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 $\lambda = 633\times10^{-9}$ m, and power 5.00 mW is focussed to a circular spot of effective diameter

$$d = 2.10\lambda = 2.10\times633\times10^{-9}\ \text{m},$$

the intensity of the focussed beam will be

$$I = \frac{P}{\left(\pi d^2/4\right)} = \frac{5.0\times10^{-3}}{\left(\pi\times\left(2.10\times633\times10^{-9}\right)^2/4\right)}\ \text{W m}^{-2}$$

$$= 3.60\times10^{9}\ \text{W m}^{-2} = 3.60\ \text{GW m}^{-2}.$$

(b)

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

$$\frac{I}{c} = \frac{3.60\times10^{9}}{3\times10^{8}}\ \text{Pa} = 12\ \text{Pa}.$$

(c)

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

$$F = \frac{I}{c}\left(\pi d^2/4\right) = \frac{P}{c} = \frac{5.0\times10^{-3}}{3\times10^{8}}\ \text{N}$$

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

(d)

Mass of the sphere

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

$$= \frac{4\pi}{3}\times\left(1.05\times633\times10^{-9}\right)^3\times4.88\times10^{3}\ \text{kg}$$

$$= 6.00\times10^{-15}\ \text{kg}.$$

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

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