10.1 Human Hearing

You can hear very quiet sounds like a pin hitting the ground, but you can also hear very loud sounds, such as a jet taking off. In this section, you will learn about the human ear and how we hear sounds.

The Human Ear

The human ear can be viewed as a detector of sound—it captures the energy of sound waves. However, as you will see, the perception of sound has more to do with the brain than the ear.

If you ask people to point to and describe their ear, most will point to the external ear, or pinna, and describe it as a round, strange-looking part of the body with a lobe at the bottom. However, the pinna is only one part of the ear. The other parts are the middle ear and the inner ear (**Figure 1**).

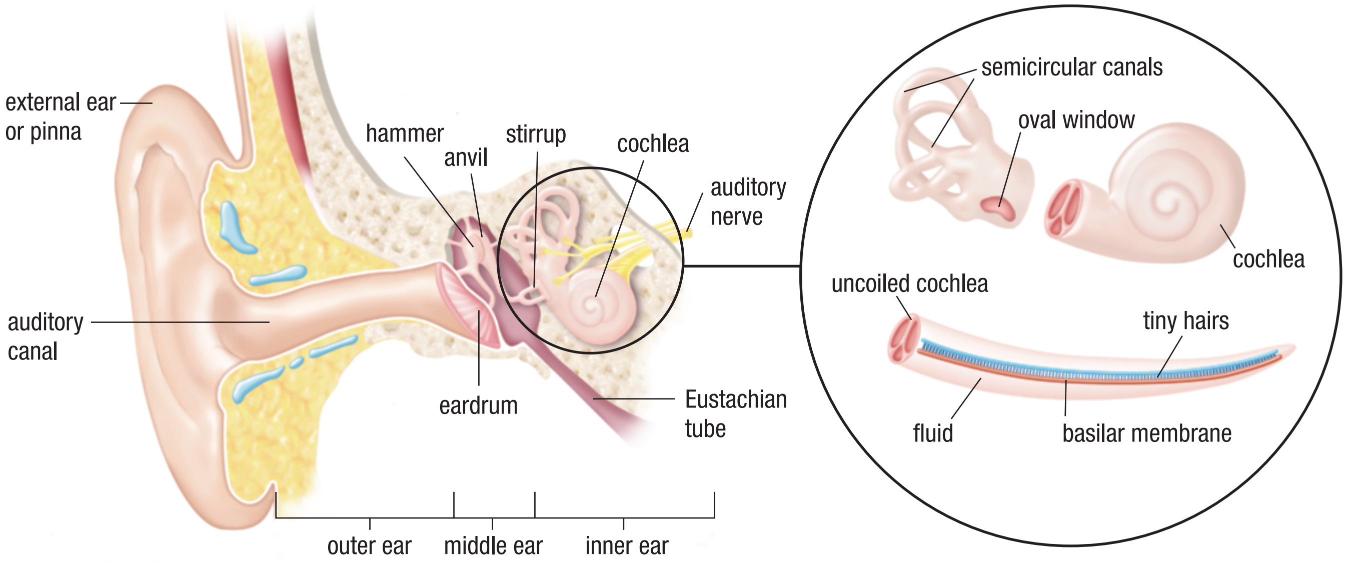

Figure 1 The parts of the human ear

The pinna acts like a funnel for sound. It directs, or channels, the sound waves into the auditory canal (also part of the external ear) toward the middle ear. The pinna is better equipped at channelling sound from a source in front of you than behind you. As you learned in Chapter 8, the audible hearing range of a healthy young adult is from 20 Hz to 20 kHz. However, the auditory canal magnifies sounds in the frequency range of 1000 Hz to 5500 Hz by a factor of about 10. As a result, most of the sound we perceive is in the frequency range of 1000 Hz to 5500 Hz.

The eardrum, or tympanic membrane, separates the outer ear from the middle ear. The eardrum is a tightly stretched, cone-shaped membrane that is thin but tough—it is less than 0.1 mm thick. It is also extremely sensitive—even the slightest vibrations can cause it to move. The eardrum is pulled inward by a muscle to keep it constantly taut.

The cavity containing the middle ear is filled with air and connected to the mouth by the Eustachian tube. The Eustachian tube only opens when you swallow or yawn. At these times, the air pressure inside the cavity will equalize with the air pressure outside. If the Eustachian tube becomes blocked (such as when you have a sinus cold), pressure equalization will not occur. As a result, pressure may build up inside the cavity, causing pain and loss of hearing.

Investigation 10.1.1

Investigating Frequency, Loudness, and Human Hearing **(p. 475)**

In this investigation, you will test the range of human hearing in your class in terms of the range of frequency and loudness, as well as different areas in the school for loudness and hearing safety.

How You Hear

You learned in Chapter 8 that sound waves are longitudinal waves composed of alternating compressions and rarefactions in the air. When these alternating waves enter the auditory canal, they cause the eardrum to vibrate.

Recall that compressions are regions of higher atmospheric pressure. The higher pressure from a compression pushes the eardrum inward because the air particles that are pushed together exert an inward force on the eardrum (**Figure 2(a)**). Rarefactions are regions of lower atmospheric pressure, so the reverse effect occurs when rarefactions come in contact with the eardrum. The particles in the air are pulled away from the eardrum, which causes the eardrum to move outward due to the higher atmospheric pressure in the middle ear (**Figure 2(b)**). The resulting vibrations of the eardrum have the same frequency as the sound wave. If the amplitude of the sound wave increases, the eardrum may begin to vibrate with a greater amplitude.

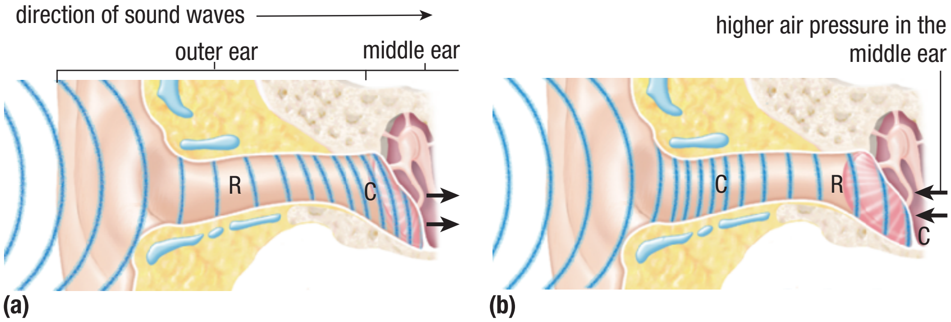

Figure 2 (a) Compressions push in the eardrum because of increased atmospheric pressure. (b) Rarefactions have the reverse effect by reducing pressure in the outer ear. The eardrum now pushes out because of the higher air pressure in the middle ear. The eardrum then starts to vibrate in response to the sound wave.

On the other side of the eardrum are the three smallest bones in the human body: the hammer (or malleus), the anvil (or incus), and the stirrup (or stapes). These bones are also shown in Figure 1 on page 450. The function of these bones is to transmit the vibrations of the eardrum to the inner ear while magnifying the pressure variations by a factor of about 22. The centre of the eardrum on the inner side is connected to the hammer. The hammer is a lever-like bone that rocks back and forth when the eardrum vibrates. The other end of the hammer is connected to the anvil, which is attached to the stirrup. When the hammer vibrates, it causes these other two bones to vibrate.

The stirrup transmits the eardrum vibrations to the start of the inner ear at the oval window, which is attached to the cochlea. When the eardrum is pushed in by a compression wave, the stirrup pushes inward on the oval window. When a rarefaction is present in the outer ear and the eardrum is pushed outward, the stirrup pulls the oval window outward.

The cochlea, a snail-shaped organ approximately 3 cm long, is divided into two sections by a partition called the basilar membrane (**Figure 3**). The vibrations at the oval window cause pressure waves in the fluid that fills the cochlea. Waves travel down one side of the cochlea, around the end of the partition, and back to the round window. These waves pass approximately 30 000 microscopic hair-like structures, each of which is attached to a single cell on the basilar membrane. These specialized structures are called hair cells. If the hairs on the hair cells start to vibrate, the mechanical energy of the hairs is converted into electrical energy in the cell, which in turn is transmitted to the brain by the auditory nerve. The basilar membrane responds to different frequencies along its length, with higher frequencies near the oval window and lower frequencies at the far end. When resonance is achieved, the membrane will vibrate in only one area, which then causes the hairs in that area to vibrate. The brain uses the number of vibrating hairs to determine the loudness of the sound and the location of the vibration to determine the frequency.

The inner ear also contains three hard, fluid-filled loops, called semicircular canals, at right angles to each other. These canals act like accelerometers that help maintain the body's balance by transmitting signals to the brain.

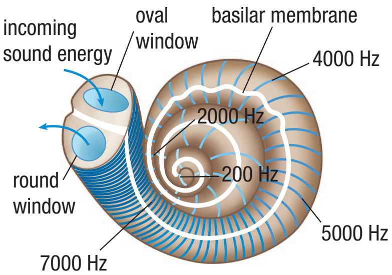

Figure 3 The basilar membrane responds to different frequencies at different locations.

Hearing Loss

Many of us take our hearing for granted, while others live with total or partial deafness. Moderately loud sounds will not usually damage the eardrum. Extremely loud sounds, such as explosions and volumes of music that are too loud for too long, however, can burst the eardrum. This damage can be repaired with surgery, but damage to the hairs in the cochlea cannot. A sudden burst of a very loud sound can rip away these hairs, as can a prolonged loud sound. Hair cells cannot be spontaneously regenerated in the human ear. Ear protection, however, can help reduce these effects. Employees in industries in which loud sounds are frequent or constant must wear ear protection. Many people with premature deafness have had prolonged exposure to loud sounds.

There is no cure for deafness when the signals from the cochlea are unable to travel through the auditory nerve. However, if hearing damage is related to problems in the eardrum or middle ear, then surgery or a hearing aid might improve hearing.

As illustrated in **Figure 4(a)**, hearing aids are often worn behind the ear or placed within the auditory canal. These aids magnify sounds and then direct them into the ear. A typical hearing aid consists of a microphone that picks up sounds, converts them to electrical signals, and sends them to an amplifier. The amplifier increases the amount of current in the electrical signal without changing the frequency and sends it to a speaker. The speaker changes the amplified electrical signal back into sound and sends it into the auditory canal. These types of hearing aids work best for mild to moderate hearing loss.

A cochlear implant (**Figure 4(b)**) works better for people with profound hearing loss because the implant bypasses the damaged parts of the ear. The implant converts sound into electrical signals and then sends the electrical signals directly to the auditory nerve. Other new types of hearing aids send vibrations directly to the bones in the middle ear or send vibrations through the skull directly to the cochlea.

CAREER LINK

Audiologists are trained to identify, treat, and prevent hearing loss.
To learn more about becoming an audiologist,

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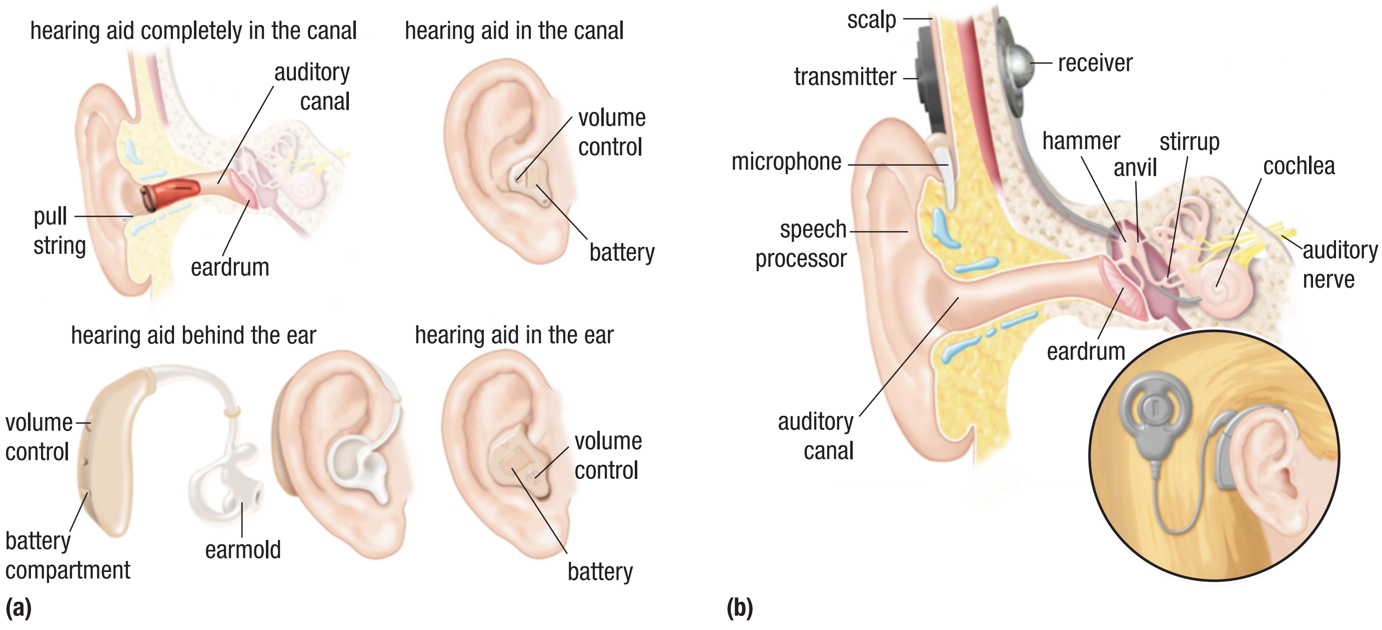

Figure 4 (a) Several different types of hearing aids (b) A cochlear implant

10.1 Summary

- The characteristics and properties of waves help explain natural phenomena, such as how we hear.
- The audible human hearing range is from 20 Hz to 20 kHz, but we perceive sound in the frequency range of 1000 Hz to 5500 Hz more than other frequencies.
- The outer ear consists of the pinna and auditory canal. The pinna gathers sound and channels it into the auditory canal toward the middle ear.
- The middle ear consists of the eardrum and three small bones: the hammer, the anvil, and the stirrup. The eardrum vibrates when it encounters sound waves, and the bones transmit and magnify the vibrations.
- The inner ear contains the cochlea and the auditory nerve. The vibrations are transformed into electrical impulses in the cochlea. The cochlea sends the impulses through the auditory nerve to the brain.
- Hearing aids can improve hearing loss in some cases.

UNIT TASK **BOOKMARK**

As you work on the Unit Task on page 486, apply what you have learned about how the human ear works. Will your constructed device produce sounds that could harm one's hearing?

10.1 Questions

1. Copy and complete **Table 1**. Include the following parts of the ear: pinna, auditory canal, eardrum, hammer, anvil, stirrup, Eustachian tube, cochlea, hair cells, auditory nerve, and semicircular canals. K/U C

Table 1 Parts of the Ear

Part of the ear	Location (outer, middle, or inner ear)	Description	Function
pinna			

2. **Figure 5** is a simple diagram that could be used to help younger students understand how the human ear works. K/U C

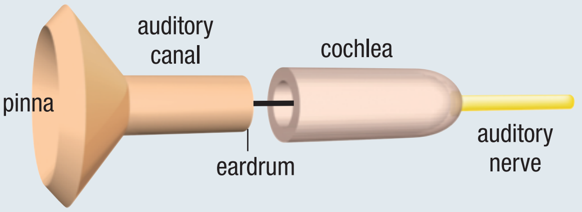

Figure 5 Schematic diagram of how the ear works

   (a) Write a paragraph that explains to a younger student how the human ear works. Refer to the diagram in your explanation.
   (b) In some ways the diagram is too simple. Explain.

3. Sometimes, when people go deep underwater, they experience severe pain in their ears due to the increased pressure of the water on the ear. Why do you think the extra pressure causes pain? What can be done to relieve the pain? K/U

4. What happens to the air pressure in an airplane that is increasing in altitude? Why should people avoid flying when they have a sinus infection or a sinus cold? K/U T/I A

5. Recently, scientists have grown new cochlear hair cells in mice. What implications might this have for hearing loss if scientists can eventually grow new hair cells in humans? A

6. Studies have shown that hearing loss increases with age, especially in people who are regularly exposed to loud noises. K/U
   (a) Give a reasonable explanation for why this happens.
   (b) What precautions should people take to avoid hearing loss as they get older?

7. Some animals, such as cats, can rotate their pinnae in different directions. Explain why this is an advantage for these animals over humans. A

8. Sometimes the eardrum can develop small perforations. In some cases, these perforations will heal naturally, just like the skin does when it receives a small cut. T/I A
   (a) What effect will these perforations have on hearing? Explain your reasoning.
   (b) Research these perforations in eardrums. Explain how the perforations can affect the middle ear if they persist, and how the perforations are repaired.

9. Research one type of hearing aid mentioned in this section. Determine the design, limitations, risks, and cost. A

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