Sound Waves Are Longitudinal Waves

If you use a strobe light to make the vibrations of a large speaker cone appear in slow motion, you will see that the cone is moving in and out, toward and away from the listener. When the speaker cone moves out, the air molecules in front of it are pushed together to produce a small volume of higher pressure air called a **compression**. When the speaker cone moves back, it produces an expanded space for the air molecules to spread out in. The result is a volume of lower pressure air called a **rarefaction**. This alternating pattern of compressions and rarefactions spreads outward through the room.

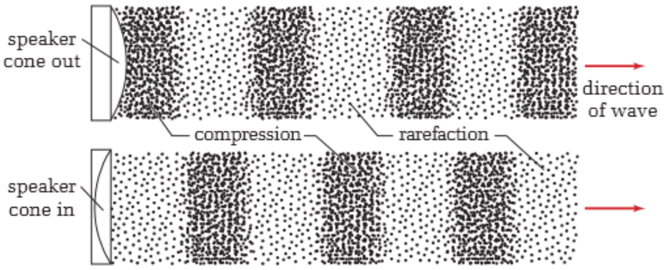
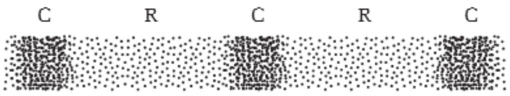


Figure 9.2 When a loudspeaker cone moves out, it exerts a force on the molecules in the air. The molecules move outward until they collide with more molecules. Individual molecules vibrate back and forth, but the collisions carry the sound energy throughout the room.

As you will recall from Chapter 8, there are two distinct types of waves — transverse waves and longitudinal waves. For transverse waves, the vibrations are perpendicular to the direction of the wave motion; for longitudinal waves, the vibrations are parallel to the direction of the wave motion. The above analysis of the sound produced by speakers demonstrates that sound waves are longitudinal. As shown in Figure 9.3, the vibrations in a sound wave correspond to the changes in air pressure at a point in space — that is, crests that are produced by compressions and troughs that are produced by rarefactions. The height of the curve represents the air pressure at that point in space.



schematic representation of the density of air molecules

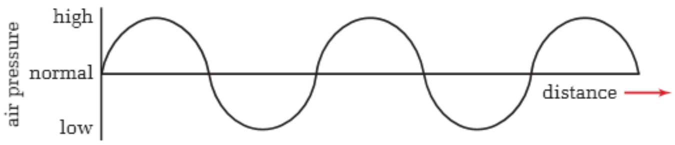


Figure 9.3 Compressions are volumes of maximum pressure, and rarefactions are volumes of minimum pressure.

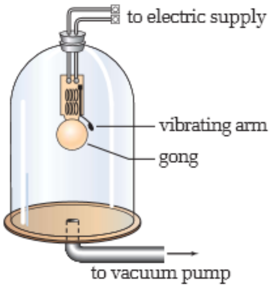
MISCONCEPTION

But That's Just Theory!

In everyday conversation, people often dismiss ideas with the phrase, "Yes, but that's just theory." This implies a misconception that theory is unreliable. While some untested theories may well be unreliable, the theories that you study in physics have been subjected to very rigorous testing. Scientists generally trust these theories much more than they trust the experiences of particular individuals. If you claimed to have invented a perpetual motion machine (a machine that would keep running forever without energy inputs), it would be very unlikely that physicists would take you seriously, even if they had not tested your machine. According to thermodynamic theory (in particular, the law of conservation of energy) such a machine is impossible. Scientists consider thermodynamic theory, because of the rigorous testing that it has undergone, extremely reliable.

PHYSICS FILE

To demonstrate that sound requires a medium through which to travel, an electric bell is sealed inside a bell jar and a vacuum pump removes the air. When the electric bell is turned on, it produces a loud ringing sound. As the vacuum pump removes the air from the bell jar, the loudness of the ringing decreases.



Properties of Sound

Humans can distinguish between sounds in a variety of ways. Sounds vary in **loudness** (perceived intensity). Jet aircraft engines are so loud that airport workers have to wear ear protection when working near them. On the other hand, the breathing of a sleeping baby is so quiet that new parents can become anxious about their child's welfare.

Sounds also vary in **pitch** (perceived frequency). Flutes and piccolos produce very similar sounds. The main difference between the two is a matter of pitch. In general, the sound of the piccolo is higher and that of the flute is lower. Sounds also vary in another important way called **quality**. The sound of a flute or whistle is described as pure, and that of a cello or organ as rich. It is the quality of a sound that enables you to identify it as being made by a piano rather than a trumpet, even when the two instruments play notes with the same loudness and pitch.

A wave model for sound must relate the loudness, pitch, and quality of the sounds that you hear to specific properties of sound waves. Everyday experience makes it clear that loudness is related to energy. To produce a louder sound from a bell, you have to hit it with more force. Yelling requires significantly more effort than whispering. Loudness, then, is in some manner connected to the **amplitude** of the sound wave. Pitch, on the other hand, is related to the frequency of the sound wave.

Pure sounds are produced by sources vibrating at only one natural frequency. Sound quality arises when the source of the sound vibrates at *several* of its natural frequencies at the same time. As shown in Figure 9.4, the superposition of these component waves — even just two of them — produces a complex wave form with a variety of smaller crests and troughs.

The conceptual links between sound perceptions and their corresponding sound wave characteristics are summarized in Figure 9.5.

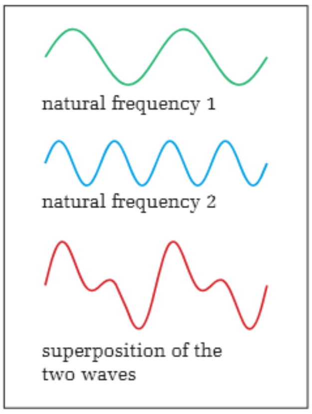
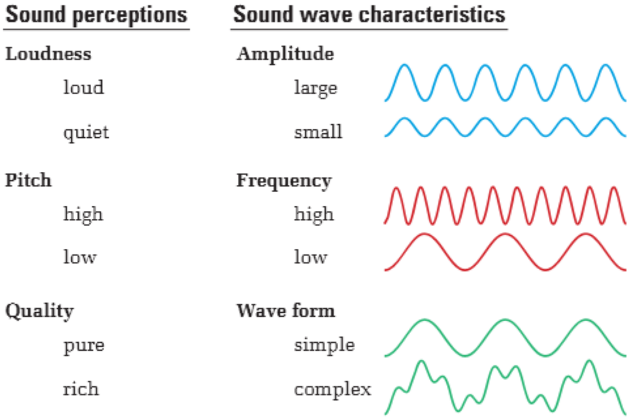


Figure 9.4 When only two frequencies are added together, the resultant wave becomes complex. The quality of this sound is richer than a pure fundamental tone.



Sound perceptions	Sound wave characteristics
Loudness	**Amplitude**
loud	large
quiet	small
Pitch	**Frequency**
high	high
low	low
Quality	**Wave form**
pure	simple
rich	complex

Figure 9.5 Characteristics of sounds and sound waves

Sound & Light: Chapter 9

- The speed of sound varies in different types of media. Generally, sound travels fastest in solids, slower in liquids, and slowest in gases.
- Recall that sound is a longitudinal pressure wave; hence it requires a medium to travel ~~though.~~ through.

- The speed of sound in air is approximated by:

$$v_{air} = 331 + 0.59T_{air}$$

- where T_{air} is the temperature of the air in degrees Celsius (not the period) and the units for the velocity are m/s. (Note: The numbers 331 and 0.59 are experimentally derived and have units such that the velocity comes out in m/s. This formula can be used only for a small range in temperature.)

- Using the Kelvin temperature scale the formula becomes:

$$v_{air} = 20.0\sqrt{T_{air}}$$

- Where once again there are units associated with the value of 20.0 that give the velocity in m/s. This equation is useful for a wider temperature range than using the Celsius scale.

- Objects traveling faster than the local speed of sound are said to be traveling at supersonic speeds. Supersonic objects generate a discontinuity of pressure and temperature in the immediate area of the moving object. The pressure drops and the temperature increases and this is generally called a shock wave.

- When objects travel faster than sound their generated sound waves bunch up into a small area. When such an object passes a listening device all of the sound is heard at once, called a sonic boom.

Example

1. What is the speed of sound in air that is 25 ºC?

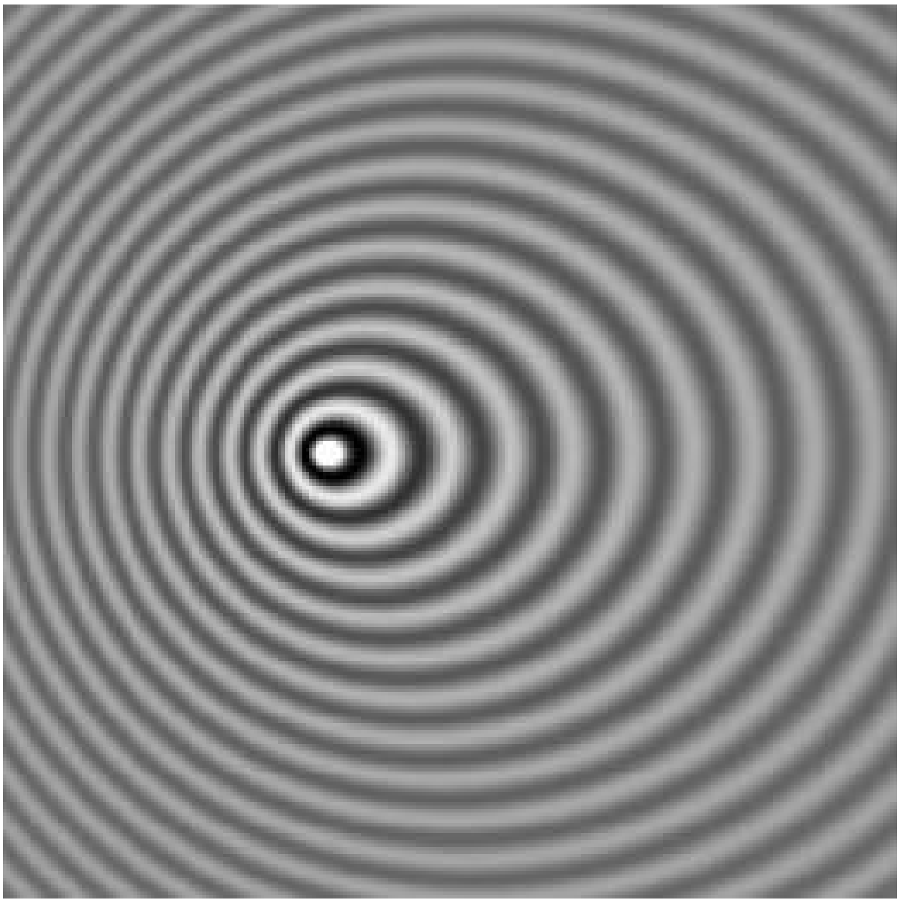
2. A fighter pilot wants to travel three times the speed of sound. How fast must she travel if the air temperature is 15 ºC?

•

What is the distance to shore if a ship captain hears the echo of his horn in 5.2 s if the temperature is -21°C?

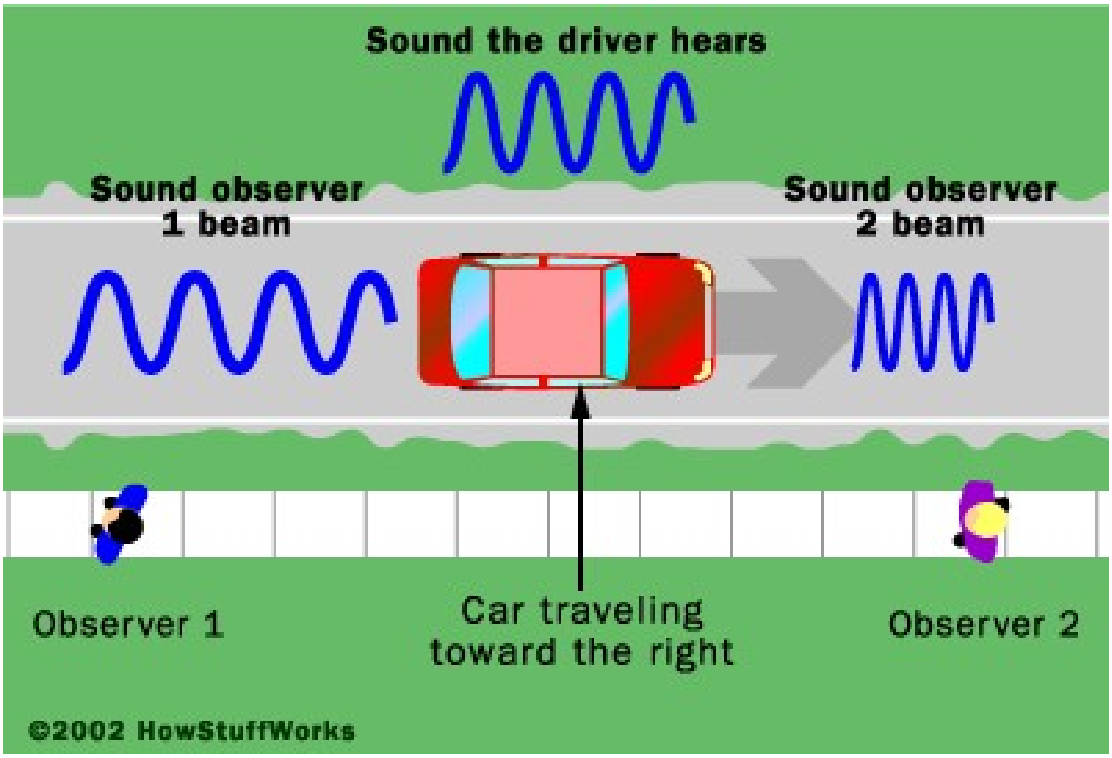
Doppler Shift

- A source generating waves moves relative to an observer, or vice – versa, there is an apparent shift in the source’s frequency.
- If the separation between source and observer is increasing, then the frequency apparently decreases.
- If the separation between source and observer is decreasing, then the frequency apparently increases.
- This can be seen by visualizing what happens to sound waves of a moving object.



http://en.wikipedia.org/wiki/Doppler_shift

- The waves compress in the direction of travel and expand in the other direction.
- This is a phenomenon familiar to many people if you’ve ever stood on a road with traffic going by.



http://static.howstuffworks.com/gif/doppler.gif

- The relationship between the frequency of a moving source and an observer (in one dimension) is represented by the Doppler shift formula as two cases: The observer and source are approaching or receding.

Approaching: $f_o = f_s\left(\dfrac{v + v_o}{v - v_s}\right)$

Receding: $f_o = f_s\left(\dfrac{v - v_o}{v + v_s}\right)$

- ➢ f_o = observed (heard) frequency
- ➢ f_s = source frequency
- ➢ v_o = observer's velocity
- ➢ v_s = velocity of the source
- ➢ v = speed of sound in medium.
- ➢ We do not need to associate a sign notation with the moving objects; the formula takes that into account.

➢ The above are the general formulas for moving observers and sound sources. The formulas become much simpler of one object is moving and the other is not.

Examples

1. What is the observed frequency of a 525 Hz source moving towards a stationary observer at 75 m/s? Take the speed of sound to be 375 m/s.

•

2. A police siren has a frequency of 1.8×10^4 Hz. A crook in his getaway car drives away from the police at 105 m/s. What frequency is heard by the crook if the police car is driving at 85 m/s? The temperature today is 25 ºC.