SOLUTION The intensity I at 30 m is

$$140\text{ dB} = 10\log\left(\frac{I}{10^{-12}\text{ W/m}^2}\right).$$

Reversing the log equation to solve for I, we have

$$10^{14} = \frac{I}{10^{-12}\text{ W/m}^2},$$

so $I = (10^{14})(10^{-12}\text{ W/m}^2) = 10^2\text{ W/m}^2$. At 300 m, 10 times as far, the intensity will be $(\frac{1}{10})^2 = 1/100$ as much, or 1 W/m^2. Hence, the sound level is

$$\beta = 10\log\left(\frac{1\text{ W/m}^2}{10^{-12}\text{ W/m}^2}\right) = 120\text{ dB}.$$

Even at 300 m, the sound is at the threshold of pain. This is why workers at airports wear ear covers to protect their ears from damage (Fig. 12–4).

NOTE Here is a simpler approach that avoids Eq. 12–1: because the intensity decreases as the square of the distance, at 10 times the distance the intensity decreases by $(\frac{1}{10})^2 = \frac{1}{100}$. We can use the result that 10 dB corresponds to an intensity change by a factor of 10 (see just before Example 12–3). Then an intensity change by a factor of 100 corresponds to a sound-level change of (2)(10 dB) = 20 dB. This confirms our result above: 140 dB − 20 dB = 120 dB.

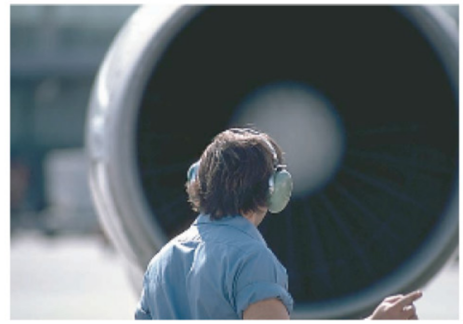

FIGURE 12–4 Example 12–5. Airport worker with sound-intensity-reducing ear covers (headphones).

EXERCISE C If you double your distance from a source of sound that is radiating freely in all directions, how does the intensity that you hear change? By how many dB does the sound level change?

* Intensity Related to Amplitude

The intensity I of a wave is proportional to the square of the wave amplitude, A, as discussed in Sections 11–9 and 11–10. We can then relate the amplitude quantitatively to the intensity I or level β, as the following Example shows.

EXAMPLE 12–6 **How tiny the displacement is.** Calculate the displacement of air molecules for a sound having a frequency of 1000 Hz at the threshold of hearing.

PHYSICS APPLIED
Incredible sensitivity of the ear

APPROACH In Section 11–10 we found a relation between intensity I and displacement amplitude A of a wave, Eq. 11–18. The amplitude of oscillation of air molecules is what we want to solve for, given the intensity.

SOLUTION At the threshold of hearing, $I = 1 \times 10^{-12}\text{ W/m}^2$ (Table 12–2). We solve for the amplitude A in Eq. 11–18:

$$\begin{aligned} A &= \frac{1}{\pi f}\sqrt{\frac{I}{2\rho v}} \\ &= \frac{1}{(3.14)(1.0 \times 10^3\text{ s}^{-1})}\sqrt{\frac{1.0 \times 10^{-12}\text{ W/m}^2}{(2)(1.29\text{ kg/m}^3)(343\text{ m/s})}} \\ &= 1.1 \times 10^{-11}\text{ m}, \end{aligned}$$

where we have taken the density of air to be 1.29 kg/m^3 and the speed of sound in air (assumed 20°C) as 343 m/s.

NOTE We see how incredibly sensitive the human ear is: it can detect displacements of air molecules which are actually less than the diameter of atoms (about 10^{-10} m).

Ear detects displacements smaller than size of atoms