Example 11.1 Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. (a) What is the energy of a photon in the light beam? (b) How many photons per second, on an average, are emitted by the source?

Solution

(a) Each photon has an energy

$$E = h\,\nu = (6.63 \times 10^{-34}\ \mathrm{J\ s})\,(6.0 \times 10^{14}\ \mathrm{Hz})$$
$$= 3.98 \times 10^{-19}\ \mathrm{J}$$

(b) If N is the number of photons emitted by the source per second, the power P transmitted in the beam equals N times the energy per photon E, so that $P = N\,E$. Then

$$N = \frac{P}{E} = \frac{2.0 \times 10^{-3}\ \mathrm{W}}{3.98 \times 10^{-19}\ \mathrm{J}}$$
$$= 5.0 \times 10^{15} \text{ photons per second.}$$

Example 11.2 The work function of caesium is 2.14 eV. Find (a) the threshold frequency for caesium, and (b) the wavelength of the incident light if the photocurrent is brought to zero by a stopping potential of 0.60 V.

Solution

(a) For the cut-off or threshold frequency, the energy $h\,\nu_0$ of the incident radiation must be equal to work function ϕ_0, so that

$$\nu_0 = \frac{\phi_0}{h} = \frac{2.14\,\text{eV}}{6.63\times10^{-34}\,\text{J s}}$$

$$= \frac{2.14\times1.6\times10^{-19}\,\text{J}}{6.63\times10^{-34}\,\text{J s}} = 5.16\times10^{14}\ \text{Hz}$$

Thus, for frequencies less than this threshold frequency, no photoelectrons are ejected.

(b) Photocurrent reduces to zero, when maximum kinetic energy of the emitted photoelectrons equals the potential energy $e\,V_0$ by the retarding potential V_0. Einstein's Photoelectric equation is

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

or, $\lambda = hc/(eV_0 + \phi_0)$

$$= \frac{(6.63\times10^{-34}\,\text{J s})\times(3\times10^{8}\,\text{m/s})}{(0.60\,\text{eV}+2.14\,\text{eV})}$$

$$= \frac{19.89\times10^{-26}\,\text{J m}}{(2.74\,\text{eV})}$$

$$\lambda = \frac{19.89\times10^{-26}\,\text{J m}}{2.74\times1.6\times10^{-19}\,\text{J}} = 454\ \text{nm}$$

Example 11.3 What is the de Broglie wavelength associated with (a) an electron moving with a speed of 5.4×10^{6} m/s, and (b) a ball of mass 150 g travelling at 30.0 m/s?

Solution

(a) For the electron:

Mass $m = 9.11\times10^{-31}$ kg, speed $v = 5.4\times10^{6}$ m/s. Then, momentum

$p = m\,v = 9.11\times10^{-31}\ (\text{kg}) \times 5.4 \times 10^{6}\ (\text{m/s})$

$p = 4.92 \times 10^{-24}$ kg m/s

de Broglie wavelength, $\lambda = h/p$

$$= \frac{6.63\times10^{-34}\ \text{J s}}{4.92\times10^{-24}\ \text{kg m/s}}$$

$\lambda = 0.135$ nm

(b) For the ball:

Mass $m' = 0.150$ kg, speed $v' = 30.0$ m/s.

Then momentum $p' = m'\,v' = 0.150\ (\text{kg}) \times 30.0\ (\text{m/s})$

$p' = 4.50$ kg m/s

de Broglie wavelength $\lambda' = h/p'$.

$$= \frac{6.63\times10^{-34}\ \text{J s}}{4.50\times\ \text{kg m/s}}$$

$\lambda' = 1.47 \times10^{-34}$ m

The de Broglie wavelength of electron is comparable with X-ray wavelengths. However, for the ball it is about 10^{-19} times the size of the proton, quite beyond experimental measurement.