

# 16.2

## KEY CONCEPT

# Frequency determines pitch.

### BEFORE, you learned

- Sound waves are produced by vibrations
- Frequency measures the number of waves passing a fixed point per second

### NOW, you will learn

- How the frequency of a wave affects the way it sounds
- How sound quality differs from pitch
- How the Doppler effect works

## VOCABULARY

pitch p. 525  
hertz p. 526  
ultrasound p. 526  
resonance p. 528  
Doppler effect p. 530

## EXPLORE Pitch

### Why does the sound change?

#### PROCEDURE

- 1 Hold the ruler flat on the edge of a desk so that it sticks out about 25 centimeters beyond the edge.
- 2 With your free hand, push the tip of the ruler down and then let it go. As the ruler vibrates, slide it back onto the desk. Listen to the sounds the ruler makes.

#### MATERIALS

ruler



#### WHAT DO YOU THINK?

- What happened to the sound as you slid the ruler back onto the desk?
- Describe the motion of the ruler.



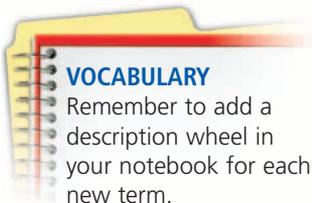
## Pitch depends on the frequency of a sound wave.

When you listen to music, you hear both high and low sounds. The characteristic of highness or lowness of a sound is called **pitch**. The frequency of a sound wave determines the pitch of the sound you hear. Remember that frequency is the number of waves passing a fixed point in a given period of time. A high-frequency wave with short wavelengths, such as that produced by a tiny flute, makes a high-pitched sound. A low-frequency wave with long wavelengths, such as the one produced by the deep croak of a tuba, makes a low-pitched sound. An object vibrating very fast produces a high-pitched sound, while an object vibrating slower produces a lower-pitched sound.



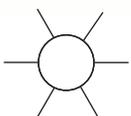
#### CHECK YOUR READING

How is frequency related to pitch?



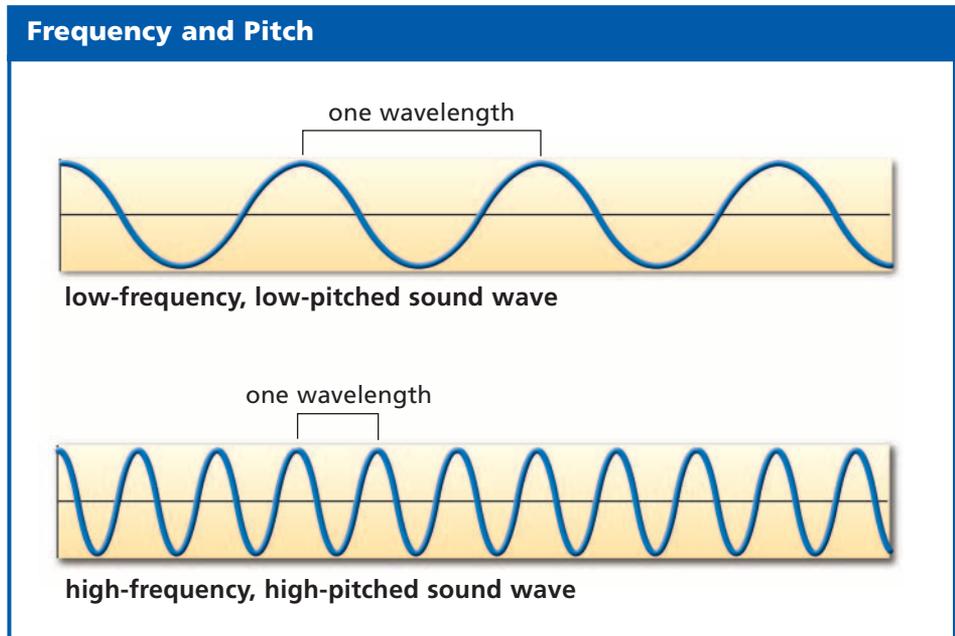
#### VOCABULARY

Remember to add a description wheel in your notebook for each new term.



## High and Low Frequencies

Frequency is a measure of how often a wave passes a fixed point. One complete wave can also be called a cycle. The unit for measuring frequency, and also pitch, is the hertz. A **hertz** (Hz) is one complete wave, or cycle, per second. For example, a wave with a frequency of 20 hertz has 20 cycles per second. In a wave with a frequency of 100 hertz, 100 waves pass a given point every second. The diagram below shows how frequency and pitch are related.



Human ears can hear a wide range of pitches. Most people with good hearing can hear sounds in the range of 20 hertz to 20,000 hertz. The note of middle C on a piano, for example, has a frequency of 262 hertz.

Sound waves with wavelengths below 20 hertz are called infrasound. People cannot hear sounds in this range. Infrasound waves have a very long wavelength and can travel great distances without losing much energy. Elephants may use infrasound to communicate over long distances. Some of the waves that elephants use travel through the ground instead of the air, and they may be detected by another elephant up to 32 kilometers (about 20 miles) away.

The highest frequency that humans can hear is 20,000 hertz. Sound waves in the range above 20,000 hertz are called **ultrasound**. Though people cannot hear ultrasound, it is very useful. Later in this chapter, you will learn about some of the uses of ultrasound. Many animals can hear sound waves in the ultrasound range. The chart on page 527 shows the hearing ranges of some animals.

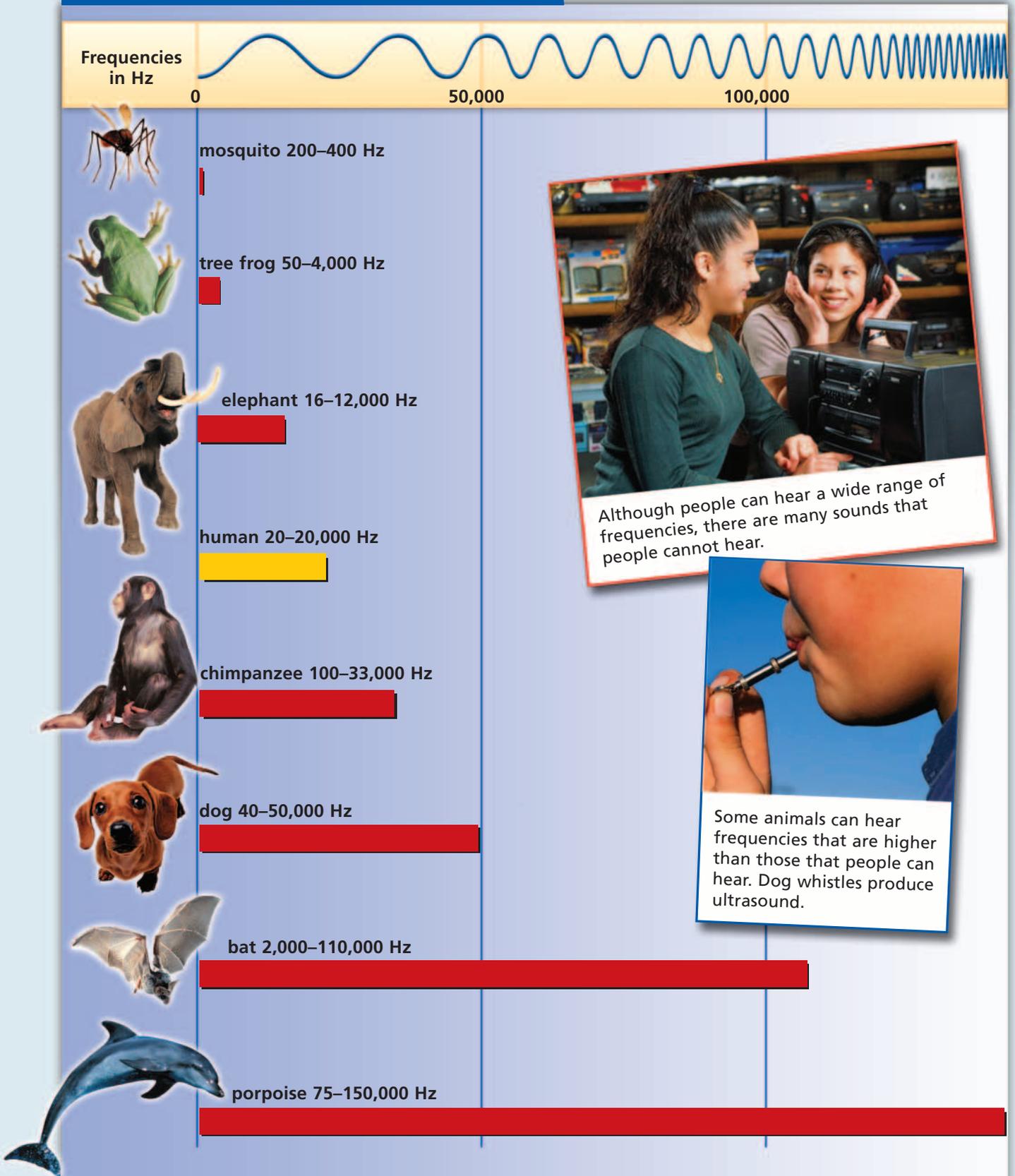
### READING TIP

The prefix *infra* means "below," and the prefix *ultra* means "beyond."



What is the range of frequencies that humans can hear?

## Sound Frequencies Heard by Animals



Although people can hear a wide range of frequencies, there are many sounds that people cannot hear.



Some animals can hear frequencies that are higher than those that people can hear. Dog whistles produce ultrasound.

**READING VISUALS**

Which animals on this chart can hear frequencies above those that humans can hear?

# INVESTIGATE Sound Frequency

## How is frequency related to pitch?

### PROCEDURE

- 1 Stretch the rubber bands around the open box.
- 2 Pull one of the rubber bands tightly across the open part of the box so that it vibrates with a higher frequency than the looser rubber band. Tape the rubber band in place.
- 3 Pluck each rubber band and listen to the sound it makes.

### WHAT DO YOU THINK?

- Which rubber band produces a sound wave with a higher pitch?
- How is frequency related to pitch?

**CHALLENGE** Suppose you are tuning a guitar and want to make one of the strings sound higher in pitch. Do you tighten or loosen the string? Explain your answer.

**SKILL FOCUS**  
Inferring



### MATERIALS

- 2 rubber bands of different sizes
- small open box
- tape

### TIME

20 minutes



## Natural Frequencies

You have read that sound waves are produced by vibrating objects. Sound waves also cause particles in the air to vibrate as they travel through the air. These vibrations have a frequency, or a number of cycles per second. All objects have a frequency at which they vibrate called a natural frequency.

You may have seen a piano tuner tap a tuning fork against another object. The tuner does this to make the fork vibrate at its natural frequency. He or she then listens to the pitch produced by the tuning fork's vibrations and tunes the piano string to match it. Different tuning forks have different frequencies and can be used to tune instruments to different pitches.

When a sound wave with a particular frequency encounters an object that has the same natural frequency, constructive interference takes place. The amplitude of the sound from the vibrating object adds together with the amplitude of the initial sound wave. The strengthening of a sound wave in this way is called **resonance**. When a tuning fork is struck, a nearby tuning fork with the same natural frequency will also begin to vibrate because of resonance.



How is natural frequency related to resonance?

## Sound Quality

Have you ever noticed that two singers can sing exactly the same note, or pitch, and yet sound very different? The singers produce sound waves with their vocal cords. They stretch their vocal cords in just the right way to produce sound waves with a certain frequency. That frequency produces the pitch that the note of music calls for. Why, then, don't the singers sound exactly the same?

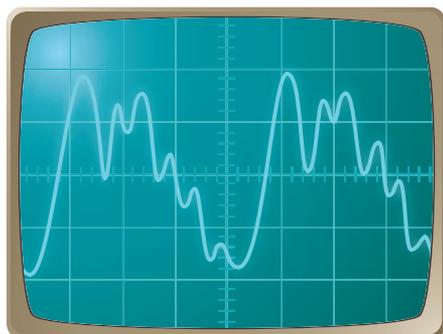
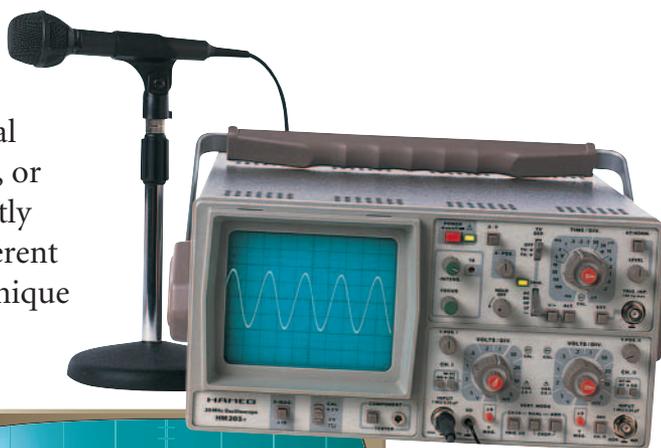
Each musical instrument and each human voice has its own particular sound, which is sometimes called the sound quality. Another word for sound quality is timbre (TAM-buhr). Timbre can be explained by the fact that most sounds are not single waves but are actually combinations of waves. The pitch that you hear is called the fundamental tone. Other, higher-frequency pitches are called overtones. The combination of pitches is the main factor affecting the quality of a sound.

Another factor in sound quality is the way in which a sound starts and stops. Think about a musician who is crashing cymbals. The cymbals' sound blasts out suddenly. A sound produced by the human voice, on the other hand, starts much more gently.

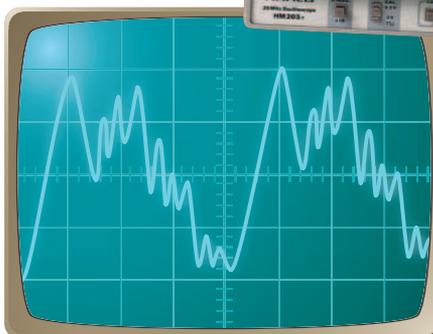


**CHECK YOUR READING** What are two factors that affect sound quality? Which sentences above tell you?

The illustration below shows oscilloscope (uh-SIHL-uh-SKOHHP) screens. An oscilloscope is a scientific instrument that tracks an electrical signal. The energy of a sound wave is converted into a signal and displayed on an oscilloscope screen. The screens below show sound wave diagrams made by musicians playing a piano and a clarinet. Both of these musical instruments are producing the same note, or pitch. Notice that the diagrams look slightly different from each other. Each has a different combination of overtones, producing a unique sound quality.



piano



clarinet

Both oscilloscope images at left show diagrams of sound waves of the same pitch produced on two different instruments. The waves, however, have different sound qualities.

## The motion of the source of a sound affects its pitch.

Sometimes in traffic, a screeching siren announces that an ambulance must pass through traffic. Drivers slow down and pull over to the side, leaving room for the ambulance to speed by. Suppose you are a passenger in one of these cars. What do you hear?

When the ambulance whizzes past you, the pitch suddenly seems to drop. The siren on the ambulance blasts the same pitches again and again. What has made the difference in what you hear is the rapid motion of the vehicle toward you and then away from you. The motion of the source of a sound affects its pitch.

### The Doppler Effect

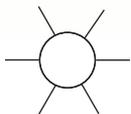
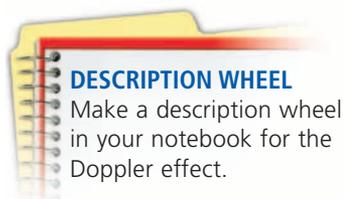
In the 1800s an Austrian scientist named Christian Doppler hypothesized about sound waves. He published a scientific paper about his work. In it, he described how pitch changes when a sound source moves rapidly toward and then away from a listener. Doppler described the scientific principle we notice when a siren speeds by. The **Doppler effect** is the change in perceived pitch that occurs when the source or the receiver of a sound is moving.

Before long, a Dutch scientist learned of Doppler's work. In 1845 he staged an experiment to test the hypothesis that Doppler described. In the experiment, a group of trumpet players were put on a train car. Other musicians were seated beside the railroad track. Those musicians had perfect pitch—that is, the ability to identify a pitch just by listening to it. The train passed by the musicians while the trumpeters on the train played their instruments. The musicians recorded the pitches they heard from one moment to the next. At the end of the demonstration, the musicians reported that they had heard the pitch of the trumpets fall as the train passed. Their experiment showed that the Doppler effect exists.



**CHECK YOUR READING**

How does the motion of a sound's source affect its pitch?

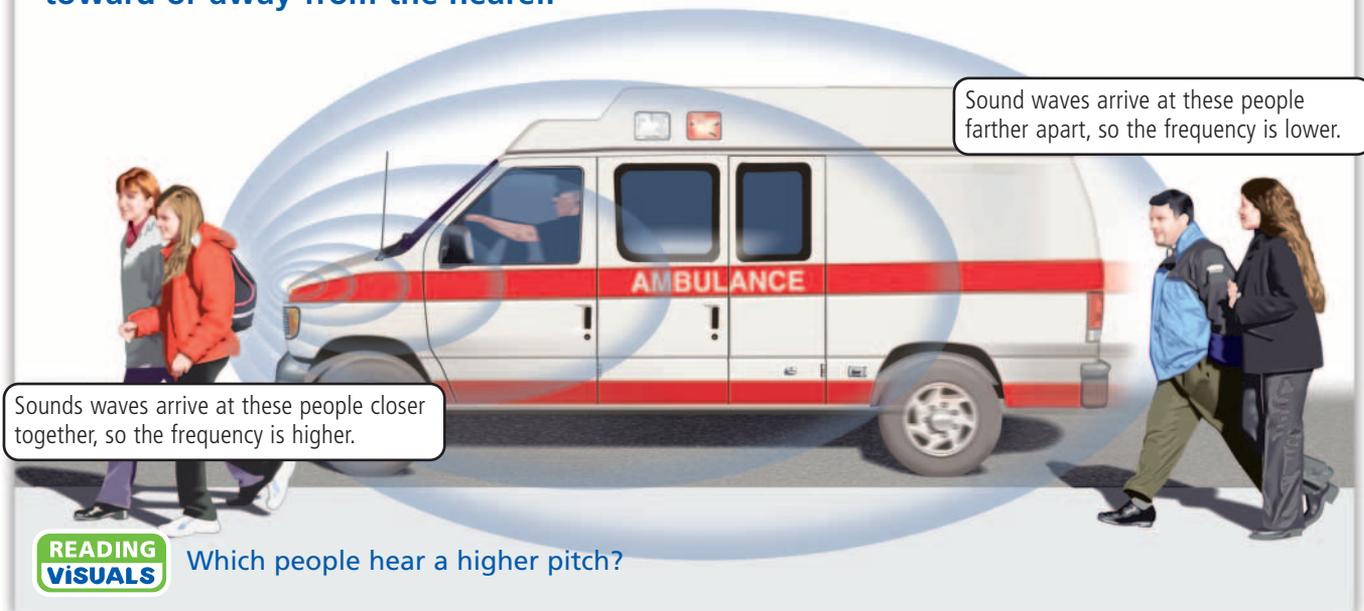


To listeners outside a train, the sound made by the train seems higher in pitch while it approaches them than while it speeds away.



## The Doppler Effect

The perceived pitch of a sound changes as the source of the sound moves toward or away from the hearer.



### Frequency and Pitch

Again imagine sitting in a car as an ambulance approaches. The siren on the ambulance continually sends out sound waves. As the ambulance pulls closer to you, it catches up with the sound waves it is sending out. As a result, the sound waves that reach your ears are spaced closer together. The frequency, and therefore the pitch, is higher when it reaches you. As the ambulance continues, it gets farther and farther away from you, while the sound waves still move toward you. Now the waves arrive farther and farther apart. As the frequency decreases, you hear a lower pitch.



Explore the Doppler effect.

## 16.2 Review

### KEY CONCEPTS

1. Describe what is different about the sound waves produced by a low note and a high note on a musical instrument.
2. Explain why two people singing the same pitch do not sound exactly the same.
3. How does perceived pitch change as a sound source passes a listener?

### CRITICAL THINKING

4. **Apply** How could you produce vibrations in a tuning fork without touching it? Explain your answer.
5. **Predict** Suppose you could view the waves produced by a high-pitched and a low-pitched voice. Which wave would display the greater number of compressions in 1 s? Why?

### CHALLENGE

6. **Infer** Offer a possible explanation for why no one noticed the Doppler effect before the 1800s.