.

Question 11.1:

Find the

(a) maximum frequency, and

(b) minimum wavelength of X-rays produced by 30 kV electrons.

Answer

Potential of the electrons, V = 30 kV = 3×10^4 V

Hence, energy of the electrons, $E = 3 \times 10^4$ eV

Where,

e = Charge on an electron = 1.6×10^{-19} C

(a) Maximum frequency produced by the X-rays = ν

The energy of the electrons is given by the relation:

$E = h\nu$

Where,

h = Planck's constant = 6.626×10^{-34} Js

$$\therefore \nu = \frac{E}{h}$$

$$= \frac{1.6 \times 10^{-19} \times 3 \times 10^4}{6.626 \times 10^{-34}} = 7.24 \times 10^{18} \text{ Hz}$$

Hence, the maximum frequency of X-rays produced is 7.24×10^{18} Hz.

(b) The minimum wavelength produced by the X-rays is given as:

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

$$= \frac{3 \times 10^8}{7.24 \times 10^{18}} = 4.14 \times 10^{-11} \text{ m} = 0.0414 \text{ nm}$$

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

Question 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?

Answer

Work function of caesium metal, $\phi_0 = 2.14 \text{ eV}$

Frequency of light, $\nu = 6.0 \times 10^{14} \text{ Hz}$

(a) The maximum kinetic energy is given by the photoelectric effect as:

$$K = h\nu - \phi_0$$

Where,

h = Planck's constant = 6.626 × 10^{-34} Js

$$\therefore K = \frac{6.626 \times 10^{34} \times 6 \times 10^{14}}{1.6 \times 10^{-19}} - 2.14$$

$$= 2.485 - 2.140 = 0.345 \text{ eV}$$

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

(b) For stopping potential V_0, we can write the equation for kinetic energy as:

$$K = eV_0$$

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

$$= \frac{0.345 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}} = 0.345 \text{ V}$$

Hence, the stopping potential of the material is 0.345 V.

(c) Maximum speed of the emitted photoelectrons = v

Hence, the relation for kinetic energy can be written as:

$$K = \frac{1}{2}mv^2$$

Where,

m = Mass of an electron = 9.1 × 10^{-31} kg

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

$$= \frac{2 \times 0.345 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}} = 0.1104 \times 10^{12}$$

$$\therefore v = 3.323 \times 10^5 \text{ m/s} = 332.3 \text{ km/s}$$

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

Question 11.3:

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

Answer

Photoelectric cut-off voltage, V_0 = 1.5 V

The maximum kinetic energy of the emitted photoelectrons is given as:

$$K_e = eV_0$$

Where,

e = Charge on an electron = 1.6 × 10^{-19} C

$$\therefore K_e = 1.6 \times 10^{-19} \times 1.5$$
$$= 2.4 \times 10^{-19} \text{ J}$$

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

Question 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?

Answer

Wavelength of the monochromatic light, λ = 632.8 nm = 632.8 × 10^{-9} m

Power emitted by the laser, P = 9.42 mW = 9.42 × 10^{-3} W

Planck's constant, h = 6.626 × 10^{-34} Js

Speed of light, c = 3 × 10^{8} m/s

Mass of a hydrogen atom, m = 1.66 × 10^{-27} kg

(a) The energy of each photon is given as:

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} = 3.141 \times 10^{-19} \text{ J}$$

The momentum of each photon is given as:

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

$$= \frac{6.626 \times 10^{-34}}{632.8} = 1.047 \times 10^{-27} \text{ kg m s}^{-1}$$

(b) Number of photons arriving per second, at a target irradiated by the beam = n

Assume that the beam has a uniform cross-section that is less than the target area.

Hence, the equation for power can be written as:

$$P = nE$$

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

$$= \frac{9.42 \times 10^{-3}}{3.141 \times 10^{-19}} \approx 3 \times 10^{16} \text{ photon/s}$$

(c) Momentum of the hydrogen atom is the same as the momentum of the photon,

$$p = 1.047 \times 10^{-27} \text{ kg m s}^{-1}$$

Momentum is given as:

$$p = mv$$

Where,

v = Speed of the hydrogen atom

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

$$= \frac{1.047 \times 10^{-27}}{1.66 \times 10^{-27}} = 0.621 \text{ m/s}$$

Question 11.5:

The energy flux of sunlight reaching the surface of the earth is 1.388 × 10^{3} W/m^2. How many photons (nearly) per square metre are incident on the Earth per second? Assume that the photons in the sunlight have an average wavelength of 550 nm.

Answer

Energy flux of sunlight reaching the surface of earth, Φ = 1.388 × 10^{3} W/m^2

Hence, power of sunlight per square metre, P = 1.388 × 10^{3} W

Speed of light, c = 3 × 10^{8} m/s

Planck's constant, h = 6.626 × 10^{-34} Js

Average wavelength of photons present in sunlight, $\lambda = 550$ nm

$$= 550 \times 10^{-9} \text{ m}$$

Number of photons per square metre incident on earth per second = n

Hence, the equation for power can be written as:

$$P = nE$$

$$\therefore n = \frac{P}{E} = \frac{P\lambda}{hc}$$

$$= \frac{1.388 \times 10^{3} \times 550 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^{8}} = 3.84 \times 10^{21} \text{ photons/m}^2\text{/s}$$

Therefore, every second, 3.84×10^{21} photons are incident per square metre on earth.

Question 11.6:

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.

Answer

The slope of the cut-off voltage (*V*) versus frequency (ν) of an incident light is given as:

$$\frac{V}{\nu} = 4.12 \times 10^{-15} \text{ Vs}$$

V is related to frequency by the equation:

$$h\nu = eV$$

Where,

e = Charge on an electron = 1.6×10^{-19} C

h = Planck's constant

$$\therefore h = e \times \frac{V}{\nu}$$

$$= 1.6 \times 10^{-19} \times 4.12 \times 10^{-15} = 6.592 \times 10^{-34} \text{ Js}$$

Therefore, the value of Planck's constant is 6.592×10^{-34} Js.

Question 11.7:

A 100 W sodium lamp radiates energy uniformly in all directions. The lamp is located at the centre of a large sphere that absorbs all the sodium light which is incident on it. The wavelength of the sodium light is 589 nm. (a) What is the energy per photon associated with the sodium light? (b) At what rate are the photons delivered to the sphere?

Answer

Power of the sodium lamp, P = 100 W

Wavelength of the emitted sodium light, λ = 589 nm = 589×10^{-9} m

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

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

(a) The energy per photon associated with the sodium light is given as:

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{589 \times 10^{-9}} = 3.37 \times 10^{-19} \text{ J}$$

$$= \frac{3.37 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.11 \text{ eV}$$

(b) Number of photons delivered to the sphere = n

The equation for power can be written as:

$$P = nE$$

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

$$= \frac{100}{3.37 \times 10^{-19}} = 2.96 \times 10^{20} \text{ photons/s}$$

Therefore, every second, 2.96×10^{20} photons are delivered to the sphere.

Question 11.8:

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.

Answer

Threshold frequency of the metal, $\nu_0 = 3.3 \times 10^{14}$ Hz

Frequency of light incident on the metal, $\nu = 8.2 \times 10^{14}$ Hz

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

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Cut-off voltage for the photoelectric emission from the metal = V_0

The equation for the cut-off energy is given as:

$$eV_0 = h(\nu - \nu_0)$$

$$V_0 = \frac{h(\nu - \nu_0)}{e}$$

$$= \frac{6.626 \times 10^{-34} \times (8.2 \times 10^{14} - 3.3 \times 10^{14})}{1.6 \times 10^{-19}} = 2.0292 \text{ V}$$

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

Question 11.9:

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

Answer

No

Work function of the metal, $\phi_0 = 4.2$ eV

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

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Wavelength of the incident radiation, $\lambda = 330$ nm $= 330 \times 10^{-9}$ m

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

The energy of the incident photon is given as:

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{330 \times 10^{-9}} = 6.0 \times 10^{-19} \text{ J}$$

$$= \frac{6.0 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.76 \text{ eV}$$

It can be observed that the energy of the incident radiation is less than the work function of the metal. Hence, no photoelectric emission will take place.

*********** END **********