## * 22–6 Momentum Transfer and Radiation Pressure

If electromagnetic waves carry energy, then we might expect them to also carry linear momentum. When an electromagnetic wave encounters the surface of an object and is absorbed or reflected, a force will be exerted on the surface as a result of the momentum transfer ($F = \Delta p/\Delta t$) just as when a moving object strikes a surface. The force per unit area exerted by the waves is called **radiation pressure**, and its existence was predicted by Maxwell. He showed that if a beam of EM radiation (light, for example) is completely absorbed by an object, then the momentum transferred is

$$\Delta p = \frac{\Delta U}{c}, \qquad \begin{bmatrix}\text{radiation}\\ \text{absorbed}\end{bmatrix} \qquad \textbf{(22–9a)}$$

where $\Delta U$ is the energy absorbed by the object in a time $\Delta t$ and $c$ is the speed of light. If, instead, the radiation is fully reflected (suppose the object is a mirror), then the momentum transferred is twice as great, just as when a ball bounces elastically off a surface:

$$\Delta p = \frac{2\Delta U}{c}. \qquad \begin{bmatrix}\text{radiation}\\ \text{reflected}\end{bmatrix} \qquad \textbf{(22–9b)}$$

If a surface absorbs some of the energy, and reflects some of it, then $\Delta p = a\,\Delta U/c$, where $a$ has a value between 1 and 2.

Using Newton's second law we can calculate the force and the pressure exerted by EM radiation on an object. The force $F$ is given by

$$F = \frac{\Delta p}{\Delta t}.$$

The radiation pressure $P$ (assuming full absorption) is given by (see Eq. 22–9a)

$$P = \frac{F}{A} = \frac{1}{A}\frac{\Delta p}{\Delta t} = \frac{1}{Ac}\frac{\Delta U}{\Delta t}.$$

We discussed in Section 22–5 that the average intensity $\overline{I}$ is defined as energy per unit time per unit area:

$$\overline{I} = \frac{\Delta U}{A\,\Delta t}.$$

Hence the radiation pressure is

$$P = \frac{\overline{I}}{c}. \qquad \textbf{(22–10a)}$$

*Radiation pressure (absorbed)*

If the light is fully reflected, the pressure is twice as great (Eq. 22–9b):

$$P = \frac{2\overline{I}}{c}. \qquad \textbf{(22–10b)}$$

*Radiation pressure (reflected)*

**EXAMPLE 22–5 ESTIMATE Solar pressure.** Radiation from the Sun that reaches the Earth's surface (after passing through the atmosphere) transports energy at a rate of about $1000\,\text{W/m}^2$. Estimate the pressure and force exerted by the Sun on your outstretched hand.

**APPROACH** The radiation is partially reflected and partially absorbed, so let us estimate simply $P = \overline{I}/c$.

**SOLUTION** $$P \approx \frac{\overline{I}}{c} = \frac{1000\,\text{W/m}^2}{3\times10^8\,\text{m/s}} \approx 3\times10^{-6}\,\text{N/m}^2.$$

An estimate of the area of your outstretched hand might be about 10 cm by 20 cm, so $A = 0.02\,\text{m}^2$. Then the force is

$$F = PA \approx \left(3\times10^{-6}\,\text{N/m}^2\right)\left(0.02\,\text{m}^2\right) \approx 6\times10^{-8}\,\text{N}.$$

**NOTE** These numbers are tiny. The force of gravity on your hand, for comparison, is maybe a half pound, or with $m = 0.2\,\text{kg}$, $mg \approx (0.2\,\text{kg})(9.8\,\text{m/s}^2) \approx 2\,\text{N}$. The radiation pressure on your hand is imperceptible compared to gravity.