* Speed of Longitudinal Waves

The speed of a longitudinal wave has a form similar to that for a transverse wave on a cord (Eq. 11–13):

$$v = \sqrt{\frac{\text{elastic force factor}}{\text{inertia factor}}}.$$

In particular, for a longitudinal wave traveling down a long solid rod,

Longitudinal wave speed in a long solid rod

$$v = \sqrt{\frac{E}{\rho}}, \tag{11–14a}$$

where E is the elastic modulus (Section 9–5) of the material and ρ is its density. For a longitudinal wave traveling in a liquid or gas,

Longitudinal wave speed in a fluid

$$v = \sqrt{\frac{B}{\rho}}, \tag{11–14b}$$

where B is the bulk modulus (Section 9–5) and ρ is the density.

PHYSICS APPLIED
Space perception by animals using sound waves

EXAMPLE 11–12 **Echolocation.** Echolocation is a form of sensory perception used by animals such as bats, toothed whales, and porpoises. The animal emits a pulse of sound (a longitudinal wave) which, after reflection from objects, is detected by the animal. Echolocation waves emitted by whales (Fig. 11–27) have frequencies of about 200,000 Hz. (*a*) What is the wavelength of the whale's echolocation wave? (*b*) If an obstacle is 100 m from the whale, how long after the whale emits a wave is its reflection detected?

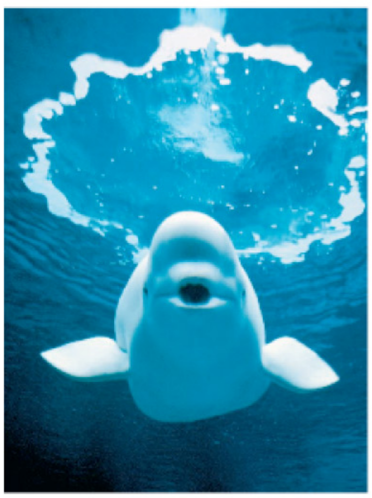

FIGURE 11–27 A toothed whale (Example 11–12).

APPROACH We first compute the speed of longitudinal (sound) waves in sea water, using Eq. 11–14b and Tables 9–1 and 10–1. The wavelength is $\lambda = v/f$.

SOLUTION (*a*) The speed of longitudinal waves in sea water, which is slightly more dense than pure water, is

$$v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.0 \times 10^9\,\mathrm{N/m^2}}{1.025 \times 10^3\,\mathrm{kg/m^3}}} = 1.40 \times 10^3\,\mathrm{m/s}.$$

Then, using Eq. 11–12, we find

$$\lambda = \frac{v}{f} = \frac{(1.40 \times 10^3\,\mathrm{m/s})}{(2.0 \times 10^5\,\mathrm{Hz})} = 7.0\,\mathrm{mm}.$$

(*b*) The time required for the round-trip between the whale and the object is

$$t = \frac{\text{distance}}{\text{speed}} = \frac{2(100\,\mathrm{m})}{1.40 \times 10^3\,\mathrm{m/s}} = 0.14\,\mathrm{s}.$$

NOTE We shall see later that waves can "resolve" (or detect) objects only if the wavelength is comparable to or smaller than the object. Thus, a whale can resolve objects on the order of a centimeter or larger in size.

Other Waves

PHYSICS APPLIED
Earthquake waves

Both transverse and longitudinal waves are produced when an **earthquake** occurs. The transverse waves that travel through the body of the Earth are called S waves (S for shear), and the longitudinal waves are called P waves (P for pressure) or *compression* waves. Both longitudinal and transverse waves can travel through a solid since the atoms or molecules can vibrate about their relatively fixed positions in any direction. But in a fluid, only longitudinal waves can propagate, because any transverse motion would experience no restoring force since a fluid is readily deformable. This fact was used by geophysicists to infer that a portion of the Earth's core must be liquid: after an earthquake, longitudinal waves are detected diametrically across the Earth, but not transverse waves.