = eV \qquad (\because e = \text{ charge of an electron } = 1.6\times10^{-19}\,C)$$
$$h = e\times\frac{V}{v}$$
$$h = 1.6\times10^{-19}\times4.12\times10^{-15} = 6.592\times10^{-34}\,Js$$

Therefore, the value of plank's constant (h) is $6.592\times10^{-34}\,Js$.

11.6 The threshold frequency for a certain metal is 3.3 × 10^{14} Hz. If light of frequency 8.2 × 10^{14} Hz is incident on the metal, predict the cutoff voltage for the photoelectric emission.

SOLUTION:

Given – Threshold frequency (v_0) = 3.3 × 10^{14} Hz, Frequency of incident light (v) = 8.2 × 10^{14} Hz.

Need to find – Cut-off voltage (V_0).

The cut-off voltage for the photoelectric emission is given by,

$$eV_0 = h(v - v_0)$$
$$V_0 = \frac{h(v - v_0)}{e}$$
$$V_0 = \frac{6.626\times10^{-34}\times(8.2\times10^{14} - 3.3\times10^{14})}{1.6\times10^{-19}}$$
$$V_0 = 2.0292\text{V}$$

Therefore, the cut-off voltage for the photoelectric emission is 2.0292 V.

11.7 The work function for a certain metal is 4.2 eV. Will this metal give photoelectric emission for incident radiation of wavelength 330 nm?

SOLUTION:

Given – Work function (ϕ_0) = 4.2 eV, Wavelength of incident radiation (λ) = 330 nm = 310^{-9} m.

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Need to find – Will metal give photoelectric emissions.

The energy of the incident photon is given by,

$$E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34})\times(3\times10^{8})}{330\times10^{-9}}$$

$$E = 6.0\times10^{-19}\,\text{J}$$

$$E = \frac{6.0\times10^{-19}}{1.6\times10^{-19}} = 3.76eV$$

Here, the energy of incident radiation (3.76 eV) < Work function (4.2 eV) i.e., no photoelectric emission take place.

11.8 Light of frequency 7.21 × 10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0 × 10^5 m/s are ejected from the surface. What is the threshold frequency for photoemission of electrons?

SOLUTION:

Given – Frequency (v) = 7.21 × 10^{14} Hz, Maximum speed of electrons (v_{max}) = 6.0 × 10^5 m/s.

Need to find – Threshold frequency (0) for photoemission of electrons.

The formula for threshold frequency is given by,

$$K = hv - hv_0 \Rightarrow \frac{1}{2}mv^2 = h\left(v - v_0\right)$$

$$v_0 = v - \frac{mv^2}{2h}$$

$$v_0 = 7.21\times10^{14} - \frac{\left(9.1\times10^{-31}\right)\times\left(6\times10^{5}\right)^2}{2\times\left(6.626\times10^{-34}\right)}$$

$$v_0 = 7.21\times10^{14} - 2.472\times10^{14}$$

$$v_0 = 4.738\times10^{14}\,Hz$$

Therefore, the threshold frequency (v_0) for photoemission of electrons is $4.738\times10^{14}\,Hz$.

11.9 Light of wavelength 488 nm is produced by an argon laser which is used in the photoelectric effect. When light from this spectral line is incident on the emitter, the stopping (cut-off) potential of photoelectrons is 0.38 V. Find the work function of the material from which the emitter is made.

SOLUTION:

Given – Wavelength (λ) = 488 nm = 488 × 10^{-9} m, Cut-off potential (V_0) = 0.38 V.

Need to find – Work function (ϕ_0).

From photoelectric equation we know that,

$$K = (E - \phi_0) \Rightarrow eV_0 = \frac{hc}{\lambda} - \phi_0$$

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$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$\phi_0 = \frac{6.6\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times488\times10^{-9}} - \frac{1.6\times10^{-19}\times0.38}{1.6\times10^{-19}}$$

$$\phi_0 = 2.54 - 0.38 = 2.16eV$$

Therefore, the work function (ϕ_0) is 2.16 eV.

11.10 What is the de Broglie wavelength of

(a) a bullet of mass 0.040 kg travelling at the speed of 1.0 km/s,

(b) a ball of mass 0.060 kg moving at a speed of 1.0 m/s, and

(c) a dust particle of mass 1.0 × 10^{-9} kg drifting with a speed of 2.2 m/s?

SOLUTION:

(a) Given – Mass of the bullet (m) = 0.040 kg, Speed of the bullet (v) = 1 km/s = 1000 m/s, and Planck's constant (h) = 6.6 × 10^{-34} Js

De Broglie wavelength of the bullet is given by,

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

$$\lambda = \frac{6.6\times10^{-34}}{0.040\times1000} = 1.65\times10^{-35}\,\text{m}$$

Therefore, the de Broglie wavelength is 1.65×10^{-35} m.

(b) Given – Mass of the ball (m) = 0.060 kg, Speed of the ball (v) = 1 m/s, and Planck's constant (h) = 6.6 × 10^{-34} Js

De Broglie wavelength of the ball is given by,

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

$$\lambda = \frac{6.6\times10^{-34}}{0.060\times1} = 1.1\times10^{-32}\,\text{m}$$

Therefore, the de Broglie wavelength is 1.1×10^{-32} m.

(c) Given – Mass of the dust particle (m) = 1.0 × 10^{-9} kg, Speed of the dust particle (v) = 2.2 m/s, and Planck's constant (h) = 6.6 × 10^{-34} Js

De Broglie wavelength of the dust particle t is given by,

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

$$\lambda = \frac{6.6\times10^{-34}}{1.0\times10^{-9}\times2.2} = 3.0\times10^{-25}\,\text{m}$$

Therefore, the de Broglie wavelength is 3.0×10^{-25} m.

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+91 98103 37915

11.11 Show that the wavelength of electromagnetic radiation is equal to the de Broglie wavelength of its quantum (photon).

SOLUTION:

The momentum of a photon having energy ($h\nu$) is given by,

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

$$\lambda = \frac{h}{p} \qquad \text{……….. (i)}$$

and

The de Broglie wavelength of the photon is given by,

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

$$\lambda = \frac{h}{p} \qquad \text{……….. (ii)} \qquad (\because\ p = mv)$$

Therefore, from equations (i) and (ii), it can be concluded that the wavelength of electromagnetic radiation is the same as the de Broglie wavelength of the photon.

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