When a sound wave is reflected from a moving obstacle, the frequency of the reflected wave will, because of the Doppler effect, be different from that of the incident wave. This is illustrated in the following Example.

**EXAMPLE 12–15** **Two Doppler shifts.** A 5000-Hz sound wave is emitted by a stationary source. This sound wave reflects from an object moving 3.50 m/s toward the source (Fig. 12–22). What is the frequency of the wave reflected by the moving object as detected by a detector at rest near the source?

**APPROACH** There are actually two Doppler shifts in this situation. First, the moving object acts like an observer moving toward the source with speed $v_{obs} = 3.50$ m/s (Fig. 12–22a) and so "detects" a sound wave of frequency (Eq. 12–3a) $f' = f[1 + (v_{obs}/v_{snd})]$. Second, reflection of the wave from the moving object is equivalent to the object reemitting the wave, acting effectively as a moving source with speed $v_{source} = 3.50$ m/s (Fig. 12–22b). The final frequency detected, $f''$, is given by $f'' = f'/[1 - v_{source}/v_{snd}]$, Eq.12–2a.

**SOLUTION** The frequency $f'$ that is "detected" by the moving object is (Eq. 12–3a):

$$f' = \left( 1 + \frac{v_{obs}}{v_{snd}} \right)f = \left( 1 + \frac{3.50 \text{ m/s}}{343 \text{ m/s}} \right)(5000 \text{ Hz}) = 5051 \text{ Hz}.$$

The moving object now "emits" (reflects) a sound of frequency (Eq. 12–2a)

$$f'' = \frac{f'}{\left( 1 - \dfrac{v_{source}}{v_{snd}} \right)} = \frac{5051 \text{ Hz}}{\left( 1 - \dfrac{3.50 \text{ m/s}}{343 \text{ m/s}} \right)} = 5103 \text{ Hz}.$$

Thus the frequency shifts by 103 Hz.



**FIGURE 12–22** Example 12–15.

The incident wave and the reflected wave in Example 12–15, when mixed together (say, electronically), interfere with one another and beats are produced. The beat frequency is equal to the difference in the two frequencies, 103 Hz. This Doppler technique is used in a variety of medical applications, usually with ultrasonic waves in the megahertz frequency range. For example, ultrasonic waves reflected from red blood cells can be used to determine the velocity of blood flow. Similarly, the technique can be used to detect the movement of the chest of a young fetus and to monitor its heartbeat.

*PHYSICS APPLIED*
*Doppler blood-flow meter and other medical uses*

For convenience, we can write Eqs. 12–2 and 12–3 as a single equation that covers all cases of both source and observer in motion:

$$f' = f\left( \frac{v_{snd} \pm v_{obs}}{v_{snd} \mp v_{source}} \right). \qquad (12\text{–}4)$$

*Source and observer moving*

To get the signs right, recall from your own experience that the frequency is higher when observer and source approach each other, and lower when they move apart. Thus the upper signs in numerator and denominator apply if source and/or observer move toward each other; the lower signs apply if they are moving apart.

➡ **PROBLEM SOLVING**
*Getting the signs right*

## * Doppler Effect for Light

The Doppler effect occurs for other types of waves as well. Light and other types of electromagnetic waves (such as radar) exhibit the Doppler effect: although the formulas for the frequency shift are not identical to Eqs. 12–2 and 12–3, as we shall see in Chapter 33, the effect is similar. One important application is for weather forecasting using radar. The time delay between the emission of radar pulses and their reception after being reflected off raindrops gives the position of precipitation. Measuring the Doppler shift in frequency (as in Example 12–15) tells how fast the storm is moving and in which direction.
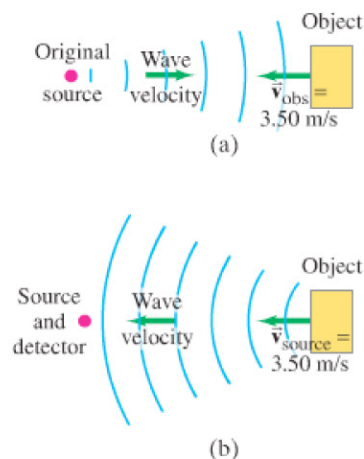
*PHYSICS APPLIED*
*Doppler effect for EM waves and weather forecasting*