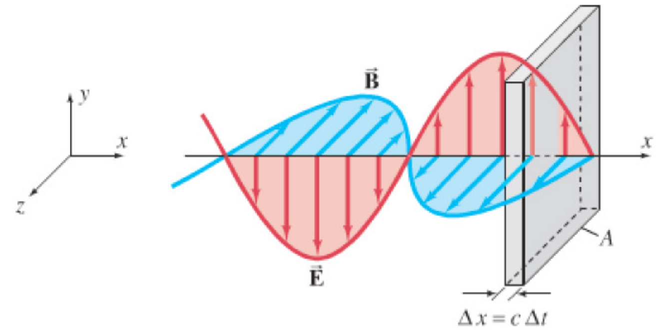

FIGURE 22–11 Electromagnetic wave carrying energy through area A.

The energy a wave transports per unit time per unit area is the **intensity** I, as defined in Sections 11–9 and 12–2.† The units of I are W/m^2. The energy passing through an area A in a time Δt (see Fig. 22–11) is

$$\Delta U = u\,\Delta V = (u)(A\,\Delta x) = \left(\epsilon_0 E^2\right)(Ac\,\Delta t)$$

because $\Delta x = c\,\Delta t$. Therefore, the magnitude of the intensity (energy per unit area per time Δt, or power per unit area) is

$$I = \frac{\Delta U}{A\,\Delta t} = \frac{\left(\epsilon_0 E^2\right)(Ac\,\Delta t)}{A\,\Delta t} = \epsilon_0 c E^2.$$

From Eqs. 22–2 and 22–3, this can also be written

Intensity of EM waves

$$I = \epsilon_0 c E^2 = \frac{c}{\mu_0} B^2 = \frac{EB}{\mu_0}. \qquad \textbf{(22–7)}$$

The *average intensity* over an extended period of time, if E and B are sinusoidal so that $\overline{E^2} = E_0^2/2$ (just as for electric currents and voltages, Section 18–7), is

Average intensity

$$\overline{I} = \frac{1}{2}\epsilon_0 c E_0^2 = \frac{1}{2}\frac{c}{\mu_0} B_0^2 = \frac{E_0 B_0}{2\mu_0}. \qquad \textbf{(22–8)}$$

Here E_0 and B_0 are the maximum values of E and B. We can also write

$$\overline{I} = \frac{E_{\mathrm{rms}} B_{\mathrm{rms}}}{\mu_0},$$

where E_{rms} and B_{rms} are the rms values $\left(E_{\mathrm{rms}} = \sqrt{\overline{E^2}},\ B_{\mathrm{rms}} = \sqrt{\overline{B^2}}\right)$.

EXAMPLE 22–4 ***E* and *B* from the Sun.** Radiation from the Sun reaches the Earth (above the atmosphere) at a rate of about $1350\,\mathrm{J/s\cdot m^2}$ $\left(= 1350\,\mathrm{W/m^2}\right)$. Assume that this is a single EM wave, and calculate the maximum values of E and B.

APPROACH We are given the intensity $\overline{I} = 1350\,\mathrm{J/s\cdot m^2}$. We solve Eq. 22–8 $\left(\overline{I} = \frac{1}{2}\epsilon_0 c E_0^2\right)$ for E_0 in terms of $\overline{I}$.

SOLUTION $$E_0 = \sqrt{\frac{2\overline{I}}{\epsilon_0 c}} = \sqrt{\frac{2\left(1350\,\mathrm{J/s\cdot m^2}\right)}{\left(8.85\times10^{-12}\,\mathrm{C^2/N\cdot m^2}\right)\left(3.00\times10^{8}\,\mathrm{m/s}\right)}}$$
$$= 1.01\times10^{3}\,\mathrm{V/m}.$$

From Eq. 22–2, $B = E/c$, so

$$B_0 = \frac{E_0}{c} = \frac{1.01\times10^{3}\,\mathrm{V/m}}{3.00\times10^{8}\,\mathrm{m/s}} = 3.37\times10^{-6}\,\mathrm{T}.$$

NOTE Although B has a small numerical value compared to E (because of the way the different units for E and B are defined), B contributes the same energy to the wave as E does, as we saw earlier.

†The intensity I for EM waves is often called the **Poynting vector** and given the symbol $\vec{\mathbf{S}}$. Its direction is that in which the energy is being transported, which is the direction the wave is traveling, and its magnitude is the intensity ($S = I$).