We have considered a moving source with respect to a stationary observer, but the Doppler effect also occurs when the observer is moving with respect to a stationary source or when both are moving at different velocities. In other words, the Doppler effect occurs whenever there is *relative motion* between the source of waves and an observer. (If the observer is moving instead of the source, the wavelength in air does not change, but the frequency at which waves arrive at the ear is altered by the motion of the ear relative to the medium.) Although the Doppler effect is most commonly experienced with sound waves, it is a phenomenon common to all waves, including electromagnetic waves, such as visible light.

ADVANCED TOPICS

See "The Doppler Effect and the Big Bang" in **Appendix J: Advanced Topics** to learn how observations of the Doppler effect with light waves have provided evidence for the expansion of the universe.

SECTION REVIEW

1. What is the relationship between frequency and pitch?
2. Dolphin echolocation is similar to ultrasound. Reflected sound waves allow a dolphin to form an image of the object that reflected the waves. Dolphins can produce sound waves with frequencies ranging from 0.25 kHz to 220 kHz, but only those at the upper end of this spectrum are used in echolocation. Explain why high-frequency waves work better than low-frequency waves.
3. Sound pulses emitted by a dolphin travel through 20°C ocean water at a rate of 1450 m/s. In 20°C air, these pulses would travel 342.9 m/s. How can you account for this difference in speed?
4. **Interpreting Graphics** Could a portion of the innermost wave front shown in **Figure 6** be approximated by a plane wave? Why or why not?

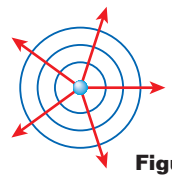

Figure 6

5. **Interpreting Graphics** **Figure 7** is a diagram of the Doppler effect in a ripple tank. In which direction is the source of these ripple waves moving?
6. **Interpreting Graphics** If the source of the waves in **Figure 7** is stationary, which way must the ripple tank be moving?

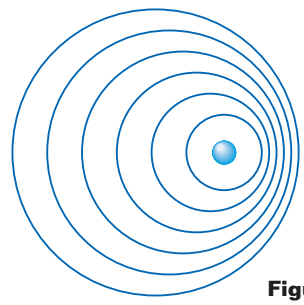

Figure 7

7. **Critical Thinking** As a dolphin swims toward a fish, the dolphin sends out sound waves to determine the direction the fish is moving. If the frequency of the reflected waves is higher than that of the emitted waves, is the dolphin catching up to the fish or falling behind?