12–7 Doppler Effect

You may have noticed that you hear the pitch of the siren on a speeding firetruck drop abruptly as it passes you. Or you may have noticed the change in pitch of a blaring horn on a fast-moving car as it passes by you. The pitch of the engine noise of a race car changes as the car passes an observer. When a source of sound is moving toward an observer, the pitch the observer hears is higher than when the source is at rest; and when the source is traveling away from the observer, the pitch is lower. This phenomenon is known as the **Doppler effect**† and occurs for all types of waves. Let us now see why it occurs, and calculate the difference between the perceived and source frequencies when there is relative motion between source and observer.

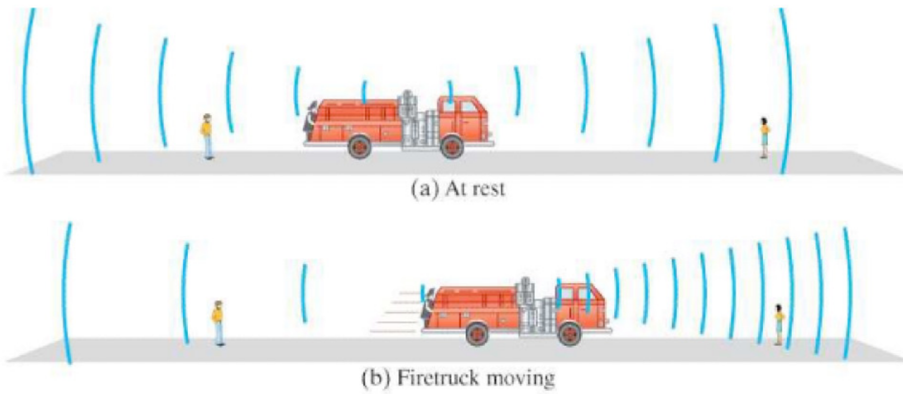
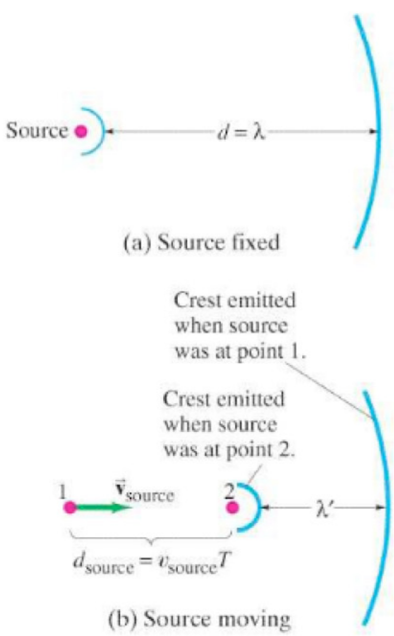


FIGURE 12–19 (a) Both observers on the sidewalk hear the same frequency from the firetruck at rest. (b) Doppler effect: observer toward whom the firetruck moves hears a higher-frequency sound, and observer behind the firetruck hears a lower-frequency sound.

FIGURE 12–20 Determination of the frequency shift in the Doppler effect (see text). The red dot is the source.



Consider the siren of a firetruck at rest, which is emitting sound of a particular frequency in all directions as shown in Fig. 12–19a. The sound waves are moving at the speed of sound in air, v_{snd}, which is independent of the velocity of the source or observer. If our source, the firetruck, is moving, the siren emits sound at the same frequency as it does at rest. But the sound wavefronts it emits forward, in front of it, are closer together than when the firetruck is at rest, as shown in Fig. 12–19b. This is because the firetruck, as it moves, is "chasing" the previously emitted wavefronts, and emits each crest closer to the previous one. Thus an observer on the sidewalk in front of the truck will detect more wave crests passing per second, so the frequency heard is higher. The wavefronts emitted behind the truck, on the other hand, are farther apart than when the truck is at rest because the truck is speeding away from them. Hence, fewer wave crests per second pass by an observer behind the moving truck (Fig. 12–19b) and the perceived pitch is lower.

We can calculate the frequency shift perceived by making use of Fig. 12–20, and we assume the air (or other medium) is at rest in our reference frame. (The stationary observer is off to the right.) In Fig. 12–20a, the source of the sound is shown as a red dot, and is at rest. Two successive wave crests are shown, the second of which has just been emitted and so is still near the source. The distance between these crests is λ, the wavelength. If the frequency of the source is f, then the time between emissions of wave crests is

$$T = \frac{1}{f} = \frac{\lambda}{v_{\text{snd}}}.$$

In Fig. 12–20b, the source is moving with a velocity v_{source} toward the observer.

† After J. C. Doppler (1803–1853).