

570.

Problem 41.45 (RHK)

A helium-neon laser of the type often found in the physics laboratories has a beam power output of 5.00 mW at a wavelength of 633 nm. The beam is focussed by a lens to a circular spot whose effective diameter may be taken to be 2.10 wavelengths. We have to calculate (a) the intensity of the focussed beam; (b) the radiation pressure exerted on a tiny, perfectly absorbing sphere whose diameter is that of the focal spot; (c) the force exerted on this sphere; and (d) the acceleration imparted to it. We may assume that the density of the sphere is 4.88 g cm^{-3} .

Solution:

(a)

As the laser beam, wavelength $\lambda = 633 \times 10^{-9} \text{ m}$, and power 5.00 mW is focussed to a circular spot of effective diameter

$$d = 2.10\lambda = 2.10 \times 633 \times 10^{-9} \text{ m},$$

the intensity of the focussed beam will be

$$I = \frac{P}{(\pi d^2/4)} = \frac{5.0 \times 10^{-3}}{\left(\pi \times (2.10 \times 633 \times 10^{-9})^2 / 4\right)} \text{ W m}^{-2}$$

$$= 3.60 \times 10^9 \text{ W m}^{-2} = 3.60 \text{ GW m}^{-2}.$$

(b)

The radiation pressure exerted on a tiny, perfectly absorbing sphere whose diameter is that of the focal spot will be

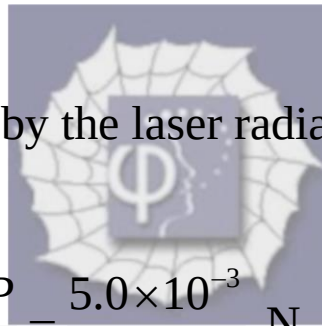
$$\frac{I}{c} = \frac{3.60 \times 10^9}{3 \times 10^8} \text{ Pa} = 12 \text{ Pa}.$$

(c)

The force exerted by the laser radiation on the sphere will be

$$F = \frac{I}{c} (\pi d^2/4) = \frac{P}{c} = \frac{5.0 \times 10^{-3}}{3 \times 10^8} \text{ N}$$

$$= 16.66 \text{ pN}.$$



(d)

Mass of the sphere

$$m = \frac{4\pi}{3} \times \left(\frac{d}{2}\right)^3 \times \rho$$

$$= \frac{4\pi}{3} \times (1.05 \times 633 \times 10^{-9})^3 \times 4.88 \times 10^3 \text{ kg}$$

$$= 6.00 \times 10^{-15} \text{ kg}.$$

Therefore, the acceleration imparted to the sphere by the laser beam will be

$$a = \frac{F}{m} = \frac{16.66 \times 10^{-12}}{6.00 \times 10^{-15}} \text{ m s}^{-2} = 2.77 \text{ km s}^{-2}.$$

